OPERATION AND MAINTENANCE
OF
IRRIGATION SYSTEMS

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BY

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PREFACE

The operation and maintenance of irrigation systems is a subject of very active interest in the western states. The large number of irrigation systems constructed during the past 15 years have served to call attention to the importance of questions of operation policies and methods. Relatively such questions are at present much less thoroughly worked out than the strictly engineering questions of design and construction.

This volume is the outgrowth of notes prepared for class use in a course in this subject given by the author at the University of California. It is based on several years personal experience and observation in irrigation work in many of the western states, and on a careful examination of available published material supplemented by correspondence and discussions with many of those connected with the operation and maintenance of irrigation systems.

The subject of this volume is necessarily one of practice rather than of theory. As in other similar subjects, practice is materially affected by local conditions, which in irrigation may vary widely in the different irrigated sections. Such variations make it difficult to distinguish the principles of the practice from the local application of such principles. An attempt has been made to give the general principles that may be recognized, illustrated by typical examples of their local application, rather than to fully cover all local variations in practice. No attempt has been made to cover practice outside of the United States.

There is very little published material relating to this subject which is generally available. References to the more important articles are given at the end of each chapter; many of these, however, have had only a limited distribution and will be available to only a few readers. Formal references to much other material found to be valuable in the preparation of this volume are not given as these consist of unpublished reports or other material of similar nature. The author also desires to express his obligation to those who, both by correspondence and by facilities for examination during visits to their systems, have been of assistance in the collection of the data on which many of the discussions in this work are based. A greater amount of data regarding the systems of the U. S. Reclamation Service has been published than for other forms of organizations, and to many members of this organization particular thanks are due. Material has also been secured from systems operating under all forms of organization in order that the treatment might be generally representative. His indebtedness to all such sources is gratefully acknowledged.

SIDNEY T. HARDING.

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July, 1917

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CHAPTER I

GENERAL MAINTENANCE

The term maintenance, as generally used, includes repairs, replacements and betterments. Repairs are the routine and generally minor work done on canals and structures in order to maintain their usefulness. Even with proper care in repairs, renewals of structures will eventually be required. Where a new structure has the same capacity and is of the same type, it is classed as a replacement; where a more permanent type of construction is used or where a large capacity is secured, it is classed as a betterment. The definition of these terms and the methods of handling maintenance accounts are discussed in more detail in Chapter IX. Routine maintenance such as repairs and smaller replacements is handled by the regular operation organization. Extensive replacements or betterments are more largely questions of engineering design and construction which are similar to those involved in the original development of the system. Such work is usually handled by an engineering organization similar to that used during the original construction period.

There is little definite data available regarding the cost of maintenance. On any system such costs will vary quite widely in different years. On some canals the separation of the costs of operation and maintenance expenditures may not be attempted. Where such segregations are made, the method of classification varies. Costs for maintenance are usually expressed in terms of the cost per mile of canal operated or per acre served. For comparisons of the economy of structures of different types annual maintenance costs expressed as a percentage of the first cost of the structure are most convenient. For canal cleaning the cost per mile of canal forms the more logical basis for comparison.

Maintenance costs per acre served may not furnish a satisfactory basis of comparison for different canal systems due to differences in conditions which are not proportional to the acreage. Acreage costs, however, are useful in determining charges as the area is more usually the unit to which the costs or payments to be made are distributed.

The 13th U. S. Census in 1910 secured data on the cost of operation and maintenance from systems serving about one-half of the irrigated area. The companies from which data were obtained were mainly the larger systems. For all the States the average annual cost of operation and maintenance was $1.07 per acre, the minimum average for a State being 63 cents for Idaho and the maximum $3.25 for Texas. For many systems, it is probable that the costs given did not include all expenses for operation and maintenance.

In connection with its supervision of public utility irrigation companies, the California Railroad Commission has secured records of the costs of operation and maintenance of a number of such companies. For 16 companies which have come before the Commission for rate-fixing purposes the average cost per acre for general salaries was 63 cents, other general expenses 21 cents, taxes 16 cents, operation 97 cents, maintenance 59 cents, a total of $2.56 per acre. The variations in these figures for particular systems were naturally quite large. The average cost per mile of canal for operation was $64 and for maintenance $52, the total including general expenses being $174. These systems had a total irrigated area of 118,000 acres and a length of canal of 1300 miles. The reports for 1914 of 24 companies gave an average of $1.78 per acre irrigated and $267 per mile of canal operated for the total cost of operation and maintenance including general expenses. The average cost per acre for operation was 50 cents and for maintenance 61 cents. The average cost per mile of canal was $91 for operation and $75 for maintenance. These reports covered an irrigated area of over 500,000 acres and a length of canal of over 1,000 miles. The figures for individual companies also varied widely.

The accounts of the U. S. Reclamation Service distinguish operation and maintenance costs. Their fiscal year ends June 30, so that the figures given in their present annual reports do not give costs for the actual operation year. The total costs for operation and maintenance to June 30, 1916, are given in the 15th

Annual Report. These have been used to compute the percent age given in Table I.

TABLE I.—DISTRIBUTION OF OPERATION AND MAINTENANCE COSTS TO DATE ON ALL PROJECTS OF THE U. S. RECLAMATION SERVICE TO JUNE 30, 1916

	Per cent. of total operation	Per cent. of total maintenance	Per cent. of total operation and maintenance	Ratio of operation to maintenance
Storage works........	11	7	8	0.75
Canal system.........	26	27	27	0.51
Lateral system........	52	53	52	0.50
Drainage system......	2	3	3	0.25
Flood protection system.............	0	0	0	0.10
Undistributed expenses	9	10	10	0.46
Total.............	100	100	100	0.62

The operation and maintenance results for 1912 have been separately published in more detail than those for later years. The average cost for acre irrigable for all projects was 36 cents for operation, 56 cents for upkeep and 35 cents for betterments. An average of only 54 per cent. of the irrigable area was actually irrigated in this year so that the cost per acre actually irrigated would be nearly double the figures given. The figures cover a wide range of conditions but generally represent systems in the earlier periods of development. There were 5,744 miles of canal operated at an average cost per mile of $74 for operation, $117 for upkeep and $73 for betterments, a total cost of $263 per mile. On the different systems the costs of these items varied by several hundred per cent. in some cases. Such variations are due to such local conditions as length of operation season, character of service given, topography, character of the soil, canal vegetation and the extent of silting.

These general figures are illustrative of the average costs on typical systems. On small or loosely handled canals the costs of operation and maintenance may be as low as 50 cents per acre per year. Under favorable conditions on large well-developed and maintained systems the direct annual cost of operation and maintenance exclusive of interest and depreciation may be less than $1 per acre. In many cases such costs will be from $1 to $2 per acre. Where long diversion canals or other difficult construction are needed, where storage or pumping are required, where the operation season is long, or where silt or vegetation are unusually expensive to handle, the costs of operation and maintenance may exceed $2 per acre.

The costs of maintenance per mile of canal for usual conditions is generally from $50 to $100 per mile. Where excessive silting or vegetation or other unfavorable conditions are encountered the cost may exceed $200 per mile. In 1915, cleaning, clearing and repairs cost an average of $375 per mile on the 335 miles of the Imperial Water Co. No. 1. The natural conditions of this system are extremely unfavorable in regard to silt and vegetation. For canals having short operation seasons with little silting or vegetation the annual cost of maintenance may be less than $50 per mile.

DAMAGES FOR FAILURE TO MAINTAIN

The extent of the responsibility of the canal owner for damages which may result from canal breaks or seepage differs somewhat in different States and involves a number of legal points. Any actual cause for complaint should be handled by the coöperation of the operation and legal organization. In addition to legal points as to responsibility, a jury trial in any particular case introduces an element of uncertainty as to the value which may be assigned to the injury.

Irrigation companies are not insurers and are liable only for such injuries to others as result from their own negligence and the failure to use reasonable care and skill in construction and operation. The care required to be used is that which ordinarily prudent men exercise under like circumstances when the risk is their own. This applies both to canal breaks and to general canal seepage. A canal company is not required to entirely prevent seepage from a canal; the skill in construction and operation must be such that the amount of the seepage does not exceed that found on well-maintained canals in similar material. The diligence and care used in preventing damage should be proportional to the risk to others. Canal owners are not responsible for damages due to acts of God which are of such unusual nature that one cannot be expected to foresee their occurrence or be able to prevent the injury caused. Breaks caused by cloudbursts on lands above the canals or floods of rare occurrence may be classed as such acts of God. The canal owner may be held responsible for damages caused by floods of such frequency that their occurrence should have been foreseen. There is much difference in the recovery of damages against systems in private ownership as compared with recovery against systems owned by the government. The government can be sued only with its consent and has consented to be sued only through the Court of Claims in suits arising in contract and not in suits arising in tort, such as those for damages. Individual officers of the government are liable only for their own wrongful act and not for the defective condition of government property.

Damages are limited to the value of the actual injury and the extent of damage must be proven by the one injured. The one injured must use reasonable diligence to minimize the resulting injury and cannot recover for damages which he could have prevented. If land is destroyed, such as by erosion from a canal break, so as to have no remaining value, the cash value at the time of destruction measures the amount of the damage. If permanently injured but not wholly destroyed, the damages are measured by the loss in cash value or the difference in value before and after injury. If only temporarily injured, the cost of restoring the land to its previous condition may be a measure of the difference in value or the damage to the land. For the destruction of crops the damage is measured by the value of the crop at the time of its destruction.

The above discussion covers damages due to an actual injury to the land. The damage to relatively large areas from the inability to deliver water due to a canal break may be much greater than the direct injury to lands adjacent to the break. Where such failure to deliver prevents planting a crop, the damages are measured by the difference in the rental value of the land with and without water. Evidence in regard to crops that might have been grown is too uncertain and speculative. Damages due to failure to deliver water are usually covered by the terms of the water-right contract in the case of systems owned by others than the land owners, the contracts containing clauses specifying the penalty or exempting the canal company. Where the canal system is owned by the land owners, damages for general failure to deliver water are not usual as those injured and those responsible have the same general identity.

Several of the States have statutes requiring canal owners to maintain the embankments of the ditches so that no injury will be caused to others. Such statutes serve to emphasize the need of diligence and skill rather than to change the extent of the liability previously mentioned. Some States also specify that a tail ditch shall be provided, the purpose being to prevent injury from overflow at the lower ends of canals. The canal owner is responsible for injury that may be caused by waste water from the canal; the land owner for damages caused by waste water escaping from farms after it has been delivered by the canal company. In some cases the liability for damages is considered to be different when caused by water flowing in canals than when caused by water retained in reservoirs, in that negligence does not need to be proven to the same extent in the cases of breaks in reservoirs.

MAINTENANCE OF CANALS

Priming Canals.—Much care is needed in running water for the first time in new canals as the banks of the canal and backfill around the structures will not be packed and settled. No amount of care in construction will make it safe to bring canals too quickly under the strain of full depth of flow. If a small depth can be carried for a relatively long time, the banks will absorb moisture and become settled; weaknesses can be detected and repaired with less damage; holes of burrowing animals can be found and closed; and cutting around structures may be repaired before the structure itself is injured. It may require several weeks use before new canal banks will become sufficiently saturated to develop weakness. If conditions will permit the priming of a new canal during the season before its use for actual delivery of water, much better results can usually be obtained. The settlement during the following winter is also a material advantage. Where checking the flow in the canal is not necessary, a new canal may not be required to carry the full depth of flow for 1 or more years depending on the rate of development. If checking to full depth is required for delivery, the canal will be under its full strain in the first year of use. Where checks are available, however, the canal can be primed by sections, holding water above each check in turn. This reduces the rate of flow and the volume of water which may cause damage in case breaks occur.

For old canals, water should be turned in from 2 to 4 weeks before delivery will be required. If 2 weeks are desired in which to bring a canal to full depth, priming should be started 4 weeks before water is needed in sufficient amounts so that an interruption in service will be serious. This allows time for repairs should need for them develop during the priming. Where there may still be frost in the banks, the running of early water helps to thaw the banks and the longer period before operation allows more time for any frost heaving to settle. Running a small flow in priming also enables the weeds and other drift which have accumulated to be carried through or collected at checks with less damage from clogging than would be the case if the water was held high for delivery.

Shutting water out of a canal too suddenly may be as harmful as filling too quickly. In some soils the sudden shutting out of water due to a break may cause more actual damage than the break itself. When the canal is running at full depth, the canal banks absorb water until a portion of the bank adjacent to the water becomes saturated. The position of the plane of saturation depends on the conditions for escape of the water as well as its absorption. The plane of saturation is held at the water surface at the inner side of the canal bank. The sudden lowering of the water in the canal removes the pressure of the water and the inner face of the bank may slip if its slope is steeper than can be held by the material in its saturated condition. With light soils the moisture in the banks may drain out before such slipping or sloughing has time to occur. Sloughing may also occur where riprap or brush lining has been used, the lining being forced out of position. Usually, however, the freedom of drainage through such porous linings will prevent their injury. Concrete lining may be forced out of position if the drainage from the bank is restricted so that pressure accumulates behind the lining. Sloughing of unprotected canal banks is more usual in heavy soils and in canals operating under relatively high velocities. In such canals the banks are usually more nearly vertical and less pressure is required to cause slipping. Sandier soils require flatter side slopes which combined with their more rapid drainage renders them less liable to such injury.

When breaks which may occur during the period of maximum demand for water are repaired, it is usually necessary to bring the canal back to full discharge as quickly as possible. This may cause additional erosion which might be prevented if more time for priming was available. Such conditions are found where the operating velocities approach those which cause erosion in the material composing the canal banks.

Canals in Unstable Formations.—Where canals are located on side hills or other unstable ground, more or less difficulty from settling or slipping of the banks or of the whole canal is to be expected. Such difficulties are usually of two general kinds: (1) where the canal is excavated on talus slopes below higher ground and destroys the natural balance which has existed, the formation may move, whether water is in the canal or not; and (2) where the seepage from the canal reaches uncompacted material which settles under the influence of such seepage water. Various combinations of these two conditions may occur.

The first condition occurs where a diversion canal is climbing from the stream to bench land and passes for part of its length through the sloping side hill. Such side hills may consist of material weathered from the bench formations. If such upper formations consist of shales, the slopes will contain clayey material and usually exist under approximately the angle of repose of the material. To cut into the slope to form a canal section destroys the footing of the higher slope. The upper material may slip, either gradually or in larger movements, crowding in the upper side of the canal or pushing the foot of the slope out and carrying the canal with it. Such movements may be independent of any canal seepage being caused by pressure from above the canal rather than conditions below. Their occurrence is liable to open cracks in the lower canal banks through which seepage may start. Cases have been observed where such movements have taken place without any evidence of seepage on the slope below the ditch. The slipping of the upper slope varies with its moisture condition and may be more marked at certain seasons. Such movements are hard to restrain and usually continue until the natural balance is restored. The angle of surcharge is large and the footing unstable, so that retaining walls are not practicable. In very steep slopes it may be preferable to construct the canal as a bench flume in order to reduce the amount of disturbance of the natural slope. In maintaining canals in such ground, the more usual practice is to meet conditions as they arise rather than to attempt preventive measures. Wasteways should be available in such locations so that the water can be turned out quickly and the damage caused by breaks limited in amount. The movement takes place gradually in many cases and gives opportunity for the exercise of much judgment as to how far it can be permitted to proceed without requiring shutting out the water. When the movement from above is into the canal reducing its cross-sectional area, the material removed should be placed as a blanket on the lower bank rather than as an additional crown on the bank. Such a blanket being in the line of seepage will add to the safety of the canal. An additional height of bank does not reduce seepage and increases th weight of the bank and the danger of its slipping. Where the formations occur in strata and the movements consist of the slipping of one stratum over another rather than as a general bulging, piling may be effective. Such piling acts to bind the strata together and has been used in some cases with good results on the Lower Yellowstone project.

Where the seepage from the canal softens the material on the lower slopes so that sloughing may occur, treatment of the canal to reduce seepage losses can be used.

These conditions of side-hill slopes composed of shaly material are found in many localities in the Great Plains areas east of the Rocky Mountains. The canal of the Billings Land & Irrigation Co. is located in such formations for a portion of its length. In 10 years there have been three breaks in a length of ½ mile and it has been necessary to shut water off during the irrigation season at other times in order to make repairs. There is no marked seepage visible on the lower slope, the movement is largely from above the canal due to the disturbance of its balance by the excavation of the canal. This slope has a rather limited extent so that it is probable that the canal will eventually cease to give trouble.

In some cases canals pass through or over uncompacted materials such as sand and gravel. Seepage from the canal may cause a rearrangement of the particles in such material so that a smaller space is occupied and settlement occurs. Such settlement may occur without the removal of any of such underlying material by seepage. An instance is reported in Colorado where a canal crossing a deposit of boulders and gravel mixed with clay settled evenly through a height of 8 inches. Where canals in fill cross material containing much organic matter, such as peats, or where the underlying material is in a semiliquid condition, the weight of the fill may cause settlement due to compression of the lower material. Where water occurs, the settlement may be accompanied by a raising of adjacent lands. For such conditions flat slopes on the banks, such as 4 to 1, or even blanketing of adjacent areas, may be required.

In side hills of coarse material, such as talus slopes of coarse gravel or sand, visible seepage may occur without immediate danger. If the seepage water is clear, indicating that underlying material is not being removed, it may be safe to leave repairs until after the end of the operation season. This may be done with less danger on old canals than on new, as settlement is less liable to occur in such cases. Where the velocity is not high, the source of such seepage may be traced to the canal and the areas blanketed with finer material deposited while water is in the canal, more permanent repairs being made at the end of the operating season.

Canals through gypsum formations require great care in operation as such material softens when wet so that it has little strength as a bank. Concrete lining may be used to prevent seepage and the saturation of the banks. On the Carlsbad project a canal even when lined gave trouble due to softening of the backfill by the seepage through the joints in the lining.

In repairing breaks in side-hill canals it is not usually desirable to rebuild on the same alignment. The canal should be thrown into the hill sufficiently far to give new footing. If the hill is too steep for such relocation, a flume should be built over the eroded section.

Overtopping Canal Banks.—Breaks directly due to the overtopping of canal banks are not usual. With the amount of freeboard which is ordinarily used, a break will generally occur at some point of weakness in the bank before actual overtopping takes place. Such overtopping is usually caused by the choking of the canal due to the clogging of checks or the slipping of material into the canal from the upper slope. Where canals are operated under checks, the turning back of water by users may overload the canal unless ample wasteways are available. Where such conditions occur, much closer control of the delivery of water is required. Some canals pick up cross-drainage and this may overload the canal where summer rains occur.

The amount of freeboard used varies in good soils with the size of the canal: for large and deep canals as much as 3 feet may be used; for laterals of from 50 to 100 second-feet capacity from 1½ to 2 feet and for less than 50 second-feet capacity 1 foot would be usual amounts. Where the flow in the canals is closely regulated, smaller amounts may be needed. The amount needed also depends on the top width of the bank, being less for wide banks. The freeboard required varies with the character of the material in the canal banks. In sandy soils as much as 2 or 3 feet freeboard may be used on small canals; in heavy soils as little as 1 foot may be used on canals carrying 200 to 300 second-feet.

Protection Against Canal Erosion.—Where the required fall can be secured, it is desirable that the velocity in canals should approach the allowable maximum for the material encountered. In the adjustment of flow which always occurs between different sections this may result in excessive velocities in some portions. The outside of curves may be eroded or short lengths of less resistant material may be subject to scour. The erosion at structures is discussed in Chapter II.

Erosion can be controlled by the use of linings of concrete, rock or gravel or brush riprap. Checks may be used to reduce the velocity below that which causes erosion; such methods require larger canals for the same capacity, however. Concrete or plaster lining will withstand relatively high velocities. If its use is contemplated it is better to include it in the original construction and thus secure the advantage of the smaller cross-section which its lower friction factor permits. While the cost of concrete lining is higher than that of other methods, the reduction in seepage loss and cost of maintenance, if given proper value in comparisons, may make such linings relatively cheaper than other forms. In some cases wood linings have been used. Such use is not at present usual due to the relatively increasing price of lumber and its shorter life.

Gravel lining or blanketing is used to cover the more easily eroded soils. Where the erosion is due to wave action or to high velocities below structures, the larger fragments of rock riprap either hand-laid or loose are preferable. Where the velocity does not materially exceed that which causes soil erosion, gravel may be sufficiently heavy to protect the canal. Its use requires a location where it can be secured at relatively short hauls. On the Sunnyside canal in Washington a gravel lining 3 inches thick has been used. The banks are given a slope of 1 on 1½ and the gravel spread down from the top of the bank by hand. The total labor cost of spreading including superintendence was 28.6 cents per cubic yard, from 10 to 15 cubic yards being spread per man-day. The gravel cost $1.35 per cubic yard delivered. For a 3-inch thickness, these figures are equivalent to a total cost of about 1½ cents per square foot. It has been found that where such gravel lining has been used on curves there is a tendency for the silt to deposit in the gravel and also for the silt bar which usually forms on the inside of such curves to be less noticeable. On the North Platte project a gravel coat 4 inches thick has been used to protect canal banks from blowing where gravel could be secured at hauls of not over 1½ miles. The cost of 7 miles of such protection was 82 cents per cubic yard or 1 cent per square foot.

Brush riprap is frequently used to prevent erosion of canals as well as to prevent cutting around structures. Such linings are often an inexpensive means of protection, particularly where willows are available or where sage brush can be secured adjacent to the canal line. While such methods are rather temporary in character, the brush may last several years, particularly if partly buried. On the Sunnyside project, sage brush and willow riprap had to be replaced after 3 or 4 years use in locations where no silt was deposited in the brush. Greasewood or arrow-weed are used in some localities, although the latter is more temporary than other forms of brush.

Sage brush riprap has been extensively used on the Minidoka project (Plate I, Figs. A and B). On some canals where erosion occurred, the brush was plowed in, being set in each furrow and covered by opening the adjacent furrow. This type of protection costs about 13 cents per square yard and can be placed only where water is turned out of the canal. When protection is required during the operation season the sage brush can be bound into bundles and fastened to a continuous wire which is held in places by stakes. This method was used near the water surface to prevent erosion from either scour or wave action, the cost being 25 cents per rod. In order to provide a rough surface into which silt might settle and be held, both sides of a portion of the main canal were riprapped with sage brush. The brush was spread in a heavy layer and held in place with ordinary chicken-wire netting. The netting was held by 2 × 4 strips fastened to 3 × 3 posts driven into the slope in rows 10 feet apart. The average cost was 28 cents per square yard for 40,000 square yards. The sage brush was cut on adjacent land above the canal at a cost of $1.50 per hay-rack load, one load making 30 square yards of riprap. Both machine and hand driving were used for the 3 × 3 posts, hand

FIG. A.—Eroded bank in sandy soil before lining, Main canal, Minidoka project.

FIG. B.—Main canal Minidoka project, lined with sage brush preparatory to silting.

(*Facing page* 12.)

PLATE I.

FIG. C.—Brush riprap used in the Imperial Valley.

FIG. D.—Willows used to reduce erosion, Snow Lateral, Billings, Mont.

driving proving the cheaper, although a very light and easily moved hammer was used. Such chicken-wire netting may have a life of only 2 to 4 years and the brush may be displaced unless silt has settled around it sufficiently to hold it.

On small laterals in sandy soil brush or even straw may be plowed or disked into both the canal bank and the water section to prevent blowing and erosion. Part of this will usually work loose and be carried down to the checks or turnouts, so that much care may be needed to prevent checking the flow at such structures. Sage brush riprap when used to prevent erosion should be laid with the roots upstream and laid similarly to shingles on a roof beginning at the downstream side. Rock, wire, or other means of holding will be required. In sandy soils greater difficulty in holding such riprap is usually encountered unless it is well weighted with rock or fastened with wire (Plate I, Figs. C and D).

In protecting canals which have eroded, it is generally considered preferable to trim the eroded section to smooth lines rather than to attempt to restore the original section, although in some cases, particularly where concrete lining was to be placed, the original section has been restored. The eroded section will more nearly conform to the natural section for the actual conditions of flow and will be more easily maintained. On curves around points, the material deposited on the inside may be moved to the outside of the curve before protection is placed, if the erosion has reduced the outer banks to less than desired size.

SILT OR SEDIMENT IN CANALS

The depositing of sediment in canals may be desirable or objectionable, depending on the extent to which it occurs. In porous soils a deposit of silt over the canal bed and sides will be of much benefit in reducing seepage losses. On a few systems silt has been artificially applied for this purpose. The extent of seepage losses is discussed in several publications. The general average values found, expressed in cubic feet depth of loss per 24 hours per square foot of wetted area, are 0.5 for impervious soils, 1.0 for rather pervious soils, 1.5 for pervious soils, and 3.0 or more for porous soil. The seepage loss, when expressed in per cent. of the discharge lost per mile of canal, varies with the size of the section as well as the material of the canal bed. For typical conditions average losses are shown in Fig. 1. Whether the value of the water that can be saved by artificial silting will be sufficient to warrant the expense, is a separate problem for each system. It depends on the cost of silting, the value of the water saved and the value of the prevention of possible damage from the water-logging of lower lands by such seepage waters.

In canals operating under checks, the deposit of silt will be greater than where the water is carried at a fairly uniform velocity from the headgate to the fields. In systems diverting from streams carrying an excess amount of silt, the deposits may be so extensive as to seriously affect the canal capacity. The majority of streams used for irrigation in the United States do not carry

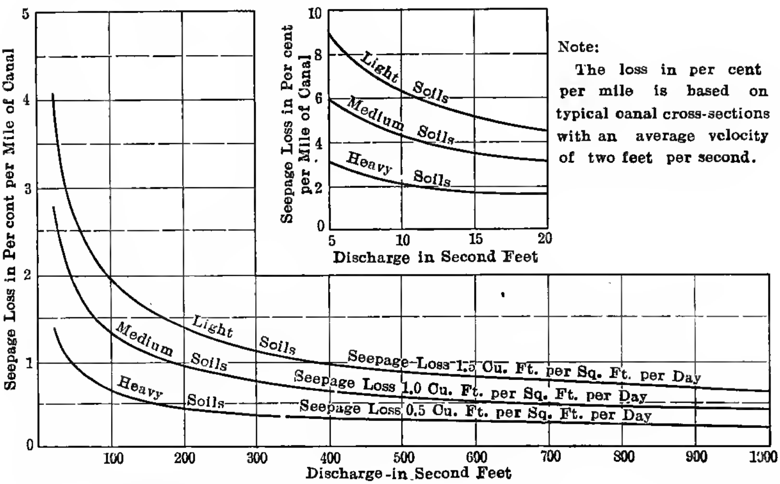

FIG. 1.—Average seepage losses in canals expressed in terms of per cent. loss per mile of canal.

sufficient silt to give serious trouble in operation. For a number of systems in the Southwest the removal of silt is the largest item in maintenance cost. The Colorado River represents the extreme condition of American practice for streams extensively used.

Artificial Silting.—Artificial silting may be carried on either during the operation season by running water containing silt into the canal and allowing it to distribute under the influences of general sedimentation, or by depositing the silt directly at the location desired during the non-operating season. The latter method is more usual and generally preferable as it is more definite. The first method may be suited to those cases where the whole system is in sandy land and may need such silting; the latter method can be used for the more usual conditions in which only short lengths of canal through porous soils require treatment. The deposit of silt, when pumped into the canal, cannot be closely controlled as to the location in which it is deposited and an excess amount must be supplied in order to secure a sufficient covering at all points. Neither method will be successful in canals where the velocity is sufficient to erode the silt. Such silt will usually resist higher velocities after it has been deposited than those required to carry the silt when in suspension. Where the frost action during the winter is severe, the silt deposited during one season may become disintegrated so that it is carried out by the early season operation of the following year.

Silt deposited in place during the non-operating season is generally known as puddle lining. On the Huntley project a total of 20,000 square yards of such lining 4 inches thick has been placed at a cost of 7.1 cents per square yard. The haul on the material averaged 1.4 miles. After spreading, a drag consisting of planks spiked together with overlapping edges was run over the surface in order to break the clods. The canal was then filled, the water being held over the section by checks for 24 hours, then lowered to a depth of 12 inches and a harrow dragged through the canal four times to puddle the material. The seepage loss after puddling was found to be 1.2 per cent. per mile. Puddling may also be accomplished by dragging a heavy chain along the canal when the silt is wet. On the Sunnyside project, such puddle linings have been found to give the best results if placed so that they will have an opportunity to dry out before water is run over them. Both sheep and laborers have been used to puddle the lining. On some of the most porous soils, gunny sacks were spread over the canal before the puddle lining was applied.

On the canal of the Bitter Root Valley Irrigation Co. an enlarged section was excavated in rock cuts which was lined with about 6 inches thickness of earth increased to 12 inches on the inside of some of the lower banks. On one of the canals on the Uncompahgre project similar lining 12 inches thick was used on both the bottom and sides. On the Sunnyside canal where gravel was encountered, the excavation was extended from 12 to 18 inches outside the final section and backfilled with surface soil or silt.

The main canal on the Grand Valley project, when located in shale, was excavated to a depth of 1 foot below grade in order that silting might occur and reduce seepage losses without reducing the canal capacity. In some cases in especially porous shale the sides below the high-water surface were taken out on a slope of ½ on 1 but the water-surface width was not changed. This gave a triangular area of excess excavation which was later filled by crowding in good surface soil from the top of the slope. Part of this was done before water was turned in and part with water in the canal. The latter method was more effective in that the material compacted better and more quickly and also spread farther out on the canal bottom. In shales which disintegrate, the canal was plowed and harrowed after the first season's use and the shale left exposed during the winter. In the spring it was again harrowed and rolled with a roller having 3-inch projections, spaced 6 inches apart.

Silting by pumping into the canal during the operation season has been extensively tried on the Minidoka project, where on the upper portion of the gravity unit the canal is located in sandy soil which does not form very stable banks and which is subject to considerable seepage loss. A portion of the main canal was restored to its original cross-section and the sides lined with sage brush. The purpose of such lining was to maintain the cross-section and to retain the silt when deposited in the brush. Silt was pumped into the canal at various times during 1914 and 1915. The seepage loss was reduced and the safety of operation increased. Excess silt was deposited in the adjacent laterals, in sufficient amounts to require removal in some cases. This silting has not been in use sufficiently long to test its permanence; during the period of maximum discharge there appears to be some tendency for the silt to be picked up by the water.

Removal of Excess Silt.—The methods of handling silt which is deposited in canals from the water diverted from the streams depend most largely on the rate at which such deposits occur. Where the rate of deposit is low and there is some margin of capacity available in the canal, the silt may be allowed to collect until it is sufficient in amount to make its removal by teams economical. The cutting of runways and other fixed charges are then distributed over a larger yardage. In systems operating under checks, the silt deposits above the checks may be sluiced out at seasons when checking for delivery is not required. Stirring or loosening the silt with harrows during such sluicing may increase the amount removed. To be successful such sluicing

FIG. A.—Silting above checks, Imperial Valley.

FIG. B.—Canal "V" used to remove silt, Imperial Valley.

(*Facing page* 16.)

FIG. C.—Canal in Imperial Valley shortly after cleaning, value of n = 0.022.

FIG. D.—Similar canal to that shown in Fig. C. with excessive growth of vegtation, value of n = 0.029 (Figs. C and D from Bull. 194, U. S. Dept. of Agric.)

requires water relatively free from silt when it enters the canal. With silt-laden water but little additional silt can be carried unless the velocity is increased.

Silt can be more economically removed by teams from small canals so that it may be preferable to use higher velocities in the larger canals if sufficient fall is not available to carry the silt through to the fields. Enlarged cross-sections may be used at selected locations from which the silt can be more easily removed. This may be accomplished by leaving the canal bottom below grade in fills. The removal of such deposits strengthens the banks in the fill. If the silt is coarse or sandy, placing it on the slopes of the fill may prevent damage from burrowing animals.

For systems handling water carrying much silt, the design of the headworks and canals must be such that the minimum amount of silt will be taken into the canal system and that as much as possible carried through to the fields or deposited in selected locations along the canal where it can be more easily handled. On the Williston project which pumps from the Missouri River, settling basins are used in which silt equal in volume to from 0.15 to 0.20 per cent. of the volume of the water has been removed. Such basins are particularly adapted to small canal systems. On the main canal supplying the Imperial Valley large dredges are used to keep the canal below the headgates clear. Much additional silt has to be removed in the smaller canals.

On the smaller canals in the Imperial Valley a number of methods of removing silt are used. Crowding with V-shaped drags or V'ing as it is called is extensively employed, the V being drawn through the canals with tractors (Plate II, Figs. A and B). These serve to partially clean the original canal section and also raise the canal banks so that greater depths can be carried. Small clam-shell dredges built to be self-propelling and to travel on the canal bank are also used. In some cases new canals parallel to the old ones have been built. As the canals are operated throughout the year, removal with teams is not practical.

The costs of these different methods have been as follows: Canal V'ing costs for 1912–1915 are given in Table II. In 1915, larger Vs with four caterpillar engines were used where previously smaller Vs drawn by two engines had been employed. There are 335 miles of canal in this system, more than one cleaning per year being required. V'ing is also being used on the Yuma project with satisfactory results both as to quality and cost.

Table II.—Cost of Canal V'ing—Imperial Water Co. No. 1

	1912	1913	1914	1915
Number miles of ditch V'd	481	431	448	361
Cost per mile for V'ing	$17.05	$21.99	$22.64	$28.02
Cost per mile repairs to engine	13.43	14.31	16.29	16.40
Cost per mile repairs to Vs	3.93	2.38	0.93	7.13
Cost per mile fuel and oil	6.52	6.69	6.64	8.05
Cost per mile of Mexican labor following V	13.42	16.04	21.07	21.64
Total average cost per mile	$54.35	$61.41	$67.57	$81.24

During 1915, two portable clam-shell dredges moved 255,000 cubic yards at a cost of 9.2 cents per cubic yard. They travelled 83 miles in going from one canal to another at a cost of $6.72 per mile. The repairs cost $349 per dredge per year as compared with an average cost of $1,480 per year for repairs on one caterpillar engine used in V'ing. Where joint grass grows at the edges of the canal, the dredges are able to remove such growth much better than other forms of equipment. Disk and grader outfits, used on canal banks after dredging to widen the bank, make roads and discourage growth, cost $20.40 per mile in 1915, 307 miles being covered.

Similar difficulties with silt have been experienced on the Yuma project of the U. S. Reclamation Service. A year's run of water causes a deposit of silt in the ditches from 6 to 12 inches in depth as well as a layer on the sides and requires annual cleaning. Formerly cleaning by team and by hand was used; a V is now used, being hauled by a tractor which pushes the mud outward to the top leaving slopes of about 1 on 1½. A trip through the ditch for each side is made. In 1915, 50 miles of canal were cleaned by teams and hand at an average cost of $579 per mile. In May, 1916, 12 miles of canal were cleaned with the V at a cost of $55 a mile, better results being secured. Dredging with drag-line excavators is used on the larger canals, the cost being from 3 to 8 cents per cubic yard, including all costs.

In cleaning main laterals on the Turlock Irrigation District, lengths of from 1 to 6 miles are worked over completely, adjoining sections being cleaned in other years, no patchwork being done. The berms formed by silt are covered with water grass which is difficult to plow. Cleaning to a 20-foot bottom width with 2 to 1 slopes costs from $250 to $500 per mile, depending on the extent of the cleaning required.

AQUATIC GROWTHS

This term is used to cover all types of growth which occur within the water cross-section of canals. Plants which have their roots in the soil above the water and trail over into the canal are discussed with other vegetation on canal banks.

Aquatic growths in irrigation canals include a large number of different plants. In addition to the actual differences in the plants themselves, there is much confusion in regard to the names by which the plants are known. In some localities the term moss is used to cover a number of different plants, none or few of which may be mosses as these are botanically defined. In other sections the general term algæ is used for growths having no relation to the true algæ. While the use of correct botanical terms may not be essential, if the common terms used are consistently applied, where there is so much confusion in regard to the terms used it is desirable to at least understand the character of plants coming within the general classifications.

Kinds of Aquatic Growths.—The type of growth generally referred to as canal moss is not a true moss. The plants of most general occurrence belong to the class known botanically as Potamogeton or pond-weeds. The pond-weeds are perennial herbs. The flowers develop fruiting bodies in the form of small rounded nutlets. The most common variety of this is known in some sections as horsetail moss, due to its appearance in the water. These plants have their roots in the sides and bottom of the canal, the growth trailing downstream under the action of the current. A single plant has sufficient branches to form a cluster about the size of a horse's tail and may grow to a length of 6 feet or more. These pond-weeds produce flowers at the base of the branches; such flowers, however, do not appear until the plant approaches maturity. The flowers are followed by the seeds by which the pond-weed propagates itself. The method of removing this plant is affected by its habit of growth, before flowering the stalk is tougher and less easily broken than when nearer maturity. Chains or other means of breaking the plant are not usually successful in the earlier stages of growth, some means of cutting rather than breaking being required.

This pond-weed or "moss" occurs very irregularly. New systems may be free from it for some years; it may then appear over the whole system in a single year. Its growth is usually greatest in the laterals or shallow canals, due probably to the effect of light. In deeper sections, particularly where the water contains silt, less trouble is experienced. It has also been found that the growth in darkened areas under bridges or in tunnels will be small or entirely absent. Its growth is also affected by temperature conditions and is most rapid in the months of higher water temperature. These are also the months of maximum demand for water, so that such plants make it doubly hard to meet the peak demand. The growth may very materially reduce the capacity of the canal. This makes it necessary to reduce the discharge, increase the depth carried or clean the canal by removing the vegetation. The amount of reduction in discharge or increase in depth which can be made is generally relatively limited, and removal of the growth is the usual remedy. The rate of growth may be as much as 4 to 6 inches in length per day and may increase the depth of water in a canal with a constant discharge as much as 0.1 or 0.2 foot per day. The total reduction in carrying capacity at a given stage may amount to over 50 per cent. of the normal. From one to three and occasionally four cuttings or other means of removal per season may be required depending on local conditions. A number of means of treatment have been developed adapted to the varying local conditions.

The water buttercup is another plant which is common in ditches and ponds in the coast States; it occurs less frequently in running water. This is a perennial which has its leaves submersed and which has yellowish flowers about ¼ inch or less in diameter. It is similar to the pond-weeds in its action in retarding flow. In some localities the buttercup may mature and break naturally in September, giving a clean channel in the later operation season.

The fine growth called frog moss is a water moss. This produces no flowers but is spread by fragmentation. The so-called black grass is similar in nature.

Algæ are cellular growths which occur in stagnant water or attached to other growths. They are devoid of differentiation into root, stem and leaf. By virtue of the possession of chlorophyll, all algæ are capable of utilizing carbonic acid gas as a source of carbon in the presence of sunlight. Algæ are a source of pollution of municipal supplies and have been closely studied in this relation in the East. The actual algæ found in irrigation canals are of much less importance or harm than the other growths to which they are attached.

Lichens may occur in some cases although very few lichens are normally and probably none are entirely aquatic. Lichens are flowerless plants composed of loose, cellular tissue, a parasitic fungus and a number of algal cells. Lichens attach themselves to other plants or to earth or rock surfaces.

The extent to which such growths may fill the canal section is illustrated in Plate III, Figs. A and B.

METHODS OF HANDLING AQUATIC GROWTHS

Cutting.—Due to the fact that these plants trail downstream from their place of growth, it is possible to effectively remove them by cutting with a form of saw or knife which is weighted so as to pass below the plant and cut just above the roots. A patented saw known as the Ziemsen Submarine Weed Cutting Saw, handled by Aschert Bros., Cedar Lake, West Bend, Wis., is generally used. This consists of a small steel band with teeth on both sides. Weights or sinkers are attached along the saw and light ropes at the ends for use in handling. The list price has been $20 for a 10-yard length complete; the blade alone is listed at $1.50 per yard.

This saw is operated by one man at each end. Better results are usually secured by sawing diagonally at about an angle of 30° with the ditch, the forward man doing most of the cutting, the rear man only drawing the saw back. If the two ends are kept abreast, the center has a greater tendency to run over the moss without cutting. The saw, if pulled with short quick jerks, will cut from 6 to 12 inches per stroke. In addition to the men cutting, from one to three men will be needed on the canal below to remove the moss as it floats down. This is usually done from bridges, checks or other structures from which the men can work. Where only the pond-weeds occur this saw will give good results. It can also be used at an earlier stage of growth than chaining. Where the finer growths usually known as black grass or frog moss occur with the pond-weed, frequent cleaning of the saw may be required due to the catching of these finer growths on the saw teeth. Two men sawing can usually cover from ¼ to 1 mile of ditch per day. One-fourth mile would represent unusually heavy moss or unfavorable conditions for working. On the Minidoka project in 1916, as many as 40 men were employed at one time in cutting moss, the average cost being $22 per mile. On the Orland project in 1914 the cost per mile cleaned with saws was $17 for each cleaning. The saw was used in channels too deep to work stock. In small laterals in which men can wade, an ordinary brush scythe will give good results. The cost with scythes in laterals was $11 per mile on the Minidoka project in 1916, the water being lowered to depths of 1 foot during cutting.

Dragging.—Heavy chains with one or two horses on each end are also used, the chain being dragged upstream and breaking the growth near the roots. This method is most successful on mature or long pond-weed. For the tougher earlier growth the chain may run over the growths without breaking it. A ¾-inch cable has also been used. On the Orland project a drag made of railroad iron, somewhat on the plan of a split-log road drag, has been used on canals in which the depth was sufficiently small to permit the use of horses in the water. The cost in 1914 was $12 per mile for each cleaning. On the Minidoka project in 1916, the average cost of chaining was $8 per mile. Where the canal has sufficient capacity so that removal may not be required until the growth is fairly ripe, some method of dragging is more usual than sawing. Where it can be used, dragging is generally preferable due to its lower cost and the greater speed obtainable.

Harrowing.—Harrowing with weighted disk harrows has been successfully used on the Bear River canal in Utah, the Truckee Carson project in Nevada and on other systems. However, in some cases where this method has been tried it has not given good results. The disks are set nearly straight so that the growth will be cut but not covered, allowing the plants to float downstream to be removed as in other methods. For depths up to 3 feet the team can walk in the ditch; it is usually better, however, to use a team on each bank. The disk harrow also appears to injure the roots and hinder growth later during the same season. Spring tooth harrows have been used on the Sunnyside and Salt River projects. Harrowing is carried on without turning water out of the canals or interrupting the delivery of water. The cost in laterals on the Minidoka project was $9 per mile in 1916.

Sun-killing.—Pond-weed and other aquatic growths can be killed by exposure to the sun for periods of from 3 to 8 days. Where the delivery methods are such that water can be turned out of portions of the system, this method is both cheap and effective. Such conditions are found where water is delivered under rotation and the rotation is carried on between laterals or sub-laterals. Under delivery-on-demand or continuous-flow methods of operation it may be possible to arrange to turn water out of sub-laterals for a few days in order to control aquatic growth. On some canals, particularly those having high velocities, alternately turning the water on and off may cause sloughing of the banks. Such turning out of water is not generally desirable for laterals carrying over 40 or 50 second-feet. It is also not adapted to canals which do not dry out quickly, as the time required is longer than water can be shut out from the ditch.

Miscellaneous Methods.—Oiling of the canal bed has been tried in a number of cases with varying success. The principal objection to the method appears to be the short time such oiling is effective and the relatively large expense in proportion to the benefit.

Chemical treatment, such as the use of copper sulphate, has also been tried. This method has been successfully used for the control of algæ in municipal storage supplies; in irrigation the quantities to be treated are much larger and the water flowing in the canals does not give as favorable conditions for the use of such chemicals as is the case with ponded water. It has been tried in a few instances with fair success in some of the smaller lined canals in Southern California.

On small canals, long-handled rakes, operated from the canal banks, may be used. On the Wapato Indian Reservation drainage canals, it is stated that two men clean about 1/5 mile per day at a cost of $25 per mile. In one case a cylinder from a threshing machine was dragged lengthwise through a drainage ditch with good results. On the Buckeye canal in Arizona it was observed that moss did not grow where cattle watered in the canal, due to the trampling of the sides. Spraying with arsenic solutions as discussed on page 29 for growths on canal banks might be effective if applied at the end of the operating season by destroying the roots on perennial plants and the seeds on mature growths. On the sub-laterals of the Sacramento Valley Irrigation Co. an oil burner for destroying weeds which grow in the laterals between irrigations has been tried with indifferent success.

SEMI-AQUATIC PLANTS

In addition to the growths entirely aquatic in nature there are a number of plants which have their roots within the canal water cross-section, but whose growth is largely above the water surface. Among such plants are tules, cat tails, water grass, bamboo and joint grass. Other growths such as Johnson and Bermuda grass may extend from the adjoining soil into the water. Such plants are more troublesome in the warmer climates than in the mountain states, particularly in marshy areas at the sides of canals or in silt-laden water. For the portions of the cross-section in which they may grow, such plants will more effectively stop the flow than the strictly aquatic plants. In water carrying large amounts of silt all forms of aquatic vegetation may reduce the velocity in their vicinity so as to cause local silt deposits. It is particularly necessary to control vegetation in such canals. The growth of the semi-aquatic plants is limited to the shallower depths. Owing to their erect growth they can not be broken off by dragging as readily as the pond-weeds. They can usually be cut with brush scythes at a cost of about $12 per mile. Plate II, Figs. C and D, illustrates the extent to which such growth may reduce the capacity of laterals.

Tules can sometimes be mowed from the banks when they do not extend too far into the canal. In the Imperial Valley one method used has been to destroy the tules before their growth becomes thick by the use of straight-handled hoes called "tule cutters" operated from the bank, the tule being cut at its roots. This also prevents their spreading. On the Alta Irrigation district near Fresno a heavy chain drag is used. This has been found to bruise the tules so that they are killed, although they are not actually removed by the chain. On the Turlock Irrigation district one plowing when water is out has been successful in destroying tules. When the extent of the growth is small, they may be dug out by hand while the ditch is still wet.

Barnyard millet or water grass is an annual which is very troublesome in parts of California and the Southern States. This grows in water up to 12 inches in depth and is the same grass which causes damage in rice fields. It is most troublesome in laterals of 10 second-feet or less capacity. Water grass will sprout and seed in about 45 days; when cut, a new growth develops from the same roots. In some cases it has been pulled out; in others, continuous grazing has been tried. Sheep will keep the growth down but will not exterminate it. Water grass may grow as much as 18 inches per month.

VEGETATION ON CANAL BANKS

The vegetation on canal banks varies from plants which are very desirable to those which are very detrimental. In blowing soils, the growth of vegetation on the banks may be very beneficial. Many plants interfere with the use of the banks, extend into the water and retard the flow, are the source of tumbling weeds which may be caught on and clog screens or structures in the canal, or supply weed seeds which may foul fields on the farms. The methods of handling such vegetation on canal banks vary with its character and purpose and include grazing, mowing, chemical treatment and seeding of desirable plants.

Including both main canals and laterals, from 1 to 2 per cent. of the total area under a canal system will usually be occupied by canal rights of way. Of such rights of way, one-half or more will consist of canal banks and adjacent areas, the remainder consisting of the actual canal section. The area of canal banks may amount to 1 per cent. of the total area under a system or the equivalent of several large farms on canals serving relatively large areas.

Native Plants.—The kinds of weeds which grow without cultivation on canal banks vary with the soil and climatic conditions. Among the more common ones, are the tumbling weeds, sweet clover, broncho grass or "cheat," Johnson grass, Bermuda grass, water grass or barnyard millet, and willows.

Three kinds of tumbling weeds are found along canals. These are Russian thistle, tumbling mustard and the ordinary tumble weed. These all break off at the ground when mature and scatter their seed by being rolled across country by the wind. They cause much trouble and expense in canal operation both for the collection and burning of those blown into the canals and also from actual damage due to the clogging of screens or structures. Russian thistle has no marked stalk, being flatly spherical in shape and growing from 1 to 3 feet in diameter. It is not an actual thistle, being properly a salt wort. It can be distinguished from the common tumble weed by its sharp spikes. Russian thistle does not usually mature and start to move until near the end of the operation season, the trouble with this plant coming mainly in the spring from the growth of the previous year. Tumbling, or "Jim Hill" mustard, as it is called in the Northwest, matures earlier in the season and may give trouble in some localities during the season of heavy demand for water when the available margin against injury due to the clogging of checks or turnouts is small. This mustard germinates in both spring and fall and grows from 1 to 4 feet high. The ordinary tumble weed is also found in many parts of the West but is frequently not distinguished from the Russian thistle.

The weeds which are blown into canals during the non-operation season are most economically removed just before water is turned in the following spring. This should not be done too far in advance of running water or a second cleaning may be required. Such weeds are collected and burned. Weeds blown into the canal during operation are usually collected at structures or screens. These require drying before they can be burned and when removed from the canal to dry require some means of preventing their being blown in again. In some cases the prevailing winds may be from one direction, such as with the natural drainage of the country, so that the weeds may be placed on the leeward side. On some systems woven-wire weed baskets are used. These are placed at structures. As the weeds are removed from the canal they are placed in the baskets until they are dry enough to be burned.

Sweet clover frequently grows to a height of several feet and of such thickness as to interfere with the use of the canal banks by the canal rider (Plate III, Fig. D). It also may extend into or droop down to the water in the canal and restrict the flow, particularly in the smaller laterals. If allowed to mature, the stalks become woody and if broken may get into the canal and cause trouble similar to that caused by tumble weeds. Sweet clover does not naturally travel in this way, however. Sweet clover is supposed to be a biennial requiring 2 years for its extermination even if seeding is prevented. It is best handled by mowing. If cut before blooming, new growth will start from the same roots.

A grass variously called needle grass, June grass, broncho grass, Mormon oats, military grass, wild brome, chess or cheat is of general occurrence particularly in the northern half of the Western States. Its growth is not objectionable from the point of

FIG. A.—Aquatic vegetation in a canal in San Joaquin Valley, California.

FIG. B.—Vegetation at sides of canal, causing silt berms.

(*Facing page* 26.)

PLATE III.

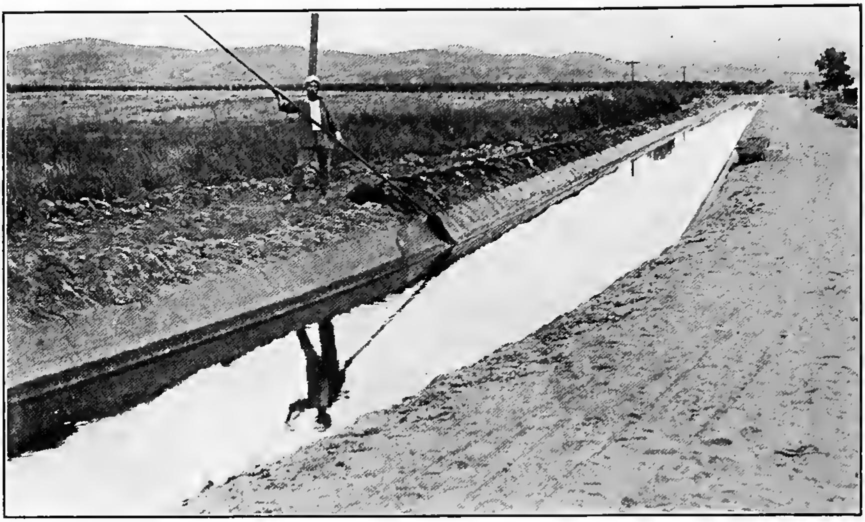

FIG. C.—Removing moss from a lined canal in Southern California.

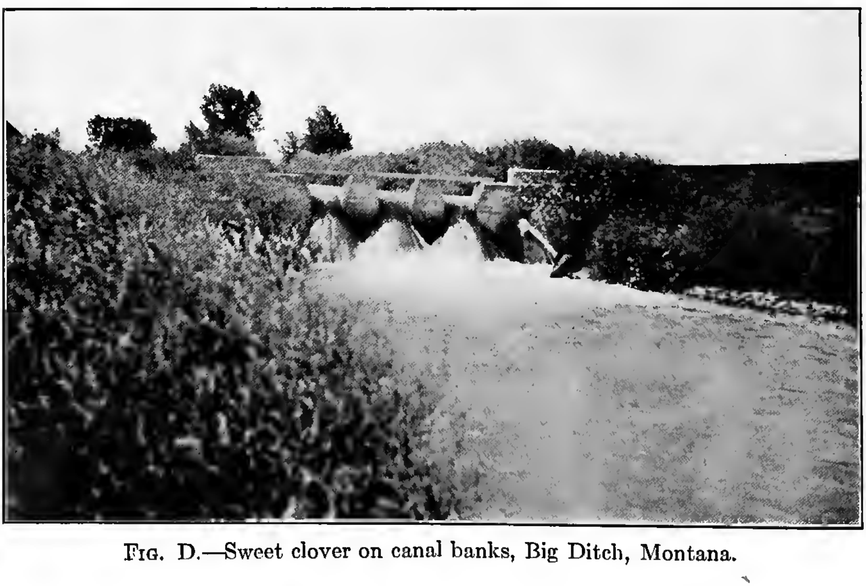

FIG. D.—Sweet clover on canal banks, Big Ditch, Montana.

view of canal operation as it does not grow sufficiently high to interfere with the use of the banks. Its seed, however, may be carried into the fields where the grass is very injurious to the first cutting of alfalfa.

Johnson grass obstructs the flow at the waters edge and by drooping into the canal. Other grasses such as joint grass are similar in effect. Johnson grass is a particularly undesirable plant on canal banks as the seed may be carried onto the farms. Once established, its persistence and hardiness make it difficult to eradicate. Several states have statutes making it unlawful to permit Johnson grass to go to seed. The cost of cleaning canals of Johnson grass may be as much as $200 per mile. Johnson grass is propagated by both seeds and rootstocks. Grazing with sheep is the most effective means of control.

Bermuda grass on canal banks may not be particularly objectionable from the point of view of canal operation as its growth is not high and it aids in holding the soil. On laterals operated only part of the time, it may grow across the bottom and obstruct the flow. Bermuda grass is found only in the South and Southwest, where winter temperatures do not kill the roots. It is a serious pest when established in fields and its growth along canals should be limited in order to prevent its spreading. It spreads by jointed rootstocks and aerial runners as well as by seed. In humid climates the seed is not fertile; in arid regions the seed is fertile and is the chief means of spreading. The growth is most rapid in the early fall. Bermuda grass is resistant to alkali, drouth and submergence, but will not stand shade.

Wild oats, sunflowers and various grasses may give trouble in different localities. These can generally be controlled by mowing. Arrow-weed causes much trouble in localities of high temperature, frequent cuttings being required for its control.

Willows grow on many canal banks particularly where the lower toe is moist or in the shallow water at the canal edge. The silt which is usually deposited around willows forms a berm which reduces the canal capacity. They are more easily killed if cut when the sap flow is relatively rapid as in hot weather. Continuous cutting is generally required. Sheep may reduce the growth by eating the leaves. Other trees which may occasionally grow along canal banks are usually more harmful than beneficial as they interfere with the use of the banks in patrolling and in canal cleaning. Brush along the banks must be cut before aquatic growths can be removed by sawing or dragging. Cutting brush on 223 miles of canal on Imperial Water Co. No. 1, in 1915, cost $34.50 per mile. Cutting willows cost $27 per mile of canal on 23 miles on the Minidoka project in 1916.

GENERAL METHODS OF CONTROL OF VEGETATION ON CANAL BANKS

Grazing.—Where the vegetation on the canal bank is heavy and of a character which furnishes nutritive grazing, the pasturing of sheep has been not only beneficial to the canal but in some cases directly profitable. This condition is found on some systems in the Southwest where Johnson grass forms a large part of the growth. Sheep are used for this purpose as they pack the banks without wearing them down as much as cattle, graze more closely and will themselves make some growth on much leaner pasturage than other stock.

Sheep may be herded on the banks or controlled by fencing. The latter method is preferable as it reduces the cost of herding and the sheep can be confined more easily to narrow areas. This, however, may require fencing canals where otherwise the expense of fencing would not have to be incurred. On the Orland project, the Reclamation Service has in some cases fenced one side of canals where the adjoining land owner has agreed to fence the other and to maintain sheep on the banks. On laterals about six head per 1,000 feet of ditch have been used. Such grazing of canals should not be confused with the trampling of banks and sides of canals where range stock are allowed access to them. Grazing or the driving of cattle across canals when not in use is generally harmful and should be prevented.

Pasturing of sheep and goats has been extensively used on the Salt River project. This not only reduced the expense of handling Johnson grass but also nearly eliminated the burrowing animals due to the packing of the banks. Two herders were used to handle 400 to 500 sheep which were grazed on from 50 to 100 yards of bank at a time. The use of dogs was not practical as there was too much tendency to crowd the sheep. It was found that the sheep ate sunflower, sourdock, sour clover, burr clover, Bermuda grass, salt bush, and most tree leaves including willows, but would not eat tobacco, thistles, foxtail when headed out and water grass when large. Banks grazed for 2 years showed 95 per cent. of the Johnson grass to have been killed. In 1914, 40 miles of canals of various sizes were grazed, decreasing the maintenance cost $115 per mile. The sheep account showed a loss of $1,480 but the band was improved during the year by the replacement of the older ewes. Similar pasturing was carried on in 1915, partly in coöperation with the land owners in fencing small laterals so that herding would not be required. The increase in the herd and returns from the wool more than paid the cost of grazing. An average of about 15 sheep or 20 goats were used per mile of canal and laterals. In other sections the results with grazing sheep have not always been successful. Where the growth is less nourishing than Johnson grass, it is more difficult to maintain the sheep in good condition although weed growth can be restricted. Occasionally the presence of poisonous weeds make grazing impractical. Ownership of the sheep by the canal company is preferable if close grazing is desired. Other owners are more largely interested in the growth of the sheep than in the maintenance of the canals.

Mowing.—Mowing, both hand and machine, is often used. Where the banks are fairly even and the space is sufficient the cost with mowing machines is much less. For small laterals hand mowing may be cheaper. Some hand work around structures may be needed in connection with machine mowing. Various makes of mowers can now be secured with which the cutter bar can be operated on a slope, either up or down. These permit running the mower on the top of the banks and mowing down the slopes on slopes as steep as 1 to 1. Mowing is not as successful with Russian thistle due to the closeness to the ground with which it grows and to its collection in front of the machine. Many weeds can be cut prior to seeding; if sweet clover is cut before blooming, new growth will start. An experienced team and driver can accomplish economical results on banks which are quite rough and irregular. In clearing canals, the material removed should be uniformly distributed on the banks if these are to be machine mowed. Under normal conditions a mowing machine should do the work of 8 to 12 men mowing by hand. One mowing per season will be sufficient in some cases, in other two or three may be required. The cost of mowing is usually from $1.00 to $1.50 per acre per cutting.

Chemical Control.—Various chemical solutions for the purpose of controlling vegetation have been used with field crops, on railroad rights of way and to a limited extent on canal banks. There are two general methods of treatment: in one of these, usually known as the root-absorption method, the vegetation is controlled by adding sufficient amounts of the herbicide to render the soil sterile so that any plants are killed or seed prevented from growing by the absorption of the poisons in the soil; in the other method, usually known as the leaf-absorption method, the poison is applied as a spray to the portion of the plant above ground, dependence being placed on the absorption of the chemical by the plant in sufficient quantity to cause its death or its failure to mature seeds. The root-absorption method may be applied to canal banks as sterility may be desirable; it is not suited, however, to agricultural lands. The leaf-absorption method is less expensive although the results obtained may be only temporary. Experiments on the use of such herbicides have been made by Mr. G. P. Gray of the California Agricultural Experiment Station, from whose reports the following information is mainly taken.

Of the various chemicals used arsenic in the form of sodium arsenite combines effectiveness with relatively low cost. Stock solutions were prepared by dissolving arsenic trioxide in sodium hydroxide and water so that each gallon of the solution contains 4 pounds of arsenic trioxide. For use this can be diluted in the proportion of 1 to 100.

For the leaf-absorption method the proportion of about 300 gallons of the diluted solution or 12 pounds of arsenic trioxide and 6 pounds of sodium hydroxide per acre are recommended. The cost per acre of the materials for such a treatment is about $1.50. It was found that such a solution was effective in killing the plants of morning glory in all cases. When applied in the dormant periods of growth, it was found that the roots were also killed to depths of 2 to 4 feet. These results were secured in the relatively humid coast areas of California; in the more arid interior the results were less satisfactory, apparently due to the drying of the spray before its absorption by the plants. The emulsifying of the solution with soap or the use of a water spray in advance of the arsenic solution are recommended for such arid conditions. No injurious effects to the soil were noticed from six successive applications of this spray. On other weeds, the spray was most effective on those having broad leaves. For grasses the addition of soap increased the effect. A solution of acid sludge and water as well as acid tar appeared to be especially effective on grasses.

In tests of the root-absorption method the arsenic solutions also gave the best results. Solutions of sodium cyanide were tried with less satisfactory results both as to effects and as to costs than were secured with arsenic. Sulphuric acid solutions were also effective but high in cost. Carbon bisulphide, applied at the rate of 10 fluid ounces per square yard, was effective. Iron sulphate and copper sulphate appeared to be of no value for the control of the morning glory. Acid sludge which is a waste product in the refining of petroleum distillates with sulphuric acid was also used. The cost per acre of materials for such root-absorption treatment was about $120 where sufficient arsenic trioxide was used to control morning glory, about 900 pounds per acre being required, and about $40 per acre where 300 pounds per acre, which controlled all plants except morning glory, was used. The cost per acre with sodium cyanide and carbon bisulphide was about $300 and with sulphuric acid about $250.

Seeded Grasses.—Many efforts have been made to find some form of beneficial or even unobjectionable plant which could be cheaply established on canal banks and which could maintain itself there. Some success has been attained but usually at a relatively high cost. The upper parts of canal banks are often very dry and composed of relatively infertile soil taken from the deeper portion of the excavation. It is difficult to secure a stand of seeded grasses which can maintain itself against the native weeds under such conditions.

Experiments with different grasses have been made on the Belle Fourche project in South Dakota. The following mixture per acre seeded was recommended for use there as the results of these tests: brome grass (Bromus inermis), 6 pounds; western wheat grass, 6 pounds; alfalfa, 6 pounds; redtop, 2 pounds. Seeding should be done in the spring when the ground is moist and no grazing should be permitted during the first two seasons in order to secure a good sod. Western wheat grass is a native of South Dakota and is the most drought-resistant of the grasses there. It is slow to start, however, making it difficult to secure a stand. Brome grass and alfalfa gave good results in most cases. When a stand is once secured, alfalfa being deep-rooted may be able to maintain itself under moisture conditions which shallow rooted grasses could not survive. In many localities the use of alfalfa on canal banks is not desirable as its roots attract burrowing animals which may injure the banks.

On the Boise project clover and blue grass have been tried. The cost was $14.85 per acre and stands were secured only where the banks could be irrigated, such as below drops. Fall-sown rye at a cost of $2.60 per acre gave the best results. Rye is self-seeding and after a few years tends to exhaust the fertility of the soil so that little else will grow. It is also extensively used to control blowing soils. On the Truckee Carson project, native blue joint or blue stem grass has proven itself to be hardy. It spreads both by runners and by seeding. A stand is more easily secured by setting roots than by seed. Gophers do not eat its roots to any extent. On some California systems, white clover has given good results. This does not grow to sufficient height to interfere with the use of the banks and will spread from the moister soil to the dryer tops of the banks. In Montana a mixture of Kentucky blue grass and timothy in proportion of 2 to 1 has been recommended for small canals. On large canals native blue stem can be used; on the smaller ditches its growth may be too rank.

Miscellaneous Methods.—Where the soil does not blow, clean cultivation can be used. Such harrowing must be repeated each year and is a relatively expensive method. On the Boise project harrowing gave fairly satisfactory results, the cost being $4.85 per acre handled per year. Several treatments per year may be required. Oiling canal banks to prevent weed growth has been tried in a few cases. The results have not generally been successful. If such treatments are sufficiently thorough to give permanent results in weed prevention the cost is higher than is warranted. Less thorough methods have little effect.

PROTECTION OF CANALS IN BLOWING SOILS

Canals in light soils often give trouble due to the blowing of the banks or wind erosion. Such troubles are due both to the filling of the canal cross-section by such drifting soil and to the eroding of the banks so as to reduce their strength. Rye has been used in a number of cases and has been found to be able to grow under conditions where other plants cannot maintain themselves. Various other methods of protection have also been used.

On the North Platte project there are about 50 miles of main canal in soils which blow. In some cases an unprotected bank with a 12-foot crown has been lowered 3 feet in 6 months. A number of methods of protection have been tried, the following summary of their experience being taken from the Reclamation Record for September, 1913. The canal has been fenced against range stock as it was found that cattle loosened the soil and caused it to blow more easily. Fencing was also necessary to protect the coverings used. The fencing has also enabled sand grass to establish itself and to hold the soil. In October, 1909, 12,000 linear feet of new bank were covered with a light coat of stable manure at a cost of 1⅓ cents per linear foot. By March, 1910, this had nearly all disappeared. As soon as holes are opened in such covering, the wind undermines the straw and gradually carries it away. Straw will not give protection unless spaded or disked into the ground. About 45,000 linear feet were covered on the top and outside slope with a 3- or 4-inch layer of gravel at a cost of 21 cents per linear foot or 81 cents per cubic yard. This has been found to be the most permanent protection and is used where the gravel haul is not over 1½ miles. About ½ mile of the outer slope of the canal banks has been covered with brush at a cost of 20 cents per linear foot. This has been quite satisfactory but is liable to destruction by fire.

About 5 miles of canal were covered with Russian thistle held in place by woven wire at a cost of 11 cents per square yard, of which 4 cents was for wire and 7 cents for labor. This is recommended for narrow, steep or ragged banks. The sand which is caught in such lining strengthens the bank. On flat slopes, the weeds were plowed in, the cost on 60,000 square yards being 6.1 cents per square yard. These weeds accumulate in the canal during the winter and can be economically used in such protection. Cement coating, calcium chloride, crude oil, sugar syrup and coal tar were also tried but none of these methods proved satisfactory.

Relatively high velocities are desirable in the portions of canals passing through blowing soils as the finer sand blown into the canal may be partially eroded by the water and the reduction in area distributed over a longer length of canal. Wind breaks located far enough from the canal to prevent the sand collecting in the canal may be used. Sand fences similar to those used on railroads may be used until more permanent relief can be secured. Using wide rights of way, such as 1,000 feet, and leaving the native vegetation on the unused portion of the right of way or the planting of rye or other growth, may be sufficient.

CANAL SCREENS

The practice in regard to the use of weed screens varies quite widely. On some systems, such screens may be provided at the inlets of all siphons and at other feasible locations. On other systems, no screens may be used. The tendency is apparently away from the use of such screens, many taking the risk of stoppage of siphons and gates in preference to the risk of stop-

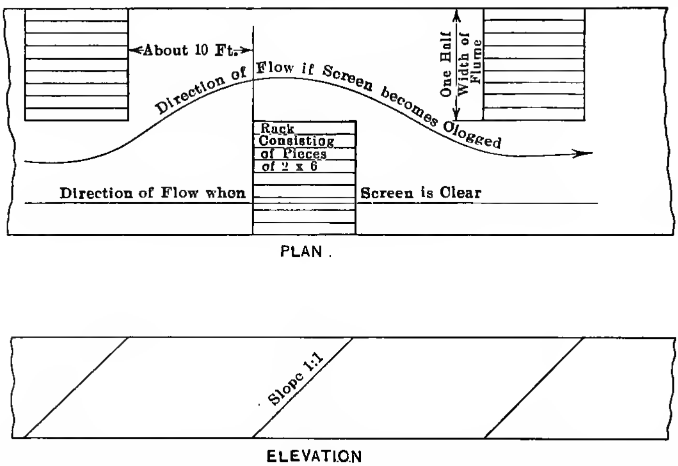

Fig. 2.—Coarse weed screen used in wood flumes by the Bitter Root Valley Irrigation Co.

page of screens. Ordinarily weeds and drift carried in the canal will be carried through the siphons due to the greater velocity in the siphon, although this may not be the case at the ends of the seasons when the discharge is smaller. Where the siphons are small, the danger of clogging is greater and screens may be used on laterals on systems where no screening is practiced on the main canal. Weeds frequently collect on turnouts or checks and affect the flow of the water, in some cases to a sufficient extent to cause injury to the canal. Similar injuries, however, are liable to be caused by the collection of such weeds on weed screens unless they are frequently cleaned. The danger of such injury has caused night patrolling to be practiced in a few cases; ordinarily patrolling for such cases will not be required after the first few years of operation, as settlement or other means of prevention of weed growth should remove the source. Such weeds reach the canal from adjoining lands below the headgate

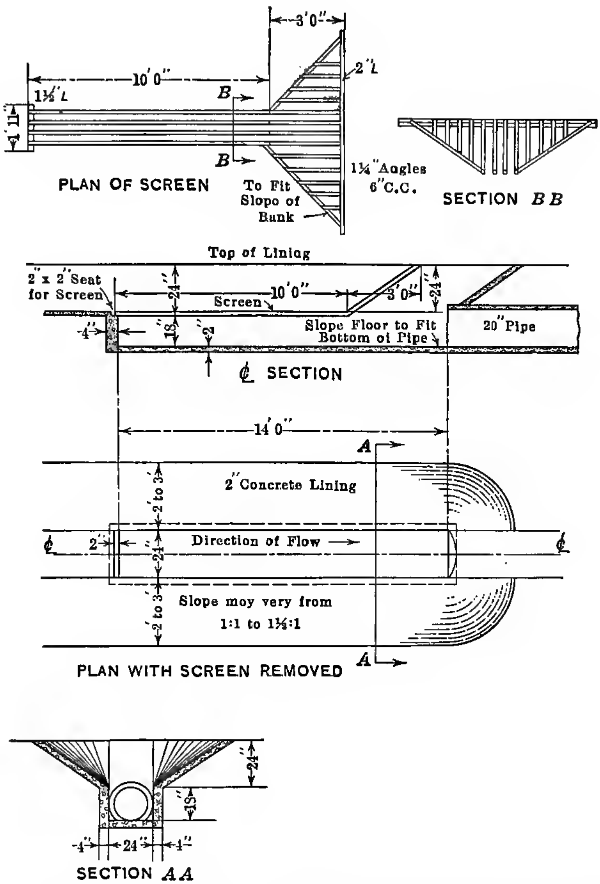

Fig. 3.—Weed screen used at inlet of 20-inch pipe lines on Umatilla project.

so that the fish or other screens used at the diversion will not prevent trouble on the canals.

A type of weed screen used on the Bitter Root Valley Irrigation Co.'s system in Montana is shown in Fig. 2. This is placed in wood flumes. The main canal is of considerable length and contains a number of flumes and siphons. When the screens are free from trash, the water flows smoothly through the racks. In case weeds are caught on the rack so as to clog the screen, the water has an opportunity to pass between the two sections of the screen as indicated by the arrow. This will cause cross-currents which makes this screen unsuited to earth canals; in flumes or lined sections such currents cannot cause erosion. Ordinary rack screens with racks of $\frac{1}{8} \times 1\frac{1}{2}$-inch strap iron $\frac{3}{4}$ inch apart are used at the inlets of siphons. These are placed on a slope of 1 on 2 with the top somewhat below the top of the bank or flume. In case of clogging, the flow may pass over the top of the screen before backing over the bank.

In Fig. 3 is shown a type of weed screen developed on the Umatilla project for use in lined laterals above pipe siphons. Where such screens have been cleaned daily they have been satisfactory, breaks not only being avoided but a more regular service being maintained. These have been used in laterals up to 20 second-feet capacity. Some débris is left on the screen to give sufficient velocity in the depressed section to prevent sand deposits. These screens have been installed in old sections at a cost of about $25; if placed at the time of construction of the lateral, the cost should not exceed $20. The advantages of this form of screen are the large area and the large quantity of drift which can be retained before serious checking of the flow takes place.

BURROWING ANIMALS

In practically all irrigated sections some of the various forms of burrowing animals give trouble in canal maintenance. Their holes are points of weakness at which canal breaks may start. Such breaks are particularly liable to occur when the water surface in the canal is raised so as to be above new holes. Such holes are also more troublesome and dangerous in fills. In some localities the prevention or repair of breaks caused by such animals may be the largest single item in the cost of canal maintenance, particularly on the laterals. Where water is rotated between laterals the burrows may be built in the banks during the time water is out. When water is turned in again the holes may start breaks. In some cases canals are operated under checks so as to maintain a uniform depth of water in the canal throughout the season. The burrows in such cases will be above the line of saturation in the banks.

The kind of animals causing the damage varies in different localities. Also, the local names for the same animal are liable to differ, causing much confusion in discussing means for their control. The most successful methods of control are based on a knowledge of the habits of the different animals, and uniformity in names is essential if such methods are to be understood. Much work has been done in studying these animals in relation to the injury which they cause to field crops, the results of which have been published in various bulletins, references to which are given at the end of the chapter. The data regarding poisons and the habits of the animals are taken mainly from these references.

The most generally employed methods of control are poisoning and trapping. A number of special methods have also been used for particular conditions.

Pocket Gophers.—The animal of most general occurrence and one giving much trouble is the pocket gopher. The gopher is also blamed for much damage caused by ground squirrels, the term gopher being used in many localities to cover all small burrowing animals. The habits and methods of handling gophers and ground squirrels differ materially and the two types should not be confused.

Pocket gophers differ in size from that of a small mole to that of a large rat, a large number of varieties being recognized. All are short-legged, have small ears and eyes and short smooth hair. The most distinctive characteristics are the large pockets from which their name is derived. These are on the outside of the head and may be from 1½ to 2 inches deep, extending back under the skin of the shoulder. The pockets are used for carrying the food secured in burrowing. When filled, the pockets more than double the size of the head. Apparently pocket gophers do not hibernate.

Pocket gophers are found over practically the entire western half of the United States, extending into Canada and Mexico. They are especially abundant in fertile soils where their burrows cause much inconvenience and loss to crops. Their food is entirely vegetative such as roots, bulbs and cultivated crops. These are cut into sections, when encountered in their burrowing, and put into the pocket to be carried to the nest. Apparently they do not require water except such as is secured in their food, as many desert species thrive for long periods, such as a year or more, where water is not available. Their burrowing into ditch banks is for the purpose of escaping the flooding that may be given their burrows in adjacent irrigated fields rather than to search for food or water.

The burrows or tunnels are located from 6 inches to a foot below the surface, are 1½ to 3 inches in diameter and have a length varying from a winding network of passages to long direct lines. The lines of burrows in fields are marked by mounds of earth spaced generally about 15 feet apart. After pushing out the loose earth in the mounds, the openings are closed from within, leaving no open runways. In this they are distinctly different from ground squirrels. Pocket gophers are rarely seen as they do not emerge from their burrows.

Among the natural enemies of the gophers are the hawks and owls and coyotes who may pick them up at the outlets of the burrows. Badgers occasionally dig them out. Weasels, who follow them into their burrows, are probably their greatest enemies as there is practically no escape for the gopher. Gopher snakes are so called from their habit of catching gophers.

Pocket gophers can be poisoned successfully if the poison is placed in their burrows. This can be done by following down the closed outlet in the mounds until the burrow is reached and placing the bait in the burrow. Better results are usually secured with some vegetable such as potatoes, parsnip or carrots cut into pieces about ½ inch square and 1 inch long. Strychnine can be sifted over the bait using ⅛ ounce of powdered strychnine (alkaloid) and one-tenth as much saccharine to 4 quarts of dampened bait or a small crystal of strychnine can be inserted in a slit in each bait.

Traps may also be set in the burrows. A number of different types are on the market which will give good results. Some of these are arranged to be sprung by the earth which the gopher pushes ahead of him in the burrow, catching the gopher behind the earth. Traps are more difficult to set for gophers as the burrow must be opened.

Ground Squirrels.—Ground squirrels are of common occurrence throughout the West. There are several varieties of these. The short-tailed gray Piute squirrel is found in the Great Basin and adjacent areas. The flickertail or Richardson ground squirrel is found in Montana and adjoining States. The larger and darker Columbian ground squirrel is common in the Columbia

River drainage area. If disturbed, this squirrel may stand erect for an instant taking a position which has caused them to be called the "picket pin." In California the gray squirrel known as the California Digger or Beechy ground squirrel is distributed widely. These do not hibernate in the warmer portions of the State. Chipmunks usually inhabit timbered areas and seldom cause trouble to canals. One variety known as the sage-brush chipmunk may be found along ditches. These are not extensive burrowers although they may use the burrows of other animals. Chipmunks do not hibernate. They usually eat poisoned grain readily.

In all except the hotter climates ground squirrels hibernate for several months of the year. Seeds and green vegetation form their principal food. Their burrows are generally not extensive although they may be larger in the later summer season than in the spring. Ground squirrels are diurnal in habit and are easily seen. They prefer to build their burrows on small elevations so that they may have a wide view from their runways as a protection against natural enemies. This is probably the reason they are so frequently found along ditch banks.

As their burrows are usually single they may be readily killed with carbon bisulphide. Trapping will also generally give good results, particularly in the earlier season when mating is taking place and the squirrels are less careful.

Poisoning is very generally practiced, the bait being placed at or near the mouth of the burrow. The readiness with which the poison will be eaten depends on the availability of other food. It is most successful early in the season when the squirrels emerge from hibernation or before green food becomes abundant. Grain may be used in the early season, later more succulent bait such as alfalfa, turnips or beets may be eaten.

Muskrats.—Muskrats differ from the other animals in that they burrow into the banks from the inside of the canal below the water surface rather than from the outside. They may enter the bank a foot or two below the water surface and burrow through to the outside. Screens can be placed across the ditches arranged to trap them and prevent their entrance to canals. Usually the difficulty caused in keeping such screens free from drift will make the method impractical. Muskrats have a value for their fur and may be trapped for this purpose alone. They are also eaten. Muskrats may be poisoned with strychnine or arsenic in carrots, parsnip or turnips. If such poisons are placed along the ditch care should be used to prevent the bait getting into the ditch and being carried to farm animals. Trapping or shooting will usually give the best results. On some systems bounties of 20 or 25 cents are paid for muskrats caught on the canals, on others a guaranteed price for the skins may be maintained as an inducement to trappers.

Other Animals.—Prairie dogs do not cause much trouble in canal maintenance. Their distribution is limited to the Rocky Mountains and Great Plains areas to the east. Their habit of living in towns makes them destructive of crops. They seldom infest canal banks.

Some of the various forms of meadow mice or rats may cause trouble in the smaller laterals, particularly around structures. The larger kangaroo rats, so called because of their long hind legs used in travelling by leaps or hops similarly to a kangaroo, may sometimes make burrows in ditch banks as they prefer slight elevations or embankments. Rats are most easily controlled through protection to their natural enemies such as hawks, owls, herons and badgers, skunks, snakes and weasels. Poisoning as for ground squirrels can also be used.

Badgers live on the various forms of burrowing animals which cause injury to ditch banks. When in pursuit of such animals, a badger may dig into and injure the bank but the benefit by continuous destruction of the other animals may be greater than such occasional loss. On some systems they are destroyed. Trapping or shooting are usual methods. Weasels are also of benefit as they kill gophers and mice. They are very active and may exterminate gophers in narrow areas. Skunks are more beneficial than harmful. Occasionally when digging for mice and small rodents they may cause damage to ditch banks but the benefit derived from the destruction of such rodents is of much value.

METHODS OF CONTROL OF BURROWING ANIMALS

Poisoning.—Strychnine forms the basis of most of the poisons used. It has the advantage that its action is certain and its character is generally well known. Its taste is so bitter that it is not liable to be eaten by children through mistake. Strychnia sulphate is soluble both in hot water and in fruit juices. The poison may be used with a wide variety of bait depending upon the feeding habits of the animal being sought.

Grain, such as wheat, barley, oats or corn, either whole or crushed, is most generally used. It may be prepared by glazing the surface with a solution of the poison or by the absorption of the solution into the grain. Glazing is quicker in action. It has also been found that ground squirrels will be killed by the absorption of strychnine from glazed grain carried in their cheek pouches before it is actually eaten. If used at a season when rain may be expected, the poison may be washed from the glazed grain before it is eaten. Such poisoned grain can usually be prepared for 4 or 5 cents per pound.

For preparing poisoned oats the following method is recommended in Circular 4 of the North Dakota Experiment Station: Mix thoroughly 1 ounce strychnine alkaloid (powdered) and 1 ounce baking soda. Sift this into ¾ pint of thin hot starch paste, stir to a creamy mass. The starch paste is made by dissolving 1 heaping tablespoonful of dry gloss starch in a little cold water which is then added to ¾ pint of boiling water. Boil and stir constantly until a clear thin paste is formed. Add ¼ pint heavy corn syrup and a tablespoon of glycerine and stir thoroughly. Pour this poison solution over 20 quarts of clean oats and mix thoroughly so that each grain is coated. Prepare 24 to 48 hours before using.

Crushed grain or cornmeal may be used. On the Orland project a mixture of oatmeal, cornmeal, salt, sugar and strychnine has given good results. A poison recommended after many trials by S. E. Piper of the U. S. Department of Agriculture is as follows: Dissolve 1 ounce of strychnia sulphate and 2 ounces of borax in 2 quarts of hot water in a closed vessel, stirring occasionally for 20 minutes or until completely dissolved. Then add 6 quarts of warm water, and sprinkle this poisoned solution over 30 pounds of rolled or crushed wheat, stirring and mixing thoroughly until it is all absorbed. Place ¼ teaspoonful of the poisoned grain near the entrance of each occupied burrow or in each runway.

Alfalfa or green grain heads may be used if the animals do not take the grain readily. One ounce of strychnine sulphate may be dissolved in 2 gallons of boiling water and sprinkled over 16 pounds of leafy alfalfa chopped into 2-inch lengths. Green grain heads in the milk or soft dough stages may be soaked for

15 to 24 hours in a solution twice as strong as the above. These green poisons should be distributed near the holes early in the morning. They are temporary as the animals will not eat them when wilted. Six to eight grain heads should be used per squirrel hole.

Trapping.—Either the ordinary No. 0 steel traps or some of the so-called guillotine traps may be used. There are a number of special traps for pocket gophers on the market which give good results. It is necessary to insert the traps for gophers in the underground runways, those for squirrels are placed at the entrance of the burrows. Trapping may be done by the ditch riders incidentally with their other duties, or bounties may be paid for those caught. The latter method is sometimes used in connection with campaigns against squirrels and gophers in farm fields. Ten cents per head is usually paid, the trapping generally being done by the local boys. The cost with regularly hired labor will usually be higher than this. On the North Platte project the land owners assessed themselves 3 cents per acre to pay bounties in 1916. In 1915 bounties were paid on over 33,000 scalps.

Suffocation.—For animals having short or deep burrows suffocation with the fumes of carbon bisulphide will often give good results. This is most effective in moist soils, as after a rain, as the gas is dissipated to a less extent in the surrounding soil. From 1 to 2 tablespoons of the bisulphide should be placed on some absorbent such as cotton waste or manure and then thrown as far down the burrow as possible. The opening in the burrow should be closed. A heavy gas is formed which sinks to the lower levels of the burrow and suffocates the animals. Carbon bisulphide can usually be purchased for about 8 cents per pound in 50-pound quantities. From ½ to 1 ounce per burrow is used. It should be handled carefully as it is mildly explosive and inflammable.

Suffocation with the exhaust fumes of an automobile is reported to have been effective on the Klamath project. A hose was attached to the exhaust pipe and led into each burrow. The burning of powder without direct explosion has also been tried. Actual drowning by pouring water in the burrow may be practiced with some forms of ground squirrels.

Natural Control.—Certain of the burrowing animals giving trouble in canal banks form a part of the food of other animals.

Gophers and squirrels are the prey of the badger, weasel, skunk and certain varieties of hawks and owls. The destruction of these animals, a usual result of settlement, may lead to a marked increase in the animals comprising their food. Unless it is certain that the larger animals cause more harm in other ways they should be protected for their control of the burrowing pests. This is particularly true of the birds. With badgers the harm done may exceed the benefit.

Special Methods.—For badly infested portions of the canal relatively expensive methods of prevention may be warranted. Concrete canal lining will prevent breaks due to burrowing animals, although the expense is not warranted for such prevention alone except in extreme cases. On the Salt River project the pasturing of sheep has been found to prevent injury by burrowing animals, the sheep driving them out of closely pastured banks. In one particularly troublesome length of canal on this project a trench 3 to 4 feet deep was excavated 2 to 4 feet back from the high-water line. In this, ½-inch mesh galvanized wire was placed and the trench refilled. The mesh prevents burrowing through the entire bank from either direction. The cost was from 20 to 30 cents per lineal foot.

The use of a wall of oil-filled soil in the canal bank has also been tried. Holes were put along the bank and filled with oil, the walls between the holes being broken down so as to form a wall of oiled earth. Gophers do not dig through such soils.

In fills made of loose dry sand the sand may run sufficiently so that the animals have difficulty in keeping their burrows open, thus driving them to other locations. It may be practical to use the sand deposited in the canal and removed in cleaning for the blanketing of fills for this purpose.

FENCING CANAL RIGHTS OF WAY

The questions as to whether canals should be fenced or not and if fenced who builds and maintains them have caused much controversy between land owners and canal companies. This is particularly true of the question of permitting fences with gates to be built across the canals at road lines in order to avoid fencing the canal through the lands.

The legal principles regarding fences depend largely on the nature of the right of way. Rights of way are of two general classes: (1) where the canal company owns the right of way in fee simple, that is, where the ownership is complete and similar to the farmer's ownership of his land; and (2) where only a right to use the right of way for canal purposes or what is termed an easement is owned. The same rules apply between right of way owned in fee simple and adjacent farms that apply between two farms. The owner of adjacent land must take reasonable precautions to prevent damage to the right of way by his stock; failure to take such precautions renders the land owner responsible for resulting damage. The canal owner is under no obligation to place fences across the right of way at roads and cannot be held responsible for stock which may either go from or onto adjoining lands. The land owner must secure permission from the canal owner to put fences across such rights of way and the canal owner may require such conditions as the construction of suitable gates or an agreement to remove on notice as a consideration for such permission.

For the rights of way held as easements the canal owner is known as the dominant estate and the original grantor of the easement as the servient estate. In such cases the land owner can use the right of way in any manner which will not interfere with the use of the easement for canal purposes and it is the canal owner's duty to fence or otherwise protect the ditch in case he wishes to protect it against damage from the ordinary use of the land by the land owner. In Durfee *vs.* Garvey (78 Cal. 546) it was held that the canal owner cannot recover damages for the cost of canal cleaning made necessary by the trampling of the land owner's cattle.

The general principles have been summarized as follows by Mr. S. C. Wiel in his work on "Water Rights in the Western States."

> "It is the ditch owner's duty to fence or otherwise keep the ditch in repair against damage from the ordinary use of the land by the land owner. And per contra if the cattle drown in the ditch, the ditch owner is not liable to the land owner. The owner of the servient estate may erect fences along the sides of a ditch or artificial water course. Unless it is expressly stipulated that the way shall be an open one or it appears from the terms of the grant or the circumstances of the case that such was the intention of the parties, the owner of the servient estate may also erect gates across the way, provided they are so located and constructed as not unreasonably to interfere with the use of the ditch."

In Utah Idaho Sugar Co. *vs.* Stevenson (97 Pac. 27) it was held that fences built to the canal edge and a wire gate on the banks was not an unreasonable obstruction of the easement. It was also held that gates ½ mile apart were not an unreasonable obstruction, but that many gates might be.

On the older systems, particularly coöperative companies, patrolling was less frequent than on present larger canals and fences with gates were usually permitted at roads. This served to keep road stock from the farmer's fields and avoided the need of fencing the right of way. On newer and larger systems where patrolling is more regular and all deliveries are made by the ditch riders, the opening and closing of fence gates is more of an inconvenience and such companies usually limit fencing across the canal as much as possible. The question of fences is often made a part of the agreement in purchasing rights of way, when concessions are made by the canal owner as to fences across the canal, a more reasonable price may be accepted by the land owner for the right of way. As a suitable fence may cost from $75 to $125 per mile, the cost of fencing both sides of a narrow right of way may be a large proportion of the value of the land. A 50-foot right of way contains about 6 acres per mile. The cost of fencing both sides at $100 per mile of fence will be equivalent to a cost of $33 per acre of land used.

There is no fixed practice in regard to fencing canal rights of way. Gates on the bank are cheaper than to fence the right of way and where cross-fences are not required too closely together the trouble in using them may not justify the cost of fencing. Where grazing of the right of way is desired, fencing will be required to protect the fields unless herding is practiced. Where canals pass through open range, it may be desirable to fence the canal as a protection from the crossing of stock and injury to the banks. For small holdings fences along the canal may be preferable to frequent gates. Such fences may be built either by the land owner or the canal owner or as partition fences by both, depending on which party receives the benefit or desires the fence.

The U. S. Reclamation Service has generally been more strict than other companies in the enforcement of their regulatinos regarding fences across canals. In 1913 a committee of the northern division recommended that no fences be allowed across canals with a capacity of over 40 second-feet. Where not considered harmful, the "Use Book" of the service states they should be built under a revocable permit, the land owner agreeing to remove the fence on demand by the service. On some projects gates are generally permitted where ditches leave public roads.

Legal Fences.—The questions which arise in regard to the damage to crops by stock have led the Western States to pass statutes defining liability for such damages and specifying the character of fences which are considered adequate. The same requirements as to legal fences for farms would probably hold in questions involving the breaking through canal fences by stock. The definitions of legal fences vary in the different States. One or more types and kind of fences are usually given as standard and a general requirement inserted that fences of any other kind must be of equivalent strength and height. Barb-wire fences are more usually specified, the different States requiring three to four wires, a height of 4 or 4½ feet, posts 3 to 5 inches in diameter set 20 to 24 inches into the ground and spaced 12 to 80 feet. For distances between posts of over 12 feet, stays are usually required from 8 to 10 feet apart. In most States, the owner of land within a legal fence can recover from the owner of stock if the stock break through the fence and cause damage; if the fence does not satisfy the legal requirements, such recovery cannot be made. Several States also have statutes either making it a misdemeanor to leave gates open or making the one leaving the gate open liable for any damage that may result. For partition fences it is usual to require the cost to be borne half and half by the adjacent owners provided both secure benefit from it. Where one owner does not have the remainder of his land fenced, he is not required to pay a part of the cost of the partition fence until he fences the other sides of his land and derives benefit from the fence.

Cost of Fences.—The cost of fences depends on the character of the fence and the local conditions. The figures in Table III are the results of investigations in North Dakota by the U. S. Department of Agriculture. While for other localities the price may vary due to local costs of posts, wire or labor, the figures given should furnish a basis of relative costs for the different types of fences.

On the North Platte project 53 miles of 4-wire fence are reported to have cost $75 per mile for materials and $50 per mile for labor. On the Yolo Water & Power Co.'s system in Cali-

Table III.—Average Cost of Fences in North Dakota Investigations of U. S. Department of Agriculture

Distance between posts, rods	Number of barbed wires	Cost per rod	Cost per mile
1	2	$0.32	$103
1	3	0.37	118
1½	3	0.29	93
1½	4	0.34	107
2	3	0.25	81
2	4	0.30	96
2½	3	0.23	74
2½	4	0.27	89
3	3	0.22	69
3	4	0.26	83
3	5	0.30	96

fornia 13 miles of woven-wire fence with posts 1 rod apart cost $1.03 per rod or $330 per mile, about 60 per cent. of which was for material. A 26-inch woven-wire hog fence with three barbed wires above can be built for about $200 per mile if posts are spaced 2 rods apart. In building laterals where fences must be removed and replaced during construction, a usual contract price for such work is 40 cents per rod for woven-wire and 20 cents per rod for common two- or three-wire fences.

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CHAPTER II

MAINTENANCE OF IRRIGATION SYSTEMS

MAINTENANCE OF STRUCTURES

Available data regarding the actual cost of maintenance of different types of structures is very limited. Such figures as have been made public vary to a considerable extent. Repairs may be made promptly when first needed giving a relatively uniform cost from year to year or maintenance may be neglected until the total cost of repairs becomes a large proportion of the first cost or until replacement is needed. In the first years of the use of a structure repairs to the material of the structure should be small in amount although the repairs to the adjacent canal such as those due to erosion or settlement may be high. Repairs to the material of the structure will increase with the length of its use until a point is reached where the annual cost of repairs and greater risk in use of the old structure make replacement desirable. This element of risk cannot be given a definite value so that no complete numerical basis for such replacements can be formulated, the decision in each case depends on the extent of the risk, the damage that would result from failure and the financial condition of the canal owner. Replacements of structures will usually have a greater cost than the original construction as the old structure must be removed and the excavation usually made by hand.

The annual cost of repairs of structures can best be expressed as a percentage of the first cost. For canal maintenance, costs are most conveniently expressed in terms of cost per mile of canal. For wood structures, the cost of repairs to the structure itself should be very small for the first one-fourth of its life, increasing with its age and becoming possibly 10 per cent. of the first cost per year during the last years of use. In some cases the total cost of repairs to wood structures during their life has equalled the first cost. Such structures as checks and turnouts may have a higher cost of maintenance than flumes on some systems; on others, particularly for bench flumes or those set on poor foundation material, the reverse may be true. Wood pipe under conditions suited to its use will usually have a lower maintenance cost than other wood structures.

Maintenance costs of concrete and steel in irrigation are not available. This is due to the relatively short time such material has been extensively used. Where such materials are properly adapted to the conditions of use the cost of repairs should be relatively low. There is, however, always the liability of mechanical injuries such as the frost heaving of concrete linings or cracking due to settlement which will make repairs necessary. For steel, protective coatings may be required at intervals. In comparing such more permanent construction with wood the relative cost of maintenance is an important element in determining the relative first cost at which the two types of structures will give an equal annual cost of service. It is not safe to assume that there will be no cost for repairs to the more permanent material although the actual cost will be less.

The following general figures have been extracted from the reports of various canal companies and the opinions of operating officials. Relatively wide variations in cost are found on different systems; the figures given represent only general averages and while probably relatively approximate as between different types of conditions will not furnish a criterion as to the costs to be expected on any single system. For wood structures the annual cost of maintenance to be expected may be taken as shown in Table IV.

Table IV.—Annual Cost of Maintenance in Per Cent. of First Costs

Period of use	Wood flumes	Wood pipe	Wooden structures
First one-fourth of serviceable life...	0 to 2	0 to 1	0 to 3
Second one-fourth of serviceable life.	1 to 3	1 to 3	1 to 4
Third one-fourth of serviceable life.	2 to 5	1 to 4	2 to 6
Fourth one-fourth of serviceable life.	3 to 8	2 to 6	3 to 8

For concrete structures, the cost of maintenance is more largely that of the adjacent canals. The cost does not vary with the life of the structure as with wood. In many cases after the first year's use the cost of maintenance may be very low. For the life of concrete structures the annual cost of maintenance may be taken as usually varying from 0 to 2 per cent. of the first cost. For steel structures such as pipes or flumes the cost of maintenance may be assumed as varying from 1 to 3 or 4 per cent. of the first cost per year, consisting largely of the cost of protective coatings.

SERVICEABLE LIFE OF IRRIGATION STRUCTURES

The life of any structure depends fully as much on the conditions of its use as on the material of which it is made. It may be necessary to use a material under conditions unfavorable to its long life and its early decay can be considered the fault of the conditions of use or possibly of poor judgment in selecting the material, rather than the fault of the material itself. Wood which is either continuously wet or continuously dry will decay slowly. The conditions least favorable for the long life of wood structures are those where it may be alternately wet and dry. Decay in wood is considered to be due to a vegetable growth which requires water, air and heat. In wood which is continuously wet, air is lacking. Extreme cold, while retarding the action of decay, will not entirely prevent it.

Concrete should have an indeterminate life unless used where it is subject to the action of certain alkalis or accidental injury. The life of steel depends more largely on the care used in maintaining protective coatings.

Wood Structures.—In general the wood structures used in irrigation can be divided into three classes: (1) wood flumes where the material is not in contact with the ground; (2) wood pipe where the water is under more or less pressure and the wood may or may not be continuously wet; and (3) ordinary wood structures where the material is more or less directly in contact with the earth. The lower portions of the trestles and the ends of wood flumes may be considered with class (3). The difference in the conditions of use affects the durability of the structures in these three classifications.

Life of Wood Flumes.—The life of wood flumes depends on the kind of material used, conditions of use and character of construction. As these conditions vary on different systems, the life of wood flumes as reported by different users varies widely. A rigidly built flume having little leakage will outlast one less strongly built. Poor footings which settle and cause leakage will shorten the life of a flume. The thickness of the flume lining also affects the length of service. Various protective coatings or even relining the flume box are used to increase the life.

The period of serviceable life which can be expected from flumes for usual conditions will not exceed 20 years for redwood or cedar, 12 to 15 years for fir, and 8 to 10 years for pine. These figures apply to the portions of the flume not in contact with the ground and are as long a life as can be expected under general favorable conditions. Some flumes have been used for periods longer than those given, but the annual cost of repairs in the later years of use or the uncertainty of service will generally make such use undesirable. The life of small flumes is generally less than that of large ones due to the less continuous use of many flumes on sublaterals. Flumes used intermittently on farms will have a shorter life than on laterals operated continuously. Bench flumes or flumes set in contact with or near the ground usually have a shorter life than well-built higher flumes. For unfavorable conditions the life of flumes may not be over one-half that given. Some redwood flumes have been in use for 25 years in California, the relatively long operation season and rains during the remainder of the year keeping them continuously moist. Others have been replaced after 15 years, the chief difficulty being with the rotting of the butt joints at the end of the lining plank and of the yokes behind them. Well-constructed fir flumes on the Hedge canal in Montana having 3-inch T & G siding were replaced in 12 to 14 years. Small pine flumes have not lasted over 4 or 5 years in some cases.

Life of Wood-stave Pipe.—The life of wood-stave pipe varies more widely than that of wood flumes as it is more dependent upon the conditions of service. Under favorable conditions, the

TABLE V.—LIFE OF WOOD-STAVE PIPE

Kind of wood	Condition of use	Average life in years
Fir	Uncoated, buried in tight soil	20
Fir	Uncoated, buried in loose soil	4 to 7
Fir	Uncoated in air	12 to 20
Redwood	Uncoated, buried in tight soil, loam or sand and gravel	over 25
Fir	Well-coated, buried in tight soil	25
Fir	Well-coated, buried in loose soil	15 to 20

life of wood pipe should exceed that of flumes; under unfavorable conditions, it may be quite short. Wood used in pipes comes into more direct comparison with other materials than does wood used in flumes and the results with its use have been more closely observed. Table V prepared by Mr. D. C. Henny and printed in the Reclamation Record of August, 1915, summarizes the data collected from a large number of installations.

The following general conclusions were also given:

"(*a*) Under favorable conditions of complete saturation, fir well-coated may have the same life as redwood uncoated.

"(*b*) Either kind of pipe will have a longer life if well-buried in tight soil than if exposed to the atmosphere. Such life may be very long, 30 years or over, if a high steady pressure is maintained.

"(*c*) Either kind of pipe will have a longer life if exposed to the atmosphere than if buried in open soil, such as sand and gravel and volcanic ash, provided in a hot and dry climate it be shaded from the sun.

"(*d*) Under questionable conditions, such as light pressure or partially filled pipe, fir even if well-coated may have only one-third to one-half the life of redwood.

"(*e*) Under light pressure the use of bastard staves should be avoided.

"(*f*) The use of wooden sleeves in connection with wire-wound pipe is objectionable and has caused endless trouble and expense.

"(*g*) If wooden sleeves are employed they should be provided, at least for sizes from 10 inches up, with individual bands to permit taking up leaks."

These results indicate the importance of the character of the backfill. If porous soils into which air penetrates easily are used, the benefits of covering are lost, with the added disadvantage that inspection cannot be readily made. A covering of heavy soil, 3 to 4 feet in depth, which maintains more constant moisture conditions and excludes air, gives the best results. The pipe should be kept full of water if a long life is to be secured. The upper portions of siphons, which may be only partly filled, have been found to have a shorter life than the parts under greater pressure. The water, when under pressure, maintains a more uniform moisture condition in the staves, a condition also more easily secured if the thickness of the staves is no greater than required for strength. Cuts from the butts of trees, being denser, are considered to have longer life than top cuts. The life of the pipe is usually determined by the life of the staves. Certain chemical conditions in the soil, such as the presence of some alkalis or of acids from decaying vegetation may result in a shorter life for the bands than for the staves. For such locations it is preferable to place the pipe above ground and free from such action.

Wood pipe is often coated, particularly the smaller machine-banded pipe. The coating on these is applied by running the pipe through a bath of warm asphaltum pitch. The pipe is then rolled in sawdust to preserve the outside coating and make handling easier. On large pipes an application of gas tar followed by one or more coats of refined coal tar, is often used. A mixture of asphaltum and tar has also been used. These are applied to the finished pipe before it is put under pressure. It is difficult to secure adherence to wet wood, particularly with oil paints. In general it appears that the use of a coating is preferable for buried pipe in dry porous soil and possibly on all buried pipes, although the added benefit may be small for pipe buried in heavy moist soils free from vegetable matter. Above ground the value of the coating is more uncertain. For the protection of the bands on exposed pipes paints similar to those used on structural steel may be used.

Life of Wood Structures.—The conditions of use for the usual wood structures are not as favorable as for wood flumes or pipes. Parts of the structure may be continuously wet, parts alternetely wet and dry and parts continuously dry. The cutoff walls and other substructure may outlast one or more renewals of the superstructure. Heavy well-built structures will have longer life than light ones due to the longer time required to cause the complete decay of the thicker material as well as to the greater resistance to injury offered by the stronger structures.

Under favorable conditions irrigation structures built of redwood or cedar may have a useful life of as high as 20 years; for average conditions the average life is about 12 years and in some cases as low as 8 years. It is longest in the larger and heavier structures such as have been used on some of the earlier systems in California. Some of these have actually been in use for over 25 years. It is shortest in regions of high temperature where the wood is both damp and heated at depths of from 1 to 2½ feet below the surface. At lower depths the heat is not sufficient to make decay as rapid; nearer the surface the structure is dryer. Small redwood structures have required replacement after 5 years in such locations. Structures built of fir have a life varying from a usual maximum of 15 years to a usual minimum of 6 years with an expected life under usual conditions of 8 to 10 years. Where pine is used, structures will not generally last over 10 years and may not last over 5 years; under usual conditions a life of 6 to 8 years is to be expected. Structures will usually have a longer life in heavy soils than in those in which the air has greater access such as sands or gravels.

Life of Concrete Structures.—Considered as a material, concrete is practically permanent. There has been some injury from the action of certain forms of alkali but the injuries to concrete structures are much more generally those due to undercutting or other accidents in use rather than to any disintegration of failure of the material similar to the failure of wood structures due to decay. Concrete has not been in use in irrigation sufficiently long to secure data on its rate of depreciation. Depreciation estimates which have been used in valuations have been based on estimated obsolescence or mechanical injury rather than on actual deterioration of the structure. In a few instances resurfacing has been required; such cases have generally been due to lack of care in the original construction rather than to actual abrasion. Structures, such as linings or retaining walls, may fail due to excess pressure behind them; such failures are not due to the material of the structure itself but to faults in drainage or design. Winter operation may cause injury in the opening of frozen gates or in the breaking of side walls.

The examples of injury from the action of alkali while scattered have in some cases been important. There is still need for further knowledge as to the details of such action and the methods of its prevention. Injury is caused by the seepage into the concrete of alkali water, the sulphates, particularly magnesium and sodium sulphate, being the most harmful. With some salts no harmful action may occur. The best remedy is prevention which can be secured most practically by using a dense well-mixed and faced concrete which reduces the absorption of the alkali water to a minimum. The conclusions of the U. S. Bureau of Standards based on the observations of the first year's tests with concrete drain tile exposed to alkali in a number of localities are that tile not leaner than a 1 to 3 mixture are apparently unaffected structurally when exposed for 1 year in operating drains in very concentrated alkali soils. Leaner mixtures are not generally recommended although in some cases tile of 1 to 4 mixture were not affected at the end of 1 year.

To overcome or reduce the effect of low temperatures on concrete, the surfaces have been treated with waterproofing solutions on the Strawberry Valley project. This was applied to structures on which surface disintegration had already begun. Vertical surfaces were treated with alum and soap solution and horizontal surfaces with paraffine. The surfaces were thoroughly dried and cleaned before treatment. The alum solution consisted of 2 ounces of alum to 1 gallon of hot water. The soap solution consisted of ¾ pound of castile soap dissolved in 1 gallon of hot water. The alum solution was applied at a temperature of 100°F. and worked in with brushes, the soap solution being similarly applied while the surface was still moist. In some cases additional coats were given. One gallon of alum solution and ½ gallon of soap solution were sufficient to give two coats to 50 square feet. The cost of treating 24,000 square feet varied from $0.41 to $1.28 per 100 square feet and averaged $0.76. Alum costs 18 cents and soap 12½ cents per pound.

For horizontal surfaces, the paraffine was boiled to drive off water, heated and applied with a paint brush. A blow torch was used to force the paraffine into the pores by its heat. The concrete would absorb only one coat of such treatment. On 4,000 square feet treated, 1 pound of paraffine was used per 11¾ square feet of surface. The cost varied from $1.70 to $3.78 per 100 square feet, averaging $2.11. Paraffine cost $4.80 per 100 pounds. The surfaces treated have shown no further disintegration after going through four winters.

Concrete pipe has been used very extensively on a number of systems during the past 10 years. With the present knowledge of its construction and use there should be little difficulty in securing well-made pipe. Such pipe should have a relatively long or indefinite life. In 1907 the Irrigation Co. of Pomona relaid a line of 8-inch concrete pipe of 1 to 4 mixture which had been laid in 1888. Only 7 per cent. of the joints were found to be perfectly sound, the remainder had disintegrated. General maintenance of such pipe lines consists of draining in winter and the sluicing of deposits which may form. It is usual for such pipe lines to operate at higher velocities than the canals so that deposits of silt or sand are not to be expected. Such deposits may occur, however, at the lower rates of discharge which may be used at the beginning and end of the season. Cracks at the joints due to the expansion and contraction of the pipes have caused trouble in some cases where the range of temperature is large or the covering of the pipes porous or thin. A length of life of 30 to 40 years has been used in valuations of concrete pipe lines. These figures are largely arbitrary, however, as direct experience has not extended over the full life of larger concrete pipe. In common with other forms of permanent materials, replacements may be more often needed due to changes in the requirements of use such as changes in location or capacity needed, rather than due to actual deterioration of the material itself.

Life of Steel.—Steel is used in irrigation practice in flumes, in pipes and in gates. The development of steel flumes has occurred within the past 15 years. A steel flume with wood supports is a combination type of structure. The trestles and stringers are similar to those used with wood flumes and should have a useful life similar to that of the same kind of material when used with wood flumes. Such trestles with steel flumes may have a longer life than with wood flumes, if the leakage with the steel flume is less. The useful life of steel flumes has not been determined, as their adoption is quite recent. Many have been built on the systems of the U. S. Reclamation Service. From observations on the Boise project it was reported at the Conference of Operating Engineers in 1914, that "Of the flumes built in 1909 practically all were more or less corroded. Of about 13 flumes built in 1910, the majority were in good condition but one was considerably corroded. Of about 21 flumes built in 1911, two were considerably corroded. Of about 14 flumes built in 1912, two were seriously corroded." It was stated that there was no decided difference between different makes of flumes. The greatest amount of corrosion and rust appeared to be along the joints, on the downstream side. It was recommended that the bands, channels or other parts forming the joints should be galvanized as well as the sheet metal of the flume. In case deterioration appears, painting was recommended. In an article in the Reclamation Record for November, 1916, Mr. F. D. Pyle states that of several kinds of paint tried on the Uncompahgre project only coal tar and coal-tar compound paints had stood one season's use and gave indications of permanence. It was also stated that the indications on that system were that unprotected galvanized-steel flumes will have a life of 10 or 12 years except under the most trying conditions, *i.e.*, high velocity of water carrying sand and fine gravel, where the life in one particular instance was only four season's use.

The use of steel and iron pipe in irrigation has generally been limited to those conditions of pressure for which other types of pipes were not suited. Their use in irrigation has not been sufficient in length of time or in amount to indicate their probable useful life for such purposes. Data, however, are available from use in mining and power service. Thin steel pipes, such as 1/8 inch in thickness, are used in the smaller sizes for the lighter pressures in some distribution systems, particularly with pumping plants. These should have a useful life of 15 to 25 years. Heavier pipe, 1/4 inch thick, should last 25 to 50 years. For pipe of the larger sizes, which can be recoated during the portion of the year when they are not in use, even longer life may be secured.

Due to the thinness of the pipe, protective coatings are relatively more important on steel pipes than on those of other material. The more generally used coatings consist of some of the forms of tar or asphalt mixtures applied hot, the smaller pipe being dipped and the larger ones treated in the field. The San Fernando siphon of the Los Angeles aqueduct was painted inside and outside with one coat of water-gas tar and two coats of coal tar. One gallon of tar covered about 200 square feet of pipe. The Spring Valley Water Co. has used a mixture of coal tar and natural crude asphaltum, using 1,400 pounds of asphaltum to 50 gallons of coal tar. Some of this coating has been in use nearly 50 years. The Pacific Gas & Electric Co. uses one coat of Dixon's Graphite Paint, inside and outside on unburied pipe, repainting every 2 or 3 years. In some cases steel pipe may be encased in concrete. Where steel pipes are laid in alkali soils special protection may be needed. Pipe 5/16 inch thick has in some cases been corroded entirely through in 3 years where laid in alkali soil in the California oil fields. On the Uncompahgre project in Colorado a 26-inch siphon was built in 1910 in alkali ground for which ingot iron pipe was used. This was in good condition after 4 years use although some rusting had occurred.

SELECTION OF TYPE OF STRUCTURES

The relative economy of wood and concrete depends on many factors, only a part of which relate directly to the first cost. For any given condition where the relative construction and maintenance costs and useful life can be estimated a direct comparison of costs on an investment basis can be made. The data for such estimates can be secured for replacements. In new systems, the selection may be based on other conditions such as uncertainty as to the capacity needed or the location of certain structures, lack of transportation facilities making the cost of cement high, or limited financial resources and high interest rates. In replacements, the location and character of the structures is more definitely known, the financial standing or resources may make interest rates less and the development following irrigation may have included improved transportation facilities. For such conditions, replacements can be determined more largely on an investment basis.

In concrete structures the cost of concrete is usually from 60 to 90 per cent. of the total cost of the structure. The total cost of wood similarly varies from 50 to 75 per cent. of the total cost of wood structures. For wood flumes, the cost of the flume box and trestle generally equals over three-fourths of the total cost of the structure as a whole. In similar types of structures an average of about 6.5 cubic yards of concrete are equivalent to 1,000 feet board measure of lumber; the ratio varies rather widely, however, in individual cases. Concrete structures should have a lower cost of maintenance than those of wood. If replacements are to be made on an investment basis the ratio of first cost at which the capitalized cost of service becomes equal can be computed for various conditions. These are given in Fig. 4, for an assumed life of 40 years for concrete structures and from 5 to 20 years for wood structures. Sets of curves are shown for interest rates of 6, 8 and 10 per cent. and for annual costs of maintenance of wood structures up to 8 per cent. Having the probable life, cost of maintenance and value of money or interest rate, these curves give the ratio of cost between wood and concrete at which they are equally desirable as investments. If, for instance, wood structures have an estimated life of 12 years, an average annual cost of maintenance of 4 per cent., and money can be secured at 8 per cent., concrete structures would be as economical as wood structures if the concrete could be built for 2.1 times as much as wood. If concrete structures could be built for less than 2.1 times the cost of wood structures, they would be more economical on an investment basis. The factors not included in this comparison, such as greater safety in operation, usually enable one to expend for concrete something more than the amount indicated. For similar conditions to the above example, except the interest rate, the ratio of first cost would be 2.35 for interest at 6 per cent. and 1.85 for interest at 10 per cent. If the life of the wood structure were only 6 years, the ratios would be 3.4, 3.0 and 2.5 for 6, 8 and 10 per cent. interest rates,

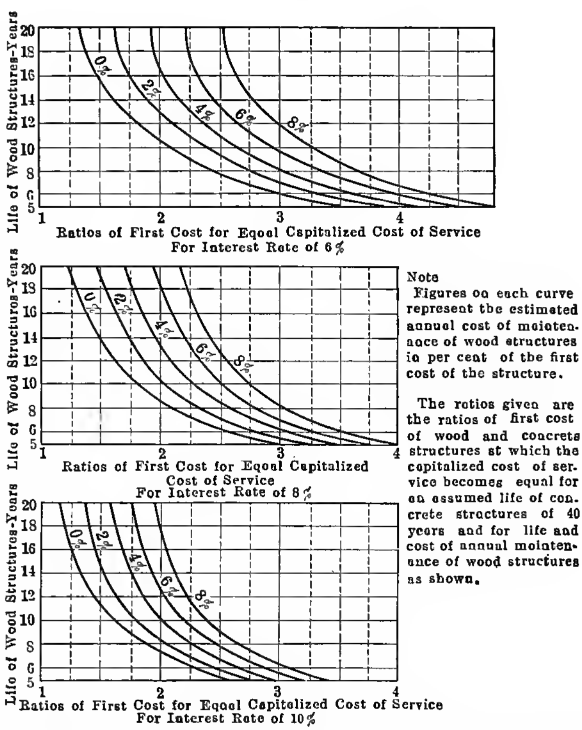

FIG. 4.—Comparison of first costs of wood and concrete structures for equal capitalized cost of service.

respectively. The smaller increased costs which one can afford to pay for longer-lived construction, when interest rates are high, is quite noticeable. If the annual cost of maintenance is disregarded, the ratios for 12-year life become 1.8, 1.6 and 1.45 and for 6-year life 2.9, 2.6 and 2.2 for interest rates of 6, 8, and 10 per cent. Longer estimated life for the concrete structures than 40 years does not materially change the ratios. A shorter life for the concrete than 40 years reduces the amount which one can afford to expend for its construction. If concrete is estimated to have a life of only 20 years, the ratios will be reduced from one-fourth to one-third from those given in Fig. 4.

Where the topography is regular, the costs of concrete structures will usually equal from 10 to 20 per cent. of the total cost of main canals and from 25 to 40 per cent. of the total cost of laterals or an average of 20 to 35 per cent. of the cost for the whole system. The similar figures for wood structures are about 8 to 15 per cent. for main canals, 15 to 35 per cent. for laterals, and 10 to 25 per cent. for systems as a whole. For irregular or steep topography the cost of the structures will usually comprise about one-half again as large a percentage of the total cost.

On many systems, the diversion canal passes through side-hill locations in which the first cost of bench flumes may be cheaper than for excavated canal sections. Where enlargements of earth canals in such locations are required it may be less expensive to secure the increased capacity by concrete lining with its lower frictional resistance. For such conditions, questions of safety in operation and decreased liability of breaks may be given greater weight than the actual relative costs. Where wood-bench flumes have been used in original construction, on some systems they have been replaced with canals excavated either entirely in earth or with a retaining-wall section on the lower bank or with concrete-lined sections. Among such canals are the Bear River canal in Utah and the Hedge canal in Montana (Plate IV, Fig. A). On the Modesto and the Turlock systems in California a number of flumes crossing drainage channels have been replaced with lined sections carried on hydraulic fills (Plate IV, Fig. B), the drainage being handled through culverts. There is a tendency toward the use of such more permanent construction on systems which have passed the earlier stages of development (Plate IV, Figs. C and D). This is due to the better financial conditions of such systems and to the change in relative costs of materials, lumber being generally higher in price at present than at the time many of these systems were built.

Wood structures, however, have the advantage that they can be used for replacements which have to be built and in use quickly, such as in repairing breaks in side-hill canals or in replacing washed-out structures.

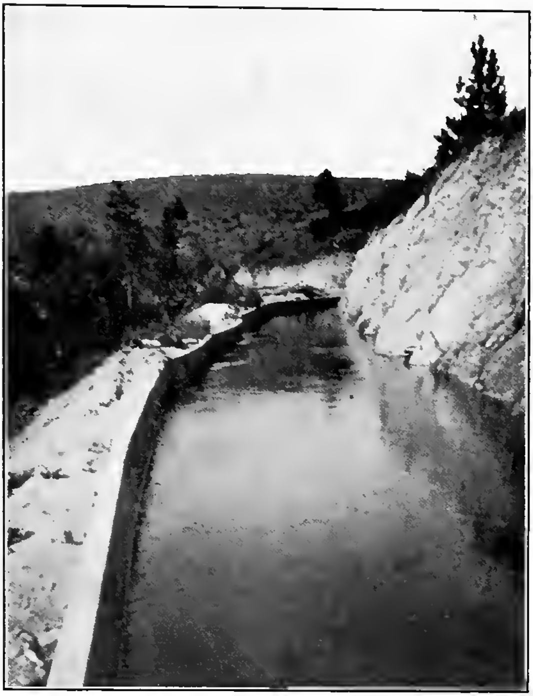

FIG. A.—Side hill canal with retaining wall used to replace wood bench flume, Hedge canal, Montana.

FIG. B.—Lined canal on hydraulic fill used to replace wood flume, Turlock Irrigation District.

(Facing page 62.)

PLATE IV.

FIG. C.—Concrete flume in light fill in sandy soil, Crocker-Huffman Land and Water Co. California.

FIG. D.—Concrete arch flume used to replace wood flume, Modesto irrigation district.

MAINTENANCE OF RESERVOIRS

Reservoir maintenance, except that due to larger accidents, is usually small in amount. Where the reservoir is situated on the stream channel, the dam is similar to those used for diversion. Where the site is not situated on a stream but is filled through a feeder canal, the problems of spillway capacity are removed or very largely reduced. The maintenance of the outlet works is similar to that of the headgate of canals. For the higher dams the erosion in the outlets and the operation of the gates has given much difficulty in some cases. Multiple sets of gates at different elevations are sometimes used to overcome such difficulties.

The action of waves on the face of earth dams may cause much trouble. Such dams are faced on the water side with coarse material or concrete. On the Deer Flat reservoir, gravel has been dumped on the upper slope to be worked down the slope by wave action should additional protection be needed. On the Belle Fourche reservoir, the concrete paving slabs have in some cases moved outward and slipped downward near the water line due to the water pressure behind them. The water which had entered between the slabs could not escape as rapidly as the waves receded, so that its pressure forced the slabs outward. This has been repaired by keying the slabs together.

Where dry-rock riprap is used, either hand-laid or unplaced, heavy wave action may cause an undermining of the paving which results in its settlement. The wave action washes out the finer material under the paving in such cases. This can be overcome by the use of heavier rock more carefully laid or by the use of grouted paving or concrete facing where heavy wave action is expected. The facing rock should not be laid directly on the earth slope; an intermediate layer of smaller rock or gravel should be used. Such riprap has a much greater resistance to wave action.

A double log boom with the logs placed about 3 feet apart anchored a few feet from the water's edge will reduce erosion due to wave action.

Some protection on the downstream slope against the action of rain may be needed. This can be secured by the growth of vegetation where the soil and moisture conditions permit or by a gravel or loose rock layer.

In several of the States, the State exercises more or less control and supervision over the plans and construction of dams. While in general beneficial, such supervision does not go as far in requiring safe construction as a canal system built on an investment basis would ordinarily go on its own accord.

MAINTENANCE OF DIVERSION DAMS AND HEADWORKS

Diversion dams are special structures whose design depends on local conditions which vary with each system. Permanence is more essential in the headgates than in any other part of the system as injury to the inlet control of the canal may cause a loss of water to the entire system. As the conditions of foundations, ice, and drift which diversion dams and headgates may have to withstand are difficult to forecast and to provide against, such structures should be built only under technical engineering advice. If well-designed and built, such structures should not have high maintenance costs. On some streams having large low-water flows in proportion to the amount diverted and fairly permanent channels, a diversion dam may not be required. This is the case with several canals diverting from the Yellowstone River. The headgates in such cases should be of substantial construction and planned so that the flow past them is sufficient for diversion and that no cutting of the canal at the headgate will occur.

On streams having poor foundations it may be cheaper to use temporary diversion dams during the low-water period of each year. During high-water periods there will usually be little trouble in securing the diversion. During low water, brush and sand sacks or other temporary dams may be used. The annual cost of such dams may be less than the fixed charges and maintenance on a permanent structure. Such methods may be used during the earlier years of a system while the amount diverted is small. As diversion increases and as funds may become available, a permanent diversion dam may be built. In some cases the stream channel may be changed during high-water flow so as to throw the low-water channel away from the headgate. This can be controlled by the diversion dam or by the proper location of the headgate. Temporary diversion dams are not suited to streams having a torrential or fluctuating flow as more than one dam may be required per season. On snowfed streams there is less fluctuation in the low flow and such temporary dams will usually not be washed out during the later irrigation season. Duplicate control of the headgates is desirable on all except small canals. This may be secured by the use of two sets of gates, so that in case of injury to one set the other set can be used. Provision should be made for flashboard grooves above the upper set to enable emergency repairs to be made. In order to regulate the flow into the canal more easily a spillway is frequently provided just below the headgate. Secondary gates below such spillways will protect the canal in case of injury to the upper gate and give a closer control of the amount diverted. Sand boxes may be combined with the spillway if there is need for their use.

Screens across headgates serve two general purposes. One is to prevent the entrance of drift, the other the entrance of fish. The first type is desirable from the point of view of canal operation as such drift may result in the clogging of screens or checks to the injury of the canal. The entrance of fish into the canal is not harmful to the canal; screens to prevent such entrance are required by law in many States, however, in order to protect the public interest in the fish.

The prevention of the entrance of drift into a canal is usually not difficult. The proper location and design of the headgates may prevent drift being carried to them when the amount diverted is a minor portion of the amount flowing in the stream. The drift occurring in streams consists more largely of logs or débris from timber. Most of this can be kept out by a log boom or by coarse screens. Where silt occurs in large quantities the prevention of its entrance requires a careful design of the diversion and headgates, the principles of which are discussed in a number of books. The general purpose of such designs is to enable the clearer surface flow to be taken into the canals. Screens used for drift may be a simple log boom arranged to divert the drift away from the gates or a rack screen of relatively wide spacing. Both types are frequently used on the same headgate.

In the majority of States, the State official in charge of the administration of the fish and game laws has the power to require screens on canals when he considers their use necessary. To prevent the entrance of fish into a canal requires screens of much closer mesh than those needed for other purposes. To hold the small fish such as are planted in many streams by the States requires a mesh so small that fine drift which would not cause damage in the canal will be held on the fish screen. Such drift clogs the screen and requires constant attention if the quantity diverted is to be kept constant. While the prevention of the loss of fish in streams is certainly desirable, it is a serious question as to whether it is practical to use a screen sufficiently fine to prevent their entrance into canals. This has been recognized in some States and the enforcement of statutes regarding such fish screens has been very lenient. In California present requirements of the Fish and Game Commission are for screens with ¼-inch opening on streams where there are trout and ⅜-inch on others. There are some 60 or 70 patented types of fish screens, both fixed and moving, on the market.

The laws of several of the States also require that fish ladders shall be provided at all dams on streams. Various designs have been approved for such ladders which in some cases operate successfully. In some cases the fish ladders have been installed for the purpose of compliance with the letter of the law only and have not been maintained so as to be of use. On dams of moderate height or on streams of moderate flood flow such fish ladders can be used with success. On high dams or large flood depths it is preferable to recognize that the dam and fish development are not in accord and waive the minor benefit of the fish in favor of the major benefit of the development. In Washington a fish hatchery may be maintained above a dam as a substitute for a fish ladder.

On large canals it is usual to keep a man at the headgate both for the purpose of regulating the amount diverted and for inspection of the structures. Such gate tenders may also patrol a portion of the canal below the headgate.

MAINTENANCE OF GENERAL STRUCTURES

Such general structures include those which resist water pressure and around or under which water tends to force a passage. Among such structures are drops, checks, division gates, lateral headgates, inlets and outlets of flumes. The two principal sources of injury in connection with the use of such structures are those due to the erosion of the adjacent canal and to the undercutting of the structure itself. Maintenance will also be required in replacing portions which decay or become injured while the remainder of the structure is in serviceable condition.

Erosion of Canals Adjacent to Structures.—At any structure through which the water has a higher velocity than that in the adjacent canal checking such velocity or protection to the canal must be used. Both methods are used, either separately or in combination. The present tendency of practice is toward the prevention of injury by means of overcoming the fall or velocity before the water leaves the structure so as to reduce the amount of canal protection needed. The lower portion of structures may be designed to deliver water to the canal below at normal cross-section and nearly normal velocity. Various forms of stilling basins and baffles are also used.

The forms which will be assumed by eddy currents and backwash as well as the amount of direct erosion depend on complicated hydraulic conditions not capable of computation. The extent of canal protection required depends on the conditions at the structure and the character of the material; its determination depends on experience in direct observation although various rules of thumb may be used (Plate V, Figs. B, C and D). The extent of the erosion which will occur even under similar conditions is quite variable.

The width of opening through checks affects the extent of erosion below. Narrow openings increase the velocity through the structure and also the irregularity of flow if more than one opening is used. Narrow openings may also give trouble from clogging with drift.

In order that excess cost in protection may be avoided, the amount used is frequently deficient. Protection against such erosion may have to be placed with water in the canal. This can be done with brush held with stakes or rock, by dumping in loose rock or by sand sacks. The brush can be bound in bundles and weighted with rock or held by stakes, or it may be piled behind wire netting. The brush used may be sage brush, if available, or willows. Such work is of rough appearance but generally effective. Sage brush will last several years when used in this way; it may be burned out before it decays in the burning of weeds unless care is used in such weed-control work. If the brush reduces the velocity in its vicinity to a sufficient extent, silt may deposit so as to hold the brush in place.

If repairs can be postponed until water is out of the canal, the brush can be more carefully placed or rock can be hand laid if desired. Concrete lining is the most permanent protection; it can be placed only when water is out of the canal. In some cases loose concrete blocks have been used in preference to continuous lining.

Toe walls, located at the lower edge of structures and projecting above the canal grade in order to form a water cushion above them, have also been used. Such walls result in disturbed flow into the canal below and a greater tendency toward erosion. On some structures on the Orland project it has been found desirable to remove such walls. Water cushions are preferably constructed below grade and the sides and floor brought to the canal section at the downstream side.

Where erosion at structures occurs the eroded material may be deposited in a canal below and obstruct the flow unless the grade of the canal is sufficient to give a relatively high velocity.

Cutting Around Structures.—Water tends to force a passage around structures due to the pressure caused by the difference in elevation of the water above and below the structure. This tendency is greatest where the fall is greatest as in drops. For some structures such as checks operated nearly open there may be little drop in the water surface and consequently little pressure to cause cutting around the structure. When water succeeds in securing access to the under side of a structure an upward pressure will be caused or a passageway around the structure will be opened. If water passes the upper cutoff wall in greater quantities than are able to escape from under the structure, the water beneath the structure will tend to have a pressure due to the elevation of the water above the structure. If the water flowing through the structure has a lower elevation than that above, as in checks or drops, the upward pressure may exceed the downward load. This results in some cases in the actual floating out of wooden structures, being aided by the buoyancy of the material (Plate V, Fig. A). Such floating is best prevented by the use of an adequate cutoff wall at the upstream side of the structure. This should extend well into the bottom and sides and be thoroughly puddled. Too deep a downstream cutoff may tend to prevent the escape of water getting below the structure and cause an accumulation of upward pressure. Such downstream cutoffs are required to prevent backwash under the structure; depend-

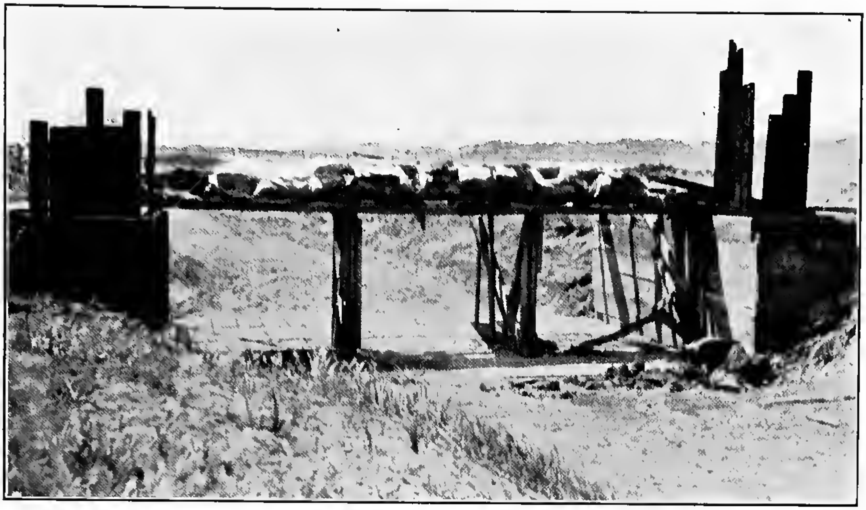

FIG. A.—Light wood check weighted to prevent floating.

FIG. B.—Erosion below structure.

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FIG. C.—Erosion below drop, Lateral on Worth Platte project, Nebraska.

FIG. D.—Erosion below drop, Modesto irrigation district.

ance against leakage around the structure should be placed on the upstream cutoff.

Proper backfilling of structures is frequently difficult to secure. On new construction water for puddling may not be easily secured. Tamping of damp earth can be made to give good results but it is difficult to secure proper care in such work.

If found in time, washing around cutoffs may be repaired without material injury to the structure. The material in washed-out timber structures can be at least partially used again; a washed-out concrete structure is more usually a total loss. On small structures, where the fall at the structure is small, particularly in heavy soils, passageways under the floor or sides may enlarge slowly and if found in time can be stopped without shutting off the water. New structures should be closely watched in their first season and given a thorough inspection after water is shut off. Cutoffs which hold during the first season's use are not as liable to give trouble later unless the quantity of water carried is materially increased or cutting is started by some burrowing animal.

MAINTENANCE OF FLUMES

Maintenance of flumes consists of repairs to both the flume and its supporting trestle. If the material in the flume box becomes worn and leaky, the inside may be lined with 1-inch matched lumber to give water tightness depending on the old material for strength, or with unsurfaced boards and some of the various tar or asphaltic paints. For smaller flumes tar paper may be placed in the flume. Such linings are more generally needed on flumes carrying water at relatively high velocity or containing sand. For such conditions the paper is not well suited.

Leakage and in some cases actual wear can be reduced by the use of coatings applied to the inside of the flume. A coating has been used on the Bear River canal system in Utah which consists of 1 part tar and 4 parts tar pitch, with gravel applied as a thick coating rolled on while hot. This has been found to stick to the sides and form a water-tight coat. To be successful it is necessary to prevent the entrance of water behind the coating, as such moisture causes swelling of the wood and cracking of the coating. Other coatings used consist of a coat of water-gas tar followed by a coat of coal tar. Various asphaltic preparations have also been used. If such coatings are to be used it is preferable to make the application when the wood is new, the adhesion usually being much closer. On the Modesto irrigation district a thin mortar lining or plaster reinforced with a wire mesh has been used on the inside of flumes to temporarily extend their lives. The use of such coatings may add to the life of the flume and reduce maintenance costs due principally to the reduction in leakage.

The repair of trestlework is more difficult and expensive. The members of the trestle should be sufficiently heavy to have an estimated life at least as great as that of the flume box so that repairs or replacements of members will not be needed during the life of the flume. As the trestlework becomes less strong due to age it may be strengthened by the use of additional sway and diagonal bracing.

A more frequent trouble with the trestles of flumes comes from the settling of footings usually due to the softening of the foundation caused by leakage from the flume. Such settlement reduces the freeboard in the flume and if of material amount reduces the capacity of the flume as well as endangering its safety. Actual profiles of flumes in use show that a flume in which no part is more than 0.2 feet from grade represents good construction and that the combination of construction errors and settlement frequently exceeds this amount even on well-built flumes, particularly if the trestle is high. If settling can be checked the stringers can be raised on the caps or the sides of the flume heightened. Sufficient freeboard should be allowed in the original plans to allow for minor settlement. A small flow should be run through the flume for a sufficient length of time in the spring to swell the wood and reduce leakage before the full load is carried.

Single spans may settle due to erosion around the footings adjacent to stream channels. It is preferable to carry the flume on long trussed spans over such points. If such erosion occurs means of protection adapted to local conditions must be used.

The maintenance of the trestles of steel flumes is similar to that for wood flumes. The smaller amount of leakage with steel flumes should reduce the liability of softening of the footings and consequent settlement. Some adjustment of the bands on steel flumes will usually be necessary each season to prevent leakage. Steel flumes may also give trouble if sufficient provision for expansion and contraction has not been made. Concrete flumes should require little maintenance; their greater weight, however, makes the use of greater care in the footings necessary. They are special structures which have not been in use to a sufficient extent to furnish direct experience.

The maintenance of inlets and outlets of flumes is similar to that for checks and drops. Cutting under or around the cutoff and wings must be prevented.

MAINTENANCE OF CONCRETE-LINED CANALS

One of the advantages of lining, particularly of concrete lining, is the reduction in maintenance cost. This may be due to the prevention of aquatic growths, and of erosion or silting, or to the lessened liability of canal breaks due to burrowing animals and the softening of banks due to seepage. Ordinarily the maintenance cost for such lining is relatively low. Injury more often results from the outside than from the inside of the canal, such as that due to the failure of the earth backing. In one instance on the Umatilla project, cracks in the lining permitted sufficient leakage so that erosion behind the lining resulted in a break. With relatively deep canals the pressure of the earth during the non-operating season may be sufficient to force the lining out of position. This may be due to frost action or to the pressure of saturated earth alone. This latter condition has been encountered to some extent on the South San Joaquin system in California. In some cases the canals were filled with water held by checks, the pressure of the water resisting that of the earth; in others, the lining was broken into blocks and relaid as riprap, the drainage through which prevented the accumulation of pressure.

The use of concrete even with relatively high velocities will not prevent the growth of aquatic vegetation in many cases. In Southern California a moss-like growth of considerable length may attach itself to the lining, particularly on the sides. This is generally removed with an implement similar to a hoe with the blade in line with the handle, the growth being scraped off and removed as it is carried down the canal. As many as three or four cleanings per season may be required. Where such vegetation occurs in concrete lining the average value of n in Kutter's formula has been found to be about 0.016 whether the concrete itself is very smooth or has only an ordinary finish (Plate III, Fig. C). On the Tieton main canal in Washington where the velocity approaches 9 feet per second a form of growth attaches itself to the concrete particularly near the water surface although the concrete is quite smooth. This growth can be removed by shutting water out for 2 or 3 days, when its hold becomes weakened so that on turning water in again practically all of the growth will be washed off. Tests on this canal have shown a quite regular seasonal variation of the value of n in Kutter's formula due to this growth. In the spring, when clean, the value of n is about 0.012; during the season it rises to a value of 0.013. On other systems the pond-weed or common "moss" grows to sufficient length so that sawing or other means used in earth canals are required.

BRIDGES

In all States, when a canal is built across a public road the canal owner is required by law to construct a bridge over the canal. In Colorado, Idaho, Montana, New Mexico and Wyoming the county will maintain such bridges, usually after they have been built and maintained for 1 year by the canal owner. In Arizona, Oregon, and Nevada the canal company is required to maintain as well as to construct the bridges; in the other States the taking over of the maintenance is usually optional with the county officials, specific statements not being made in this regard in the statutes of some States. The county officials are generally given authority to require bridges which meet their approval, particularly where the county is to maintain them. Such requirements are usually quite general, however. Failure on the part of the canal owner to construct or to repair a bridge when ordered to do so by the county renders the owner liable to fine or even imprisonment in some States; more usually, however, if the work is not done within from 3 to 10 days after notice is given the county can do the work and charge the costs to the canal owner.

The following statute of Wyoming is typical (Paragraph 2567).

"**Owner of Canal Must Maintain Bridge at Road Crossing.**—Any person, company, corporation or association of persons, operating or maintaining in whole or in part, either as owners, agent, occupant or appropriator any ditch, canal or water course, not being a natural stream, for irrigation or any other, and different purpose, shall put in, construct, maintain and keep in repair at his, her, its or their expense, for one year, where the same crosses any public highway or publicly traveled road, a good substantial bridge, not less than fourteen feet in width, over such ditch, canal or water course where it crosses such road. Any violation of the provisions of this section shall be a misdemeanor, and upon conviction thereof, the person so offending shall pay a fine in any sum not exceeding one hundred dollars for each day such ditch, canal or water course shall be unbridged, insufficiently bridged, or permitted to remain out of repair; Provided, that after the expiration of one year, from the construction of said bridge, the road supervisor of the road district in which said bridge is located, shall upon being notified by the owner or owners of the ditch, canal or water course over which such bridge is constructed, at once inspect said bridge, and if found in a good and lawful condition, shall accept the same for the county in which it is located, and said bridge shall thereafter be maintained by the said county" (L. 1895, ch. 69, Paragraph 55; R. S. 1899, Paragraph 1959; L. 1901, ch. 21).

The above discussion applies where the road is in use before the construction of the canal. When a new public road is opened across a canal, the public is required to build the bridge. In the City of Madera *vs.* Madera Canal & Irrigation Co. (115 Pac. 936) it was held that the canal owner must prepare the right of way so as not to obstruct the road but this does not include the bridge which is a part of the road. The canal owner must prepare the banks of the canal so that they will not interfere with access to the bridge. California statutes provide that no damages shall be given for a right of way for a road across a canal.

Bridges across canals on private roads or to reach parts of a farm intersected by the canal may be built by either the canal company or the land owner. Such bridges are frequently made a part of the right-of-way agreement when the canal is built through lands in private ownership, the canal company more often building such bridges as a part of the right-of-way consideration. If the canal company also controls the ownership of the land at the time of construction as in colonization or Carey Act systems, it may be considered to be better policy to construct such bridges and include their cost in the price of the land. Where additional bridges are desired after construction, the cost is more usually paid by the land owner and the bridges either built by or the character of construction approved by the canal owner. Such additional bridges will be needed as land holdings are subdivided. Larger bridges such as those over main canals and large laterals are better built by the canal company; small ones, such as single-span stringer bridges, may be built by either the canal company or land owner. Such bridges do not usually need to be of as heavy construction as bridges on public roads.

The kinds of bridges for public roads may be controlled by the legal requirements. In Oregon, Colorado, and New Mexico and Wyoming, such bridges must be at least 14 feet wide; in Washington and Idaho, 16 feet wide. In Nevada they must be built according to the standard plans and specifications of the county commissioners. The Idaho statute further requires easy grades on and off the bridge, floor not less than 3 inches thick on stringers not less than 6 inches square nor more than 3 feet apart unless the canal is small enough to be carried in a culvert. When a bridge is built, the canal owner reports to the road supervisor and on acceptance of the bridge it becomes county property.

An 18-ton tractor is as heavy a load as is to be expected on county bridges. Several States have laws requiring those crossing bridges with tractors to lay heavy planking or use other methods to strengthen the bridge. The heaviest wagon loads are those used in hauling sugar beets and may amount to 7 or 8 tons.

Wood-stringer bridges can be used up to 16- or even 20-foot spans. With 16-foot roadway these can usually be built for $5 or $6 per foot of span. Such bridges with multiple spans are frequently used in larger canals, being cheaper than trusses. Where drift is liable to catch on the piers or where erosion around the pier footings may take place, such bridges may not be desirable. Permanent pier footings of concrete projecting about the canal grade increase the life of the posts and reduce maintenance costs. Maintenance consists mainly in replacing the flooring due to its wear under traffic. Where the canal section is restricted by the end walls, some cutting of adjacent canal banks may occur. It is usually cheaper in the end to make the span equal to the water-surface width at full-supply level. Clearance above full-supply level should be sufficient to prevent drift catching on the stringers. Substantial railings on the bridge and approaches are needed on highway bridges. Farm bridges can be made narrower and the railings omitted. A wheel guard should be used, however.

Fording of canals should not be permitted unless a wide shallow section is provided and crossing should be restricted to bridges. Fording by cattle breaks down the canal slopes.

TELEPHONES

Telephone lines are essential in the operation of any large irrigation system and their ownership and control by the canal system is preferable. On the canals, such telephone systems should connect each ditch rider's house with the main office so that daily reports can be made where these are used or that orders for the following day may be given. There should also be connections by which the riders can reach headquarters quickly in case of trouble on the canals. This can best be accomplished by having a telephone line along the main canal with telephones at intervals or by having the rider carry a portable instrument. The former method is more usual. On laterals which are located in well-settled districts supplied with local telephone service, separate canal lines are not necessary. However, in order to avoid the delays and uncertainties of service on farm party lines, it is an advantage to have a separate system to each ditch rider's headquarters. Direct telephone service to the headworks or wasteways is needed so that water can be shut out promptly in case of breaks in the system.

In some cases service arrangements are made with local telephone companies. This is not generally desirable for the main lines as the cost of building connections outside the settled areas may be nearly as great as that of constructing an independent system. During the first years of operation the settlement of the lands may not be sufficient to warrant the construction of such local systems and independent canal lines may be necessary. In such cases there is usually a demand from settlers to be allowed to use the company lines. It is not usual to permit such use except in cases of emergency. After the lands have become settled and developed, local service within the irrigated area may be used.

Such telephone lines are of two kinds: metallic circuits, in which two wires are used; and grounded circuits, in which one wire grounded to the earth is used. The grounded line is somewhat cheaper but the service is generally not as satisfactory. Only a few telephones, preferably not over eight or ten, can be used on grounded lines and if the line is long it may be difficult to get distinct transmission unless the grounds are very carefully made. Return circuits can carry more connected telephones and usually give clearer transmission. Telephone sets arranged so as to be switched off the line when not in use are preferable. About twice as many of such instruments can be carried on a single circuit as compared with call telephones.

The average amount of material required per mile of telephone line is given in Table VI.

TABLE VI.—MATERIALS REQUIRED PER MILE OF TELEPHONE LINE

Material	Amount required	
	Ground circuit	Metallic circuit
25-foot poles (6 inches top diameter)	33	33
40-foot poles (6 inches top diameter) at road crossings	2	2
No. 12 B.W.G., B.B. galvanized-iron wire nails, pounds	165	330
Glass insulators	40	75
12-inch wood brackets	40	75
60d galvanized-steel wire nails, pounds	8	15
5/8-inch × 6-foot galvanized-iron anchor rods	5	5
5/16-inch 7-strand galvanized guy wire, feet	100	100

The cost of such telephone lines varies with the price of material, character of excavation for the poles and other factors. Ground circuits can usually be built for from $80 to $150 per mile; metallic circuits cost $15 to $25 more per mile.

The 15th Annual Report of the U. S. Reclamation Service gives the average cost of 2,376 miles of telephone line as about $185 per mile. An average of one telephone to each 2.4 miles of line was in use. For the area which the Service was prepared to irrigate in 1916, on all projects, there was an average of 1 mile of telephone lines for each 640 acres, usually varying from 300 to 1,200 acres on different projects. The cost of telephone lines has been about 0.4 per cent. of the total expenditures, or an average of 26 cents per acre for the area irrigable in 1916. The telephone lines of these projects are probably more extensive than those on many other systems so that these figures should represent as high a total cost as is to be expected.

The telephone system on the Imperial Valley Water Co. No. 1 consisted of 48 miles of line, 31 telephones and one switchboard in 1915, having a value of $9,940 or $207 per mile of line.

Ditch riders can patrol the parts of the telephone system which parallel their beats. This may make it desirable to carry such lines along canals although the length might be reduced by more direct lines. It will also usually be necessary to have available a troubleman for repairs which cannot be made by the ditch riders. Such a troubleman may be a member of maintenance crews and give only part time to telephone repairs.

Where lines are carried through timber, trees may be used for poles. Grounded lines are preferable due to the danger of short-circuiting by falling branches. More slack should also be given. The standard construction of the U. S. Forest Service is a grounded line of No. 9 B.W.G. Best Wire.

On large systems more than one shift of telephone operators may be used. It is more usual, however, to arrange for night calls to be received by some employee not regularly on duty. This may be done by connecting the superintendent's residence with the system so that he may be called directly or by having some employee quartered in the building in which the switchboard is located. During the day special operators may be used if the number of calls warrant it; more usually such employees can also do certain other routine or clerical work as well. The cost of operation is practically the salary paid to such operators. These are usually necessary only during the operation season. The cost of maintenance may be as high as $30 per mile per year although little direct data regarding such costs are available.

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CHAPTER III

ORGANIZATION FOR OPERATION AND MAINTENANCE

GENERAL ORGANIZATION

The duties and requirements of an organization for the operation and maintenance of an irrigation system differ from those for its original construction or extensive betterment. During the first years of operation there may be a large amount of construction remaining to be done, so that it may be necessary to maintain the two forms of organization.

The organization of different systems varies widely both in the character of the duties that may be handled and the extent to which they may be carried out. There are several factors which affect the form of organization which may be used, among which are: (1) size of system, (2) character of the company, (3) the method of delivery, (4) value of water, and (5) average size of farm.

The size of the system or area irrigated is the most important factor in determining the extent of the organization. On some of the smaller or simpler systems the entire office work may be handled by a secretary on part time. It is only on the larger and more complex systems that a complete organization is needed or that its cost can be afforded. On large canals, some definite system both for the delivery of water and for the records is required if satisfactory results are to be secured. It is probable that the average cost per acre for the organization is higher on many large systems than on the smaller ones, the greater amount of detail handled on such large systems more than balancing the lower cost per unit accomplished which can be secured where the amount to be done is larger. This is due also to the fact that canals covering large areas are more complicated as the more easily covered lower lands are usually served by the smaller canals. With large systems the prospective damages due to possible breaks are greater and a closer control of the water is essential. With large areas more book records are required, as there is less of the individual contact between the irrigators and the operation officials other than the ditch riders. On small systems a secretary and the ditch riders may comprise the operating force. As the size increases and more ditch riders are needed, the secretary may also be the superintendent or a separate superintendent may be employed to direct the ditch riders and also to handle maintenance and engineering work directly. With further increases in size the organization becomes more complex until with the very large systems the duties under each division of the work are sufficient in amount to require the continuous time of at least one man.

The character of the controlling company very materially affects the operation organization. With systems controlled by the land owners, such as coöperative companies or irrigation districts, the more simple and less expensive organizations are general. This result is secured partly by doing without some of the service which may be given by the more highly developed organizations such as hydrographic and similar work and also partly by using a somewhat lower average scale of pay. The systems of the U. S. Reclamation Service generally have the most complete and detailed organizations. This is partly due to the necessity of following governmental requirements as to accounts and records and partly to the use of a more detailed control of delivery and use of water than are usual on other systems. Such government projects are also subject to the inherent disadvantage of all government work where the lack of direct responsibility to those actually supplying the funds from their own resources makes the incentive for economy less direct. This is being partly overcome in some cases by giving the settlers under each project a larger share in the selection of the policies for the system. With Carey Act projects, a wide variety of conditions are found. Some have quite complete operation organizations, others operate as cheaply as possible until the system can be turned over to the settlers. As it has become recognized that the time until such systems can be turned over to the settlers is longer than many Carey Act projects first anticipated, the tendency is toward more complete operating organizations and better maintenance. The commercial or public utility irrigation companies generally use organizations of similar detail to those of other similar corporations, the result being that usually less detail control is exercised than on the government systems. In several States such utility companies are subject to public control in regard to the service given which in turn affects or controls the organization which it is necessary to use.

The method of delivery, which is itself influenced by the value of water, controls some portions of the organization. Where quantity rates are used, more detail individual records are required, which make necessary larger organizations, particularly in the hydrographic work. Where the water supply is ample it is cheaper to have some excess canal capacity and looser operation methods than to closely control the use of a smaller supply for the same area. Where the cost of the water itself is relatively high, relatively expensive organizations for securing more economical use are warranted. The average size of farm affects the organization. For small farms more deliveries and greater detail of records are required; for large farms using a continuous flow little detailed attention in operation is required. Similarly, delivery to laterals only instead of to individuals very materially reduces the extent and complexity of the main-canal organization.

The value of good service is becoming more generally recognized and the tendency is toward a more complete control of the systems by a more detailed organization in order that such better service can be consistently given.

Organization Divisions.—Three general divisions of the organization can be made, the duties of which are fairly distinct although the actual personnel may overlap, particularly on the smaller systems. These are: (1) the operation proper or delivery of water division, (2) the engineering division, and (3) the clerical division. The following outline chart shows the organization and duties that come within the different divisions. A somewhat similar chart has been prepared by G. H. Bliss of the Boise project of the Reclamation Service, references to which are given at the end of the chapter. Only large systems would use such an organization in its entirety, it covers practically all duties that would be performed on any system and as such forms a good basis of discussion. On the larger number of systems some of the duties would be omitted or combined with others.

Organization Chart

GENERAL SUPERVISION.

Board of directors or equivalent. Determines the general policies and expenditures of the system.

Direct Supervision.

Manager, directly responsible for the expenditures and the carrying out the policies of the directors; heads of divisions directly under his supervision on large systems; on smaller systems manager may also act as the head of the divisions. Assistant manager may also be used in some cases. Under the manager come the following more or less distinct divisions:

Operation division.

Engineering division.

Clerical division.

In addition there may be legal department either permanently maintained or retained or employed only as needed.

Operation Division.

Usually in charge of the superintendent or water master, handles the securing of water and its delivery and the maintenance of the system during the delivery season. Also, usually handles maintenance work during non-delivery season except the larger construction work which may be handled by the engineering division. Superintendent controls division of water to the different ditch-rider beats, handles complaints not settled by ditch riders, supervises maintenance crews and generally directs the operation. On large systems, two or more superintendents reporting to the manager may be used, each having charge of a particular division or unit. Under the operation department are the:

Ditch riders, or equivalent employees, who are assigned to definite beats, on which they make deliveries of water, patrol their assigned ditches, make minor repairs and notify superintendent of those requiring the maintenance crew.

Gate tenders at reservoirs or headgates.

Maintenance foremen, who handle small crews who make repairs as needed on any part of the system, and install new delivery gates or minor structures as required. Handles vegetation in canals and on canal banks when too large in amount to be controlled by the ditch riders.

Telephone operators and linemen, who operate and maintain telephone service when separate systems are owned and operated by the canal company; linemen may be combined with the maintenance crew. It is desirable to have 24-hour connection with superintendent on large systems.

Superintendents' clerk, who handles routine matters such as records of complaints, timekeeping, etc. Sometimes combined with the clerical department.

Engineering Division.

Usually in charge of the engineer or assistant engineer who may also be the superintendent; handles all strictly engineering matters, such as the construction of extensions, larger betterments or other work important enough to be distinguished from ordinary maintenance. Under the engineering department are:

Instrumentmen, who handle field surveys, stake out construction work, etc.

Inspectors, who inspect construction, usually combined with instrumentmen.

Draftsmen, who handle office work for engineer. This may also be handled by instrumentmen.

Hydrographer, who handles ratings of canals and delivery devices, compiles hydrographic records, makes seepage measurements, ground-water studies where such are needed, compiles water-delivery records in shape to be posted by the clerical division where water is sold on a quantity basis.

General foreman or construction superintendent, who handles force-account construction work which comes under the engineering department.

CLERICAL DIVISION.

In charge of secretary or chief clerk, who handles clerical and fiscal matters. The duties handled include:

Collections of assessments and charges.

General accounting system.

Purchasing of supplies and materials ordered by other departments.

Messes and corrals.

Equipment inventories.

Storehouse supervision.

Correspondence.

General Supervision.—General supervision should be exercised by those responsible for the policies of the system. For enterprises controlled by the land owners this will be the board of directors elected by the owners. The manager should be given full control in carrying out the actual operation and maintenance. It is not desirable to have the board of directors act directly as manager; there should be some single individual with full authority and responsibility who is judged by the results and left free, except in matters of general policy, to secure the results by his own methods. The duties of direct management of large systems require an experience not usually possessed by the elected directors.

Direct Supervision.—The duties of a manager require both executive ability and engineering and agricultural experience. Executive training has been more readily secured in the past in engineering than in agricultural lines so that the majority of present managers have been trained in engineering. Frequently engineers connected with the construction of a system will remain with it during operation. Strictly, engineering training may, however be a disadvantage, unless there is combined with it some general agricultural knowledge and an understanding of agricultural conditions and people. Knowledge of the use of water is as essential as knowledge of its development and conveyance. The best training is in actual operation, such as can be obtained by working up through the operation department or through the hydrographic work of the engineering department.

The positions of irrigation managers paying sufficient salaries to be permanently attractive to properly qualified men have been largely a development of the past 15 years. This is coincident with the construction of the greater number of large systems whose size is sufficient to enable them to pay such salaries. Such positions tend to be more permanent and remunerative on systems controlled by corporations. The larger coöperative systems in many cases do not appreciate the economies which a good manager may effect. With such coöperative companies the salary is often on a lower scale and where the members of the board of directors are frequently changed, the tenure of the position may be less certain.

Much has been written regarding the difficulties of such positions and the necessary qualifications of an irrigation manager. The general qualifications needed are similar to those required by the manager of any service which delivers to a large number of consumers any of their necessities. These include a knowledge of how to be firm and insistent when necessary, but a better knowledge of how to avoid the need of such insistence and a uniformity and fairness in dealing with all classes, both successful and unsuccessful.

The assistant manager as a distinct position is not usual. The head of one of the departments, generally the operation division, may become acting manager in the manager's absence. When a system is so large that assistant managers are needed, it may be preferable to divide the system into units in each of which the organization is more or less distinct.

OPERATION DIVISION

The main purpose of an irrigation system is to deliver water at the times and in the quantities needed to produce the best results from its use. This is the duty of the operation department and it is, therefore, the most important of the three divisions outlined. It is the one that comes into the most direct and closest contact with the irrigators and the one by which the land owners often judge the whole organization. As previously stated, the personnel may overlap and be interchangeable with the other divisions; the duties of the operation department are relatively definite, however.

The operation department is usually in charge of a superintendent or water master who is the authority next above the ditch riders. A capable superintendent can often secure results which no other member of the organization could accomplish, due to having sufficient authority to act and a better understanding of the conditions and point of view of the farmers which comes from his more direct contact with them. An understanding of ditch operation and the handling of water from actual experience is practically essential for such positions. This can be obtained most directly from actual experience in ditch riding.

DITCH RIDERS

The most important as well as the most numerous part of the operation force are the ditch riders. These are the members of the operation force who come into daily contact with the farmers, the deliverymen who are constantly in touch with the customers.

Various names are used for these employees handling the patrolling of the canals and the delivery of water. Among these are the terms ditch rider, ditch tender, zanzero, patrolman, and ditch walker. The first three are more generally used where the duties of delivery are relatively more important than the observation of the canal; the last two are applied to those watching canals for purposes of maintenance rather than delivery.

The work of ditch riders can be measured in terms of the irrigable or irrigated area handled, the miles of canal covered, or the number of farms or turnouts served. With the wide variations of conditions on different systems the work accomplished naturally varies materially. Where the irrigated farms are scattered or where the irrigated area per farm is small as in the first years of operation of new systems, the length of ditch to be ridden will more largely determine the beats rather than the area actually irrigated. Where small irrigation heads are delivered to

TABLE VII.—SUMMARY OF THE WORK OF DITCH RIDERS

For Systems Delivering to Individuals

	Number of records	Irrigated area handled per ditch rider, acres		
		Average	Minimum	Maximum
Area irrigated per mile of canal				
Less than 50 acres	9	850	550	1,500
50 to 75 acres	9	1,560	420	3,000
75 to 100 acres	12	1,750	1,090	2,550
100 to 150 acres	12	2,300	1,400	3,400
150 to 200 acres	7	2,750	1,250	4,000
Over 200 acres	3	2,970	2,700	3,360
Mean	52	1,900		
Per cent. of area irrigable which was actually irrigated				
Less than 30	7	780	420	1,330
30 to 40	4	1,240	550	1,720
40 to 50	9	1,490	1,090	1,940
50 to 60	8	1,990	1,600	3,100
60 to 80	8	2,350	1,250	3,000
80 to 100	5	3,110	1,770	4,000
Mean	41	1,800		
Number of farms per mile of canal				
Less than 1	4	720	530	865
1 to 2	11	1,610	1,030	2,440
2 to 3	11	1,780	550	3,110
3 to 4	7	2,350	420	4,000
4 to 6	8	3,310	1,500	3,400
Over 6	9	2,220	1,000	3,700
Mean	50	1,900		
Average area irrigated per farm				
Less than 20 acres	13	1,510	420	3,000
20 to 30 acres	8	1,860	1,250	3,360
30 to 40 acres	13	2,030	650	3,500
40 to 60 acres	10	2,200	1,090	4,000
Over 60 acres	9	2,360	630	4,500
Mean	53	1,970		
Average number of farms per ditch rider				
Less than 25	7	1,000	630	1,600
25 to 50	18	1,980	420	4,000
50 to 75	14	2,340	1,250	4,500
Over 75	15	2,330	1,250	3,550
Mean	54	2,040		
Length of canal in miles per ditch rider.				
Less than 15	13	1,480	420	2,840
15 to 20	18	1,890	730	3,400
20 to 25	14	1,980	630	4,000
Over 25	10	2,330	1,330	3,000
Mean	55	1,900		

small farms at short intervals, the length of ditch and area served per ditch rider will usually be relatively small. Whether the main-canal organization delivers to individual or to lateral associations affects the work of the main-canal ditch riders very materially.

Area Handled per Ditch Rider.—In the preceding tables, summaries of the practice of many systems are given. These include both private and government projects and are typical of general conditions. Where, however, the individual examples forming each mean vary as widely as they do in these cases, the resulting means can be taken only as relative tendencies rather than as exact figures. About two-thirds of the data were taken from the various reports of systems of the U. S. Reclamation Service for different years; the remainder include other forms of organizations scattered through all the States. Table VII gives the data for delivery to individuals, Table VIII that for delivery to the heads of laterals only.

Delivery to Individuals.—For delivery to individuals any condition which reduces the area irrigated per mile of canal will reduce the area served per ditch rider. This is shown in the first comparison of Table VII, the area increasing consistently with the area irrigated per mile of canal. Where canals can be run on ridges or downslopes, so that deliveries can be made to both sides, the area handled per ditch rider will be larger as the patrolling the ditches is relatively less in amount. This is also shown in the second comparison. When only a small per cent. of the land covered is actually irrigated, the area irrigated per mile of canal will be small, thus reducing the area served per rider. The data for this comparison are taken entirely from systems of the U. S. Reclamation Service as the records for other systems did not give the irrigable area separately. These figures indicate that one ditch rider should be able to handle from 2,500 to 3,000 acres on well-developed systems under usual methods of delivery. In the earlier years the length of canal patrolled becomes a better criterion of the work of the ditch riders as such patrolling is relatively more important than the delivery of water. The area handled per ditch rider is increasing on these systems as the projects become more fully developed. On 13 projects in 1912, the average irrigated area per ditch rider was 1,415 acres; for the same systems in 1914 it was 2,020 acres.

The comparison of number of farms per mile seems to indicate that from three to six farms per mile of canal gives the balance between area irrigated and size of farm which is most favorable. For fewer farms the effect of the greater amount of riding per delivery reduces the area, for more farms the greater detail of delivering to small holdings apparently begins to reduce the area served per ditch rider. This latter condition does not hold, however, where water is delivered under rotation to small holdings at relatively infrequent periods such as 30 days.

Larger-sized farms mean fewer turnouts, and less frequent changes in delivery resulting in larger areas served per rider as shown in the fourth comparison. The area served also appears to increase with the number of farms up to about 50 farms per ditch rider. Where more than this number are handled the average size apparently becomes sufficiently less to balance the increase in number.

The larger number of farms are mainly for those systems where infrequent deliveries are made or where daily visits are not made if the delivery is continuous. The area served also increases with the length of canal covered per ditch rider. Where patrolling is relatively less important and inspection of canals less frequent more area can be covered if the method of delivery does not require daily visits to all turnouts.

Of the three methods of delivery, continuous flow gives a higher average area served per canal rider than either rotation or delivery on demand. This does not mean that for any given system a change from continuous flow to rotation would reduce the area per rider but indicates that continuous flow is used on systems where the other conditions such as large size of farms, lack of close control of delivery and ample water supply are also favorable to large areas per rider. With continuous flow there are fewer changes of headgates required. For delivery in rotation, if the period between deliveries is 3 to 4 weeks, only a small portion of the farms will be receiving water at any one time and large areas may be handled if the other conditions are favorable. Where the rotation period is short, such as deliveries at alternate 4-day periods, the frequency of changes may result in smaller areas per rider than under continuous flow. With delivery on demand, unless a relatively long period of notice is required, the ditch rider cannot plan his deliveries as far ahead and will not usually be able to care for as large an area. Where 2 to 4 days notice is required, this disadvantage may be largely overcome.

The measurement of the water delivered to individuals will not materially affect the area served per ditch rider. Where the charges for operation are based on such measurements, it is desirable that daily records be secured. This may involve extra visits to headgates in some cases, although except for small heads delivered continuously, daily visits during the times of delivery are usual on most systems. The actual reading and recording of gages, openings and other field notes in connection with measured delivery will not reduce the area in a beat to any extent.

The extent to which handling of headgates by the farmer is permitted affects the area per ditch rider. If all gates are locked, closer attention by the rider is required. On the "Big" Ditch near Billings, Mont., 4 riders handle 25,000 acres delivering under continuous flow to individuals and some laterals which are usually small. This system consists of a main canal about 40 miles long, having good wasteway facilities. Each farmer or group of farmers operate their own headgates as long as they do not take water in excess of the amount to which their shares entitle them. The ditch rider's duties consist mainly in patrolling the ditch, regulating headgates taking a noticeable excess, and regulating the canal flow at the wasteways. This method gives a very low cost of operation for the system; if the value of the time spent by each farmer in visiting his headgate was included, the total cost of service might be greater than on other systems more closely controlled.

The numerical comparisons given in Table VII are made by separating data according to a single variable where the actual result depends in each case on the combined effect of a number of variables. Within any given project, the area served by different ditch riders will vary as the conditions on the different parts of the system vary. It appears, however, that the following generalizations are warranted:

1. The irrigated area served per ditch rider is most directly affected by the percentage of the land under the canals which is irrigated.

2. The area served increases with the average size of farm, the rate of increase in area served being less than the increase in the size of the farm.

3. The area served is not increased for more than 3 or 4 farms per mile of canal.

4. The area served is not increased where each ditch rider

handles more than 50 farms, the increase apparently being balanced by the decrease in irrigated area per farm.

5. Methods of delivery requiring few changes of headgates, such as continuous flow or long rotation periods, or methods of operation in which the control of delivery is less exact, are favorable to large areas.

Delivery to Laterals Only.—On some systems, particularly the older ones, the organization operating the main canals makes delivery only to laterals or to groups of farmers who attend to the further subdivision of the water among themselves. In such cases the amount of water in each delivery is larger than for delivery to individuals and the ditch riders on the main canals can handle much larger areas. On such systems the irrigated area per main canal ditch rider varies from 4,000 to 10,000 acres or more, depending upon the size of laterals. The riders under the laterals cover about the same or a little larger areas than those on similar systems delivering directly to each individual, making the total delivery force somewhat larger although the organization of the main canal is much simpler. On other systems a mixed practice is followed, deliveries being made directly to those farms near the main canals and laterals and to lateral associations for the more distant lands. This is shown by the comparison given in Table VIII. The number of records for delivery to laterals is less than those given for delivery to individuals and the means are consequently less dependable. The area served increases with the area irrigated per mile of canal as this increases the average size of laterals to which delivery is made. The effect of delivery to the heads of sub-laterals as compared with delivery to individuals is shown on the gravity unit of the Minidoka project. In 1911, delivering to laterals each ditch rider handled an average irrigated area of 4,860 acres; in 1914, after the operation of the laterals had been taken over and deliveries were made to each farm, the average was 2,650 acres.

Summary of Area Handled per Ditch Rider.—The average area irrigated per ditch rider for the 58 records of delivery to individuals is 1,870 acres. As this includes many new systems it is lower than the general average. The average of 20 records for delivery to laterals only was 7,200 acres. The irrigated area which a ditch rider may be expected to handle under different conditions may be summarized as follows:

Less than 1,000 *Acres.*—During the first year's operation of

TABLE VIII.—SUMMARY OF THE WORK OF DITCH RIDERS

For Systems Delivering to Laterals Only

	Number of records	Irrigated area handled per ditch rider, acres		
		Average	Minimum	Maximum
Area irrigated per mile of canal operated				
Less than 100 acres	4	6,640	3,550	10,000
100 to 200 acres	8	5,780	3,000	13,000
200 to 400 acres	4	7,800	3,700	15,000
Over 400 acres	4	9,200	5,670	12,000
Mean	20	7,040		
Number of farms per mile of canal				
Less than 2	6	5,430	3,000	10,000
2 to 4	4	5,510	3,500	9,000
4 to 6	3	9,550	4,860	13,000
Over 6	4	8,090	5,670	1,200
Mean	17	6,800		

systems serving lands difficult to prepare for irrigation where the area irrigated per farm is small or where only a small proportion of the farms are actually irrigated. For small farms which require frequent deliveries.

Between 1,000 *and* 1,500 *Acres.*—For systems in which only from one-third to one-half the land is irrigated; where the patrolling of the canal is relatively more important than the delivery of water; where the soils or other conditions are variable, requiring variable periods between irrigations and variable sizes of irrigation heads.

Between 1,500 *and* 2,000 *Acres.*—For systems in which from one-half to two-thirds of the area is irrigated, for systems supplying small orchard tracts with small and closely controlled irrigation heads; for systems supplying farms irrigating 20 to 30 acres under average conditions.

Between 2,000 *and* 2,500 *Acres.*—For average systems in which from two-thirds to three-fourths of the area is irrigated; where the average area irrigated per farm is over 30 acres; for well-controlled systems serving small orchard tracts requiring relatively infrequent deliveries; where the average number of turnouts per mile of canal is three or more.

Between 2,500 *and* 3,000 *Acres*.—For average systems well-developed; for small sizes of farms with deliveries not as closely controlled as in class above; where area served per mile of canal exceeds 150 acres; where rather large irrigation heads are delivered under rotation.

Between 3,000 *and* 4,000 *Acres*.—Systems delivering to small laterals, or large farms; where delivery is not as closely supervised as in above classes where large irrigation heads are delivered at relatively long periods to well-developed areas.

Between 4,000 *and* 4,500 *Acres*.—Systems requiring less detail supervision of delivery, such as allowing the users considerable latitude in regulating their gates; delivery to small laterals or group ditches; systems requiring infrequent changes of delivery such as continuous flow to large farms in compact areas.

Between 5,000 *and* 7,500 *Acres*.—For delivery to individuals only under the most favorable conditions, such as compact well-developed areas of large farms requiring little control of delivery; for delivery to medium-sized laterals requiring only average supervision.

Over 7,500 *Acres*.—For delivery to relatively large laterals where area served per mile of main canal is relatively large.

Length of Beats.—The length of canal patrolled by a ditch rider depends on the relative importance of maintenance and of water delivery. For canals with ample freeboard or few dangerous locations, patrolling the entire length each day may not be necessary. Where canals are carried across flat lands with the water surface held above the lands on both sides, daily patrolling of each bank may be needed. The average length of canal per beat of the same systems used in the discussion of the area irrigated per ditch rider was 20 miles for delivery to individuals and 25 miles for delivery to laterals only. The less detail required in delivery to laterals appears to enable the ditch rider to cover a somewhat greater average length of canal.

The number of farms served per ditch rider varies widely. For small orchard tracts of 10 to 20 acres irrigated under rotation at 30-days intervals, conditions typical of a number of southern California systems, from 100 to 300 tracts may be served per ditch rider, the average of several systems being about 175. For delivery to laterals, the total number of farms depends on the size of the laterals and may exceed 300 on some systems. The average for the system of the U. S. Reclamation Service has been about 50 farms per rider for delivery to individuals and about 110 for delivery to laterals. These figures are probably representative of average conditions in the mountain States where the individual farms have an average size of over 40 acres or for delivery to sub-laterals serving only a few farms.

Compensation of Ditch Riders.—The pay of ditch riders varies with the conditions of service. It is usual for the rider to furnish and maintain his own horses. Where motorcycles or autos are used they are generally supplied by the company. If the rider furnishes his own horse, it will receive better care. The company may not be able to use such stock to advantage in the non-operation season. In some cases, particularly on diversion canals or other locations outside the settled areas, the company may furnish quarters to the rider. The usual rate of pay on government systems varies from $75 to $90 per month, with an average of about $85. The pay is sometimes varied with the requirements of the different beats, such as $75 per month when 1 horse is used and $90 when 2 are needed. On other systems the average pay ranges from $90 per month when a horse is furnished by the ditch rider to about $70 without the horse.

On systems having operating seasons of 9 months or over, the ditch riders may be employed continuously throughout the year, being used on maintenance work during the short non-operating season. Where the winter seasons are closed and relatively long, it is not usual to carry the riders throughout the year, as construction work cannot be carried on during the winter. Including fall and spring maintenance work, some of the riders may be carried for a total of 8 months in the mountain States. In some cases the number of riders can be gradually reduced toward the end of the season, as the deliveries to be made are less in number and the flow in the canals is less, reducing the danger of breaks. Where the riders can be employed at maintenance work on their beats, it may be preferable to have this done rather than to enlarge the beats of some riders to cover territory with which they are not familiar.

In most cases, horses are used for the transportation of ditch riders. Where roadways have been made on the top of canal banks or where public roads are used instead of following the canals, carts may be used. Riding is usually preferable to driving as the ditch rider has a better opportunity to follow the canals and inspect them. More rapid travel, such as motorcycles, is not usually desirable as the rider's attention is given to the machine rather than to the ditches. For concrete-lined or pipe systems on which patrolling is not needed, motorcycles and autos may be used to advantage.

On a few systems requiring many ditch riders, inspectors of their work have been used. Where this is done the better practice is to use such inspection for instruction to the riders rather than as a separate checking of their records or deliveries. An inspector going with the rider, advising him on his methods of measurement, or gage reading, will be of more benefit than one making separate readings for the purpose of finding errors. Such duties of inspection are more usually handled by the water master or superintendent.

Patrolmen.—On long diversion canals, patrolmen may be used who make no divisions or deliveries of water. Such locations are frequently along side hills in which the danger of breaks is relatively large. Such patrolmen more usually walk their beats, as the flumes, walled sections and other special forms of construction may make riding difficult. The usual beat consists of from 6 to 8 miles of such canal, which is covered daily. In extremely bad ground night patrolling may be used if the canal is being crowded to capacity. Such ditch walkers also are usually expected to perform the routine maintenance work on their beat, such as cleaning screens, cutting weeds on the banks, and trapping or otherwise controlling burrowing animals.

It is usual to station a gate tender at the diversion dam or headworks and also at larger reservoirs. This is done in order to regulate the flow as desired and to prevent injuries to structures by drift. In some cases, such gate tenders may patrol an adjacent section of canal.

ENGINEERING DIVISION

With all systems there is a transition period between construction and operation during which water will be delivered to some lands and more or less extension and structure work will be carried on. For such periods the engineering department may be more nearly that used for construction than for operation. The same condition may exist during periods of extensive betterment work. Some engineering organization is, however, required on systems on an operation basis in order to handle the usual or routine engineering work. Such instrument work as the location of new structures, surveys for new laterals or extensions, drainage investigations and general miscellaneous work will be required. On larger constructions, particularly if done by contract, inspectors may be needed. Office drafting will include routine map work, particularly during periods of settlement when land plats showing the status of contracts must be kept up to date, designs of new structures, records of the construction and location of new structures, and maps for extension or drains. On smaller systems all such work including some hydrographic observations may be handled by one man. On larger systems the duties may be sufficient to require separate instrumentmen, inspectors and draftsmen. During the earlier years some systems may furnish aid in locating farm ditches, such aid being handled by the engineering force.

The hydrographic work varies from none to a detailed system which includes records of the flow in all canals and delivery to each user. It is preferable to have the hydrography under the supervision of the engineering department although the results are secured from gage readings taken by the operation force and the use of the results is largely by the operation division. It is, of course, necessary that the hydrographer be in close touch with both the clerical and operating divisions and coöperate with them. To secure such coöperation is part of the duties of the manager. In some cases the clerical division may make the routine computations of the quantity delivered. It is preferable, however, to have such computations made by the hydrographer and the results posted in the individual accounts by the clerical division. The hydrographic methods are discussed in detail in Chapter V.

The operation force may become the engineering department in the non-operating months. Except for new work such as extensions, structures are usually constructed outside of the operation season. Ditch riders may become foremen and hydrographers instrumentmen. Such interchanging maintains the personnel intact throughout the year and results in economy in most cases if the construction work consists of many minor items rather than a few complex structures requiring special skill. The opportunity to use part of the operation force in this way during the non-operating season may make it desirable to do work by force account instead of by contract. As a rule, however, it is preferable to work by contract where the conditions are such that definite specifications can be written, where the quantity of work to be done is sufficient to furnish a good basis for unit prices, or where special equipment is required. This applies to earthwork in masses, large flumes or other structures. On small scattered structures, and general canal cleaning, force account methods give good results.

CLERICAL DIVISION

This is the office and accounting division. It is in charge of the secretary on coöperative systems or the chief clerk on government systems; the title varies in other cases. The accounts include these discussed in Chapter IX. There are also the individual accounts of each land owner which may vary from a single seasonal assessment to frequent entries covering charges for water as it is delivered. Construction mess and corral accounts, material and stock records, correspondence, and purchases are also handled in this division. The number of clerical employees varies with the size and the character of the ownership of the system. For larger systems, the duties of the different clerical employees may be quite distinct, such as the bookkeeper, material clerk and purchasing agent, in smaller systems the duties overlap and one man may handle all clerical matters.

SIZE OF ORGANIZATION

At the 1911 Operation and Maintenance Conference at Boise, a paper was presented by Mr. R. K. Tiffany, then manager of the Sunnyside project, in which a series of organizations for different sized systems were given as shown in Table IX. As stated by Mr. Tiffany the number of employees given would represent about the maximum which would be required. Under favorable conditions the number may be materially reduced and many systems are operated with smaller organizations.

As an instance of the effect on the organization of the main canal system of the delivery of water to laterals only or to individuals, a case on the Boise project was cited. On 32,000 acres, of which 21,000 were irrigated, water was delivered to laterals only on about half of the area; one water master, one field clerk, 2 gate tenders and 8 ditch riders handled this area at a cost of 5

TABLE IX.—SIZE OF ORGANIZATION

Position	Size of project					
	20,000 acres		50,000 acres		100,000 acres	
	Number of employees	Monthly salary	Number of employees	Monthly salary	Number of employees	Monthly salary
Manager	1	$200	1	$250	1	$300
Chief clerk	1	125	1	150	1	175
Bookkeeper	....	....	1	125	1	125
Stenographers	....	....	1	90	2 @ $90	180
Engineer	1	125	1	150	1	150
Hydrographer	....	....	....	.....	1	100
Inspector	....	....	1	100	2 @ $90	180
Water masters	1	125	2	275	3 @ $150	450
Ditch riders	8 @ $90	720	20 @ $90	1,800	40 @ $90	3,600
Telephone lineman	....	....	....	.....	1	90
Water-record clerks	1	75	1	90	2 @ $90	180
Total per month	....	$1,370	....	$3,030		$5,520
Cost per acre per month	....	6.8 cents	....	6 cents	....	5.5 cents

cents per acre per month. On another division containing about 33,000 acres of which 15,000 were irrigated, water was delivered to each individual farm at a cost of 12½ cents per month.

The average size of the clerical force for government projects was given as follows at the same conference: up to 15,000 acres, one clerk; 15,000 to 40,000 acres, two clerks; 40,000 to 75,000 acres, three clerks; 75,000 to 120,000 acres, four clerks; 120,000 to 175,000 acres, five clerks; 175,000 to 240,000 acres, six clerks. These do not include the keeping of the strictly operation or water-delivery records. It was considered that one man should handle about 2,000 individual accounts in the books. For other forms of organization the clerical force is usually somewhat smaller.

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CHAPTER IV

METHODS OF DELIVERING IRRIGATION WATER

The purpose of all the methods of delivery used on irrigation systems is to furnish to each individual the quantity of water to which he is entitled at the time at which its use is desired. The extent to which this is accomplished, both in quantity and time, measures the success of the operation methods used. Under the different conditions of the use of water and of the water supply which are found on different systems, no one general method of delivery can be expected to be suited to all cases. The selection of the method to be used on any particular system should be based on a careful study of such local conditions. On the larger projects conditions within the project may vary to such an extent that different methods of delivery will be required on different parts of the same project.

In the selection of the delivery methods the farm needs are the determining factor. The financial success of the system depends upon the financial success of the users and convenience and even economy in operation of the canals are secondary to convenience and economy in the use of water on the farm. The requirements of economy in delivery are not necessarily in conflict with the use on the farm; where they do differ the use on the farm should control. The attempt to adjust the farm use to some desired operation method has always resulted in failure where the method used has not fitted into the normal farm needs.

There are three principal methods of delivery used in the operation of irrigation systems. These are known as (1) continuous flow, (2) rotation, and (3) delivery-on-demand. The general nature of each method is indicated by its name. The practice on any given project may be to some extent a combination of any two of these methods, although the elements of each can be distinguished.

Among the factors which influence the choice of the method of delivery to be used are the character of the soil, topography, kind and diversity of crops grown, extent and nature of the water supply, average size of farm, length of irrigation season and character of the farmers. The character of the soil affects the method of delivery in regard to the frequency of irrigation and depth applied at each irrigation. The topography influences the size of irrigating head which can be used and thus the rate at which irrigation can be accomplished. The kind of crop influences the seasonal use of water. The times at which irrigation of grain is needed are relatively short, and when needed, irrigation cannot be delayed without injury for as long a time as with some other crops. Forage crops usually require relatively large amounts of water distributed over a relatively long growing season. Alfalfa, being deep-rooted, may permit a greater variation in the time of different irrigations and be better adapted to relatively infrequent rotation periods. Cultivated crops are not suited to the use of large irrigation heads. Orchards usually require less frequent irrigations, and the time of irrigation is more adjustable than with other crops. Crops such as potatoes and sugar beets may require frequent irrigations at certain times during the season. Where the character of the water supply permits it, the time of irrigation should be adjusted to the crop needs; where water supplies such as flood flows only are available, the use must be adjusted to the supply. The average size of farm determines the area served per turnout, the length of time required to irrigate each farm and the frequency of change in headgates. The length of season is also a factor; where the season of operation is long the total saving due to more efficient methods is greater. The character of farmers is also important; if experienced in irrigation under one method, it may be more difficult to secure a change in methods than would be the case with new irrigators who could be started under the desired methods from the beginning.

Legal Definitions.—In the earlier adjudications of appropriation rights, water rights were defined in terms of continuous flow. The rights of each area of land or of each canal were expressed as the right to take water at a certain rate when the use was beneficial. The present laws in some States define the extent of the water rights acquired by appropriation in terms of both the maximum rate of use and the total quantity per acre which can be used in any season. The continuous-flow right is best suited to the conditions which were generally found on the earlier systems, and as these conditions are changing, it is becoming less generally desirable than formerly. Provisions are now made directly in the laws of some States and also in the decrees of some of the courts for rotation between rights where the extent of each right is small, and also for prorating the available flow at times of extreme scarcity instead of a strict observance of priorities. The Wyoming statutes now provide (Laws 1909, Chapter CVIII No. 1):

"Rotation among water users. To bring about a more economical use of the available water supply, it shall be lawful for water users owning lands to which are attached water rights, to rotate in the use of the supply to which they may be collectively entitled; or a single water user, having lands to which water rights of a different priority attach, may in like manner rotate in use, when such rotation can be made without injury to lands enjoying an earlier priority."

The Idaho Supreme Court (Helphrey *vs.* Perrault, 86 Pac., 417) has expressed itself as follows:

"Rotation in irrigation undoubtedly tends to conserve the waters of the State and to increase and enlarge their duty and service and is consequently a practice that deserves encouragement insofar as it may be done within legal bounds."

In a later case (State *vs.* Twin Falls Canal Co., 121 Pac., 1939), in discussing the contracts which contained a clause that delivery would be made

"according to such rules and regulations based upon a system of distribution of water to the irrigators in turn and by rotation as will best protect and serve the interests of all the users of water from this canal system,"

the same court states:

"The rotation system is recognized by the leading writers on irrigation and irrigation engineering as a most efficient and desirable method and as producing the highest duty of water of any method of use."

And again:

"If each user cannot secure sufficient water for the irrigation of his land by a constant flow of his proportionate share of the water in said canal, but can receive sufficient by rotation, that system should be used."

On any given project a combination of all of these various factors may be found. Where the conditions under any system vary to the greatest extent, the method of delivery used will need to be the most irregular. Where the conditions are most uniform, some definite system of delivery can be developed which will give both economy in operation and satisfaction in use. The methods suited to small systems largely in one type of crop may be totally unsuited to a larger system having variable soils, topography and crops.

CONTINUOUS DELIVERY

This method is used to a large extent on the systems in several of the Rocky Mountain States. A continuous-flow method does not mean that use is actually continuous. The right to secure water when needed is continuous. The actual use is usually intermittent, depending on the varying conditions on each farm. The canal capacities must be sufficient to either deliver the total amount of all continuous-flow rights equal to the maximum total demand which can be made or for such proportion of this maximum demand as judgment and experience indicate will occur at any given time. This usually results in making the sub-laterals, and sometimes the laterals, of a capacity equal to the total rights under them and in making the main canals of somewhat less capacity. Where the crops are mainly of one kind, there may be periods during the season when nearly all lands will desire their full flow.

The continuous-flow method is best suited to large farms or to topographic conditions which make the use of small irrigating heads necessary. On large farms what may be continuous delivery from the turnout becomes on the farm a system of rotation between the different fields of the farm. For farms under conditions of irrigation which may limit the irrigation head which one man can efficiently handle to 2 second-feet, a condition quite usual in the mountain States, 20 days would be required to cover 160 acres to an average depth of 6 inches. If a farm of this size consists of some grain and cultivated crops with the greater proportion in forage, more usually alfalfa, there will be some months of the season when practically continuous use of the water will be required. For similar farms of smaller size, rotation between the farms may be practiced. Rotation on a 160-acre farm where only small heads can be used would require the use of two irrigators for about half the time which may be less efficient from a farm labor standpoint than one irrigator all the time.

Where soil, topography or crop conditions reduce the size of irrigation head so that the stream that can be handled becomes small in proportion to the size of the farm, continuous-flow methods of delivery are preferable. An extreme condition of this character is found in some parts of the foothill regions in California where streams as small as 3 or 4 miner's inches are delivered to small irrigated farms. Furrow methods of irrigation are used. By adjusting the number of furrows in use at any time to the size of the stream received, good efficiency in application can be obtained. Continuous-flow delivery is also adapted to truck and small fruit crops which during certain seasons of their growth require water at very short intervals and for which only small heads can be used. Where the conditions are such that irrigation heads relatively large in proportion to the size of the farm can be used, either of the other methods of delivery is preferable.

The operation of the canals under continuous-flow delivery is usually easier than for either rotation or demand delivery. There is less fluctuation in use. By maintaining the water surface at proper heights above the outlets so that the requisite quantities will be delivered at each farm, little canal regulation may be required. At the beginning and end of the season, when the use of water is more irregular, regulation of both the canals and turnouts will be required as the demand varies. Such a system of delivery is particularly suited to canals having good water rights to direct flow in the stream and where the water is available when its use is desired. If the canals are short or are provided with adequate wasteway facilities, so that water not used can be readily disposed of, the continuous-flow method of delivery permits a more simple system of operation than either of the other methods. Continuous-flow delivery is used on the majority of canal systems in Wyoming, Montana and western Colorado and to a large extent in other mountain States.

ROTATION DELIVERY

There are many variations in rotation methods of delivery, but the main purpose in all cases is the same. This purpose is the delivery of relatively large irrigation heads for relatively short periods of time. In practice it varies from the delivery to any farm for from one-thirtieth to one-half of the total time. It may be handled on a fixed schedule arranged in advance of the season and strictly adhered to, or it may consist merely of informal trading of water arranged between individual users at different times during the season. This latter practice often occurs on systems which are operated on general continuous-flow methods.

The advantages to the farmer of the rotation method are the reduction in labor cost of applying water to the land, and the smaller amounts of water required to cover the land when large irrigation heads are used. This, of course, implies that the conditions are such that relatively large heads can be handled on the land; the use of larger irrigation heads than can be effectively handled results in an excess amount of surface waste. If crop or topographic conditions limit the size of irrigation head which can be used to a size which requires its use for a large proportion of the season to irrigate the average size of farm, the advantages of rotation delivery are largely lost.

Rotation Schedules.—The rotation period varies with different systems. From an operation standpoint, the greatest advantages are secured when the period between deliveries to each farm is made relatively long. The period can be made the longest on those systems where the irrigated area consists largely of one crop which requires water at fairly regular but not frequent intervals. This condition is found for orchards in southern California where irrigations at intervals of 30 days are usual, with some as long as 45 or even 60 days. Water rights there are often expressed in terms of the continuous flow of a certain fraction of a miner's inch per acre. This is allowed to accumulate until water can be taken for from 1 to 3 days at a rate which will give the desired size of irrigation head. One owning 10 acres might receive 60 miner's inches for 1 day per month or 30 miner's inches for 2 days per month.

The same conditions of fairly regular and relatively infrequent irrigations are found for the deeper-rooted forage crops, particularly alfalfa, where the soil conditions are such that moisture is retained within reach of the plant roots. This condition exists in many parts of the San Joaquin and Sacramento Valleys in California where alfalfa is the predominating crop, comprising from 60 to 75 per cent. of the irrigated area under several systems. The topographic conditions are such that irrigation heads of from 10 to even 20 second-feet may be handled. Rotation schedules on such systems are based on the alfalfa, water being delivered for from 20 minutes to 1 hour per acre irrigated at each run, the time varying with the size of irrigation head delivered, so as to give an average depth per irrigation of from 6 to 8 inches. The time between irrigations varies with the soil types; for medium types of soil or for light soil on which ground water is retained within reach of the roots, periods as long as 30 days may be used. Where the soil is light without any impervious layer or ground water near the surface, or for very heavy soils into which only small amounts of water can be made to enter at each irrigation, periods between irrigations as short as 12 to 14 days may be needed. On the Salt River project in Arizona, where the proportion of alfalfa is somewhat less, the area in cereals and cotton being relatively larger, the usual schedule provides deliveries at periods of 8 days, continuing for from 24 to 48 hours for each 160 acres, a 10-second-foot head being used. Where alfalfa predominates, the remaining crops may be irrigated with separate smaller heads. These may be run independently of the alfalfa heads; some additional water may be run at the same time as the alfalfa head and delivered to such other crops on farms adjacent to those irrigating alfalfa; or, at certain times, such as Saturday of each week, the alfalfa heads may be divided and small heads delivered to all farms for the miscellaneous crops. Such other crops usually consist of orchards, vines and gardens irrigated by furrows where irrigation heads larger than from 2 to 5 second-feet cannnot be handled. Where the other crops consist more largely of cereals, more frequent deliveries with relatively large irrigation heads for sufficient time to irrigate only a portion of each farm are more usual.

In the Rocky Mountain States the crops on any farm are usually more diversified and each farm requires water at more frequent intervals. Also, the farms are larger and the topographic conditions are frequently such as to prevent the use of large irrigation heads. These conditions make it necessary that water be delivered to each farm for about one-half the time and that the period between deliveries be relatively short. This may be accomplished by the delivery for half the time of irrigation heads about twice as large as the average rate of use. The periods of delivery usually vary from 4 days on and 4 days off to delivery on alternate weeks. Where much grain is raised, the farmers may prefer the shorter periods, particularly for the part of the season in which grain is irrigated. The delivery on alternate weeks is used on a considerable number of projects. The shorter period may be desirable in the earlier years of a system, the time being lengthened as the lands become better prepared and the farming practice better planned and organized. The rotation used may be varied on different parts of the same system. On the Tieton project in Washington, a rotation schedule based on the delivery of 1 second-foot to each 40 acres for 7 days out of each 21 is used on the less steep lands where larger heads can be handled. On the steeper and more shallow lands, a schedule based on 1 second-foot to 60 acres for 7 days out of each 14 is used, more frequent and lighter irrigations being needed. All land under this system has relatively steep slopes, so that only small irrigation heads can be used. On the Bear River canal in Utah, water is delivered to all users 1 hour per week for each acre, the irrigation heads being about 2 second-feet. A fixed schedule is used, being adjusted each year so as to equalize night and Sunday use. On the Flathead project of the U. S. Reclamation Service 7-day periods are used. On the North Platte and Huntley projects, 4-day periods have been found to be satisfactory.

Rotation Between Laterals.—The rotation method may be arranged to rotate the delivery among farms on the laterals, or it may be arranged to rotate the flow between different laterals. For the first case, sufficient area to use a rotation head continuously may be arranged on a lateral and the water rotated between the farms in the area. Such a method gives continuous flow in the laterals. For the second case, a sufficient number of irrigation heads may be turned into a lateral to completely irrigate the lands under it in perhaps one-half the time of the rotation period. These irrigation heads would then be turned into other laterals, each lateral being dry for part of the time. This gives a rotation in flow between laterals, as well as between farms, and is sometimes known as the periodic method of delivery. This second method has both advantages and disadvantages. It has the disadvantages that laterals of larger capacity are required; the life of wooden structures may be reduced, due to alternate drying and wetting; it is inconvenient where laterals are depended upon for stock water, although a small stock stream may be run continuously; the liability of breaks, particularly those resulting from burrowing animals, is greater than where water is maintained continuously in the lateral; and there is danger of erosion and bank slipping, if laterals of much size are rapidly filled or emptied. The rotation between laterals has the advantage that the area from which canal seepage occurs is reduced; where aquatic growths occur, the drying between periods of use tends to kill such plants, and delivery can be more conveniently handled, as those laterals not in use do not need to be patrolled and the area handled per ditch rider may be greater. The disadvantages mentioned will usually make it preferable to operate continuously all laterals having a capacity of over 40 second-feet, and on systems delivering relatively small irrigation heads laterals smaller than this would be used continuously.

Delivery Up or Down Laterals.—When water is delivered from any lateral under rotation methods, the head may be run through to the lower end of the lateral, and delivery made in order up the ditch, or delivery may be begun at the upper end and carried through in order down the lateral. Both methods are used on different systems.

Delivery down the lateral is usually preferable where all changes are made by the ditch rider. Such conditions occur where deliveries are not made for less than 24-hour periods and where water is turned both on and off by the riders. This is usual only where relatively small irrigation heads are used or where the farms are relatively large. It also has the advantage that those past whose turnouts the water is being carried have received their supply and there is less temptation for them to take water out of turn. On closely handled systems, taking water out of turn should not occur under either method. In rotating down a lateral it is also more convenient to serve any turnouts which for any reason have been missed in the regular turns. Turnouts to which delivery has been made can be locked and those further down on the lateral left unlocked. Each man can then take whatever water reaches his headgate.

If delivery is made in rotation up the lateral, the ditch rider can supervise the filling of the lateral and the proper setting of all checks. The closing of turnouts and taking of water by those next in turn can then be largely handled by the users themselves if only one irrigation head is run in the lateral. The handling of turnouts by the users is of particular advantage where large heads are used and delivery to each farm may be made for only a few hours. Permitting such changes removes the necessity for night riding of the laterals. No one should be permitted to turn water back, however, at any time, without arranging for it to be taken by someone else.

If a break occurs on the lateral while rotating up, delivery can be made to some farm above the break without having to turn the water back into the main lateral. In rotating down the lateral, all farms above will have been irrigated and such water would be wasted, even if turned out to upper farms. In rotating up a lateral, no time need be lost between turns; the ditch is filled before delivery begins. In rotating down the lateral, there will be some time lost, which if allowed for makes the times irregular and if not allowed for may be an item for dissatisfaction when turnouts are some distance apart. When the lands are only partly in use, as in the first few years of operation of projects, and the turnouts may be some distance apart, rotating up the lateral may cause more waste if water is not taken for any reason after it has been run down the lateral.

In general, rotation down the lateral is preferable where the periods of delivery are multiples of 24 hours or where the laterals are relatively small and easily regulated. Rotation up the lateral is preferable where the time of delivery to each turnout is short and where breaks in the lateral are liable to occur.

Fixed and Flexible Rotation Schedules.—The rotation schedules may be fixed in advance of the irrigation season and strictly adhered to, or the deliveries may be made in what amounts to rotation on demand or in the order of notice given by the user.

With fixed rotation schedules, each owner can be notified of the days during the season on which water will be available for his use. Such methods are better suited to crops such as orchards or those where irrigation is not definitely required within any short period of growth. For crops, such as grain, which may require water within relatively short periods of time at certain stages of their growth, the actual time when needed varying with the climatic conditions in each year, prearranged rotation schedules are not suited unless the period between deliveries is made quite short. Where the conditions permit their use, a fixed, prearranged schedule of delivery enables both the operation to be more efficiently planned and the farm work to be arranged to better advantage. Fixed schedules should not be adhered to so closely but that variations can be made for unusual conditions. If any user does not take the water when offered during any run, it is usual to have the right to demand water at that run lost. The following rule of the Turlock irrigation district is typical of usual practice:

"The irrigator who fails to use his allotment of water during an irrigation will not be entitled to any more water at any future irrigation than if he had used his full share at the time of allotment."

Individual exchanges of turn are usually permitted where the operation is not interfered with or other irrigators injured. The responsibility of satisfying the one giving up his turn is placed on the one securing the benefit, exchanges of turn being arranged by the irrigators. When interruptions occur in the schedule, it is customary to advance the schedule for the period of delay.

Delivery During Shortage.—Rotation schedules may be arranged for periods when water is plentiful, so as to allow ample quantities of water to each user. When the water supply becomes less, the schedule may be modified, either by reducing the irrigation head, the time of each delivery or the frequency of delivery. It is usually preferable to reduce the time of each delivery. The reduction of the size of irrigation head will generally reduce the efficiency of its use. The reduction of the time water is delivered per acre may reduce the area which can be irrigated at each turn. All laterals may be operated continuously during periods of ample supply, with rotation between laterals used at times of low flow.

On the Sunnyside project in 1915, a shortage of water was met by shutting water out of each one-ninth of the project for 2 days in turn, which was later changed to shutting water out of each one-sixth of the project for 3 days in turn. As the shortage increased, the supply in the river was rotated with other canals, the water secured by the Sunnyside project being rotated between the two parts of the system in turn for half of each period, deliveries being made only to fruit, vegetables and young seeding in bad shape and denying water to old alfalfa land or lands without crop.

DELIVERY ON DEMAND

Under this method the user has a right to a certain rate of flow or to a total seasonal amount in acre-feet which can be taken on demand, subject to such regulations as may be necessary in the operation of the system. These necessary regulations are usually such that the actual deliveries may be more largely an informal rotation method, rather than strictly a delivery on demand. Any approach to actually delivering on demand requires large canal capacities in proportion to the area served, as well as a water supply available for use at fluctuating rates.

Delivery on demand is the simplest method from the standpoint of the user. It requires less judgment on the part of the irrigator in forecasting the water needs of his crops. Its use is quite general for the earlier years of the operation of a system when both the canal capacity and water supply are in excess of the requirements of the small proportion of the irrigated area served in the first years. Where the capacity of the canals is properly proportioned to the area served, actual delivery on demand during times of maximum use is impractical if irrigation heads larger than the rights to continuous flow are used. For such conditions some restrictions on the demands must be used. This is done by requiring requests for delivery to be made a certain time in advance of the desired use. Three days' notice is required on many systems, only 1 day on others and longer times on a few systems. When delivery can be made in less time than the period of notice, it is usually done. When the demands exceed the supply, the period until delivery is actually made may exceed the period of notice, delivery being made as rapidly as possible in the order in which the requests were received. As the irrigation heads delivered are usually similar in size to those used under rotation methods, this amounts to an irregular rotation method of delivery.

The rule governing delivery of Imperial Water Co. No. 1, has been:

> "All applications for water must be in writing on blanks furnished by the company and must be delivered at least 3 days before the water is needed. Efforts will be made to make delivery in less than 3 days and where possible, delivery will be made within 24 hours."

Delivery on demand is used by the Santa Ana Valley Irrigation Co. during the winter and spring season when the supply is large in proportion to the use, rotation being used during the summer. The Bitter Root Valley Irrigation Co. in Montana delivers on demand with a limitation that the use in any 1 month shall not exceed 6 inches depth on the land. The North Poudre canal in Colorado uses delivery on demand. As their supply is secured largely from storage near to the lands irrigated, the available supply is known relatively closely in advance and can be prorated to the land, to be taken on demand.

It is an advantage to the user to be able to secure water when desired. Greater flexibility in planning other farm operations is possible if the time of irrigation can be adjusted to other farm work and to the needs of the different crops. Where the water supply is ample, the question involved may be to decide how far the canal system is justified in increasing the capacity of the canals, so as to be able to more nearly deliver on demand with its resulting high peak load in comparison with the saving in construction cost of smaller canals and the resulting necessary restrictions on use. The conditions of water supply determine canal capacities in many cases; where the water supply is secured through storage, the question of the maximum rate at which delivery shall be made is one of maximum canal capacity. Where water is secured through direct diversion, the maximum rate of diversion may be limited by the character of the stream flow or of the water right. Actual delivery on demand without restrictions is possible only for short canals delivering from streams of ample flow or from reservoirs. For long canals or usual conditions of water supply, a compromise between the desire to deliver the peak demand and the resulting higher cost of the system is usual. Delivery on demand for long canals makes desirable ample wasteway facilities, in order to dispose of water not taken for use.

Different means of restricting the maximum rate of use may be used. The delivery in order of request is one of these methods. Water rights may be based on the delivery of a certain number of acre-feet per acre during the season with a restriction on the amount which can be taken during any 1 month. The land may be entitled to water at a certain continuous rate of flow per acre, such as $1/80$ second-foot. This defines the maximum demand that can be made on the system. In practice, except for large farms, the water to which two or more farms are entitled may be combined and rotated among the farms; if such rotation does not follow any regular schedule, it may be practically a delivery on demand, but is limited by the maximum rate of use restrictions.

From the point of view of the canal system, the delivery-on-demand method is suited to systems serving crops such as orchards, where the demand is more uniformly distributed throughout the season. This is the case for some southern California systems, the method being, in practice, a rotation in the order of demand rather than rotation by a fixed schedule. The method is also suited to systems where the canal capacity is large in proportion to the area actually irrigated. This occurs in the first year's operation of all systems. It also occurs where the available supplies are stored in the vicinity of the land and the storage can be drawn on as desired. The same condition favorable to delivery on demand may exist for canals diverting from streams of plentiful water supply and provided with ample wasteway facilities. This is the case of the "Big" Ditch in Montana where the system used is a mixture of continuous flow and demand, each user being limited to his right to continuous flow in times of heavy use but being generally able to secure larger heads at other times. In practice, delivery on demand is more often an element in the use of either of the other methods. rather than a complete method in itself.

SPECIAL METHODS

There may be special forms of delivery which do not fall into any of the three methods discussed. In a few exceptional cases, the seepage from the canals may raise the ground water sufficiently high so that surface application is not needed. Where the height of the water table can be controlled, this form of subirrigation has many advantages. Delivery may consist in supplying sufficient amounts to the canals or areas used for seepage, to maintain the water table. Delivery in such cases is usually continuous. Such conditions are favorable only in porous soils free from alkali; there are areas of this character in parts of the delta region of California and in special areas in other States. The subirrigation of one portion of a system is usually accompanied by the water-logging of lower lands.

In a few systems delivery is made under pressure pipe lines, somewhat similar to water-works practice. These have been used for small areas in orchards, mainly in the coast States. Delivery is under more complete control and a greater choice of methods is possible.

MEASUREMENT OF DELIVERY

The questions involved in the desirability of measuring water delivered to individual farms are not necessarily different for the different methods of delivery. Measurement is probably less usual in systems operating under continuous-flow delivery. Some form of measurement is needed, however, to equitably divide the water among the different users, although records of the total amount used per season may not be kept. Measurements of rate of flow may be more useful than measurements of total quantity received. With rotation delivery, the rotation head used on several farms may be measured at one place on the lateral if only one irrigation head is run on the lateral and the record completed by recording the length of time the head is used on each farm. If the charges are to be based on the quantity used, measurements at the farm delivery box are preferable. With the more irregular delivery on demand, measurements of rate of flow and records of time used on each farm are needed. The use of both a uniform schedule of time per acre and size of irrigation head will give a similar quantity per acre so that a quantity rate for water approaches a uniform rate per acre.

FORMS USED FOR THE DELIVERY OF WATER

Nearly all canal systems find it desirable to use printed forms for obtaining the records of delivery of water. Some of such

Loe Molinoe, Cal.,________________191___

CONELAND WATER CO.,
Loe Molinos, California

Gentlemen: On the_________day of______________191 _____

I deeire the water turned on for my use on Lot ______Blk______

in Subdivieion No. __________________

(Sign Here)___________________________________

Notice to Water Users

This application cerd must be mailad or presented in the Company's office three days before the date the water is to be used.

CONELANO WATER COMPANY

FIG. 5.—Form for application for water delivery used by Coneland Water Co.

forms are combined with the records of measurement where records of the quantity delivered are obtained; these combined forms are discussed in Chapter V. Some systems use two forms, however, which relate only to the delivery of water. These are the forms for applications for water delivery and for notices to consumers regarding the time when delivery will be made.

Forms of Application for Water Delivery.—Blanks giving all the data needed in such applications requesting water delivery

$\$$__________ ____________________________

Riverside Water Company

Deliver to ____

At ____

____ *inches per day*

Commencing ____________________, *190* __, *for* __________ *days*

By ____

Above Water Ordered subject to the Rules of the Company.

FIG. 6.—Form for application for water delivery used by Riverside Water Co.

FACE OF CARD

NAME OF WATER USER	Acres in Cultivation	Second Feet Requested
Total . . .		

Remarks: ____

BACK OF CARD

7—307b
January, 1914

DEPARTMENT OF THE INTERIOR

UNITED STATES RECLAMATION SERVICE

WATER REQUEST

________________________ 191____

U. S. Reclamation Service:

I hereby request delivery of water at the rate of ________________ second-feet for ____________ days beginning ________________________ 191___ from turnout No. ________________ for ________________________ lateral to irrigate the lands indicated on the reverse side hereof

____

Community Water Master or Canal rider

To Community Water Master or Canal Rider.—In requesting water service give at least 2 days advance notice of your needs, using one of these cards for each run of water desired or any change desired during a run. State any requests for water for other purpose than irrigation. If practicable, report any waste of water or use of an excessive quantity in irrigation.

FIG. 7.—Form for application for delivery of water to laterals of U. S. Reclamation Service.

can be printed on cards the size of a postal. The water company's address can be printed on the reverse side and the cards distributed among the users. Such cards are also a convenient size for posting in the boxes sometimes attached to headgates. Where telephone requests are accepted a stamp indicating that a request has been received in this manner can be used, the form being filled out in the office when received. The forms used by the Coneland Water Co. and the Riverside Water Co. in

Turlock Irrigation District

APPLICATION FOR WATER FOR SEASON 1916

ROTATION NO.

Owner. Mr.______________________________

(Filled in by Ditch Tender)

Private Ditch______________________________

Drop ______________Dist Lat. No.______________

CROPS IRRIGATED

ALFALFA	BEANS	BERRIES	CORN	GARDEN	GRAIN	NEW LAND	MELONS	NURSERY	SWEET POTATOES	TREES	VINES

____

____

Location of Land______________________________

_______Sec.______T.______S., R.______E.________

____

(Irrigator Sign Here)

______________________________Ditch Tender

Put remarks on other side

FIG. 8.—Form for seasonal application for water used by Turlock irrigation district.

California, Figs. 5 and 6, are typical of requests for individual deliveries. The form of the U. S. Reclamation Service, Fig. 7, is useful for delivery to community laterals.

On some systems consumers are required to make an application for water at the beginning of each season. This is done in some cases to secure the areas to be irrigated which are used in planning rotation schedules. The applications on some systems, such as commercial companies, are combined with an agreement to pay the charges for the season, such applications being required before the consumer becomes eligible to receive service. Forms of the first class are illustrated by that of the Turlock irrigation district, Fig. 8.

In some cases the consumers are required to sign receipts for each delivery of water. This will remove grounds for later controversy as to the time of deliveries. Although the consumer's receipt has little meaning in regard to the rate of flow, as he is not usually experienced in measurement, such receipts are useful in

Turlock Irrigation District

WATER RECEIPT FOR SEASON 1916

ROTATION NO.

Owner. Mr.________________________

(Filled in by Ditch Tender)

Private Ditch ________________________

Drop____________Dist Lat. No.____________

	HOUR	DAY	MONTH
Water Turned On			
Water Turned Off			
Water Refused			

CROPS IRRIGATED

ALFALFA	BEANS	BERRIES	CORN	GARDEN	GRAIN	NEW LAND	MELONS	NURSERY	SWEET POTATOES	TREES	VINES

Sec. Ft.______ Total Hours_________Acre Feet_______

(Irrigator Sign Here)

____________________Ditch Tender

Put remarks on other side

Fig. 9.—Form for receipt for water delivery used by Turlock irrigation district.

regular rotation schedules when those not taking water for any cause may be required to sign a refusal form showing the failure to take water to be from their own choice. The form of the Turlock irrigation district, Fig. 9, is bound in triplicate in small books, each sheet having a different color. These are filled in by the ditch rider and signed by the user, one copy each going to the user, the office and the rider. Blanks with receipt stubs where water is delivered on demand on a quantity basis are illustrated by those of the Yolo County Consolidated Water Co. in California, Fig. 10.

Forms for Notices to Consumers Regarding Delivery.—For fixed schedules under rotation delivery a notice is frequently sent to the users stating the time at which water will be delivered.

DELIVERED TO..........
feet of water from.....o'clock...M.
191.....to.....M.
191.....making....hrs.
Amount,$.........
No. 500
Agent.
Name..........
Amount,$.........

No. 500 ....WOODLAND, CAL..............191....
Received of Yolo County Consolidated Water Company
From the........Ditch....feet of Water, from... o'clock... M.......
.......191.....to.....o'clock.....M..............191.....making.....hours,
for which I promise to pay the sum of $.......with interest from.......
...191...at the rate of one per cent per month at Woodland, California
Received Payment..........................
Yolo County Consolidated Water Co.
By..........................

Fig. 10.—Form for water receipt used by Yolo County Water Co.

This may be done at the beginning of the season or for each delivery during the season. In some cases a reply will be made to the application for water under the delivery-on-demand system,

BACK OF CARD

DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
WATER NOTICE

....191.......

Dear Sir:
Delivery of water to turnout ....from the....................lateral
or canal will be according to the following schedule:

From:	To:	Second-feet or Miner's inches
....	....	....
....	....	....
....	....	....

The above schedule supersedes that of any previous notice.

Water User's Farm Unit or Holding	
..............Sec..........T..........R..........	
..............Sec..........T..........R..........	....
..............Sec..........T..........R..........	Canal Superintendent or Rider.
..............Sec..........T..........R..........	

Fig. 11.—Form for notice of delivery of water used by U. S. Reclamation Service.

stating the time water will be furnished. Post-card forms can be used for this purpose. That of the U. S. Reclamation Service (Fig. 11) is typical.

Monthly notices may also be sent to the users giving the water used for the previous month or to date for the season. This is done on those systems requiring monthly payments. It is also frequently done on those systems supplying water under an agreement as to the number of acre-feet per acre which will be supplied. For such cases the notice enables the user to determine the amount of water used and that to which he is entitled during the remainder of the season. Fig. 12 shows a form used under the gravity unit of the Minidoka project.

DEPARTMENT OF THE INTERIOR

U.S. RECLAMATION SERVICE

Dear Sir

Our records show that your assessed area is ________________ *acres*

A charge will be made for water delivered to above land in excess of 1 acre-foot per acre assessed or ________________ *acre-ft.*

Amount delivered to date, ________________ *acre-ft.*

Balance available, ________________ *acre-ft.*

Excess delivered to date, ________________ *acre-ft.*

Charge for excess water delivered to date at 5c. per acre ft., $ ________________

Remarks: ________________

Farm Unit, ______ *Sec.* ______, *T.* ______, *R.*

Farm Unit, ______ *Sec.* ______, *T.* ______, *R.*

Project Manager

FIG. 12.—Form for monthly notice of water account used in 1915 on gravity unit, Minidoka project.

SUMMARY OF DELIVERY METHODS

There is a marked tendency toward the adoption of some form of rotation delivery. Its advantages for small farms or topographic conditions permitting the use of large irrigating heads have always been recognized. The use of the method is now being extended for those conditions where short periods and relatively small irrigation heads must be used. With the larger water supplies usually available in the earlier systems, the use of the continuous-flow method was natural. As water is becoming more valuable, the expense of securing more economical use through more rigid operation methods is becoming warranted. The average size of irrigated farms is also decreasing and land is being prepared for the use of larger irrigation heads. The difficulty of securing good farm irrigators and the higher price of farm labor are making it necessary to secure methods of applying water to the land which are more efficient from the labor view-point. For these changed conditions, the rotation method of delivery is well suited.

The period of change from one method of delivery to another is always a trying one. The irrigators have become accustomed to the former practice, the farm ditches if built for continuous flow have to be enlarged and the method of preparing land may often need to be changed. This involves considerable expense to the farmer, unless the change is made gradually as the crops in each field are changed. Where forage crops left for several years from each seeding are used, it may take several years before such changes can be economically completed on the farm. It is the expense of such changes, unless made gradually, which forms the grounds for most of the opposition to changes in methods.

During this period of change a mixed method of delivery may be needed, giving varying sizes of irrigation heads to different users, depending on their ability to handle water. If the most desirable size of irrigation head can be determined in advance of the preparation of the lands and the practice developed in accordance with the use of such heads, much later trouble and expense may be saved. To attempt to force changes in farm practice from the outside may, and sometimes has, resulted in developing an active opposition to the change which has retarded the adoption of improved methods beyond the time when natural conditions, if left undisturbed, would have caused the users to adopt them of their own accord. If the change from continuous flow to rotation is made after the project is completely developed, it may be difficult to give satisfactory service under the mixed practice required during the period of change. If the change can be made while the lands are only partly developed, the excess canal capacity will be of much assistance during the period of change.

CONTROL OF LATERALS

Whether the main canal organization should control delivery to each individual farm or only to the groups of farms under each lateral, as a whole, is a subject on which there has been much debate. The two general methods represent retailing and wholesaling of water; in the latter case the lateral organization acts as the middleman. As in other types of business some conditions are favorable to each method.

It is now generally conceded that it is preferable to have the laterals constructed by the same organization which builds the main canals. This is particularly true on new systems where the settlers are secured gradually, as otherwise the burden of lateral construction on the first settlers would be excessive. It is also recognized that new settlers require all of their resources in preparing their lands for irrigation without giving time to outside construction. Construction within a given distance of each farm is also the only basis on which the total cost is made uniform as the cost of lateral construction will vary with the topographic conditions in different parts of the system.

The operation of laterals by some form of coöperative association is an outgrowth of the earlier and smaller system both built and operated by such organizations. On the larger systems the personal acquaintance and unity of purpose which made such smaller systems successful is more difficult to secure. The coöperative lateral associations are most successful where the conditions are similar to those of the earlier developments, such as those cases where all the lands are settled at the time of construction, where the owners are bound together by other forces such as necessity, race or religion, or are accustomed to coöperation in other lines. It is not successful where the settlers are secured from scattered sources and have little or no irrigation experience.

The principal weakness of such lateral associations is the lack of a definite organization. It is necessary to have such organizations both to deal with the main canal organization and to compel compliance with the lateral regulations. Where the area covered by a lateral is too small to require the continuous time of a ditch rider, there is liable to be little direction in the distribution of water. This may result in the lower owners having to act as unofficial ditch riders in order to get water through to their lands. This causes loss of time on their part and more or less continual friction between the users, unless the lateral capacity and water supply are in excess of their needs. On larger laterals the organization may be similar to a mutual or stock company which is incorporated and with more definite regulations and methods of assessment.

The lateral association may have trouble with both operation and maintenance. Those located near the upper end may object to doing their full share of the maintenance. Those at the lower end can secure water only when the whole lateral is in condition for operation, and it sometimes happens that such owners have to do more than their proportion of such work. This has been partially remedied in some States by the enactment of laws by which one owner on a lateral can, on the failure of the others to do their part, do the work and collect the cost from the others. Maintenance of canals is more easily secured than maintenance of structures, as canal cleaning can be done by the owners without cash outlay; structure materials require cash assessments. The enforcement by the main-canal organization of a rule that no water will be delivered to any lateral until it is in condition for delivering to all owners will also assist in procuring proper maintenance.

The desirability of such lateral associations from the point of view of the main-canal operator depends on the method of charging for water, the extent of responsibility of the main-canal system for individual delivery and the size of the lateral. The detail records are materially reduced where the main-canal system delivers to a lateral as a unit without records or collection from the individuals. Where rotation delivery is used, the area under the laterals may be large enough to use a given number of delivery heads continuously, giving continuous delivery to the lateral and simplifying the main-canal operation. Delivery on demand is more difficult to adjust. If water is paid for on an acre-foot basis, unless sold at wholesale to the lateral, it is essential that the delivery to each farm be under the control of the main-canal organization. Where the operation charges are on a flat acreage basis, this is not necessary. On some systems there is a preference for the employment of ditch riders who do not have any land or other direct interests under their beats. This can be more easily secured where the main canal controls the complete delivery as the officers of the lateral associations are more usually those securing water from the lateral.

On systems where it is contemplated that the canal system will be turned over to the land owners on the completion of the payments for construction cost it has been argued in some cases that by first turning the laterals over to the users under them, they would gain experience which will later enable them to handle the entire system more efficiently. On a few of the systems of the U. S. Reclamation Service such attempts have been made but the land owners have not generally cared to undertake such partial control. This method might be desirable if it is intended that each land owner shall share in the operation of the whole system. On large systems this is not desirable, as the operation should be turned over to elected officials who are given full responsibility and power. The individual water user should qualify himself to judge of the efficiency and economy of the results secured but to participate only through elected or selected officers.

Examples of Practice.—On the gravity unit of the Minidoka project the laterals were built and operated by lateral associations. The results were not satisfactory and practically all of the laterals were taken over and operated by the Reclamation Service. On the pumping unit of the same project all laterals were built and are operated by the Reclamation Service. At the time of construction the Modesto and Turlock irrigation districts did not build the laterals. At present a large part of these laterals have been taken over by the district organizations in order to be able to give better service. On the adjacent South San Joaquin district, built after these districts had been in operation for some years, laterals were built by the district to deliver water to each 40 acres. A number of cases have come before the California Railroad Commission in which land owners under laterals have desired to have the main-canal system take over the operation and maintenance of the laterals. Where the lateral is not owned by the main-canal system the Commission has held that it has no authority to compel them to operate it, although in some cases, such as those under the Fresno Canal and Irrigation Co.'s system, the canal company had reserved the right to take over the laterals at their own option. The Commission has, however, approved agreements whereby by the payment of a rate in excess of that allowed for delivery to the lateral only, the main-canal system has consented to take over the laterals. Such additional rates are based on the estimated cost of the additional duties placed on the main-canal system.

In decision No. 1265 of the California Railroad Commission, involving the Soledad Land and Water Co., it is stated:

"Experience has shown that it is to the interest of both the consumer and the company that the operation and maintenance of all the distributaries to the point of delivery of water to individual consumers shall be conducted by the company. Where the company controls and operates the ditches and laterals under uniform rules, fair and equitable distribution of the water is possible and the system can be maintained in good order and repair. On the other hand, where consumers are compelled to care for the ditches and laterals serious evils result. Where several consumers are located on a lateral and they do not require water at the same time, a man who first needs water is compelled to clear and clean the lateral or ditch from the plant to his land at his own expense. Thereafter, the other consumers on this ditch or lateral can, with slight expense to themselves, take advantage of their neighbor's expenditure. Controversy will also arise over distribution of the water. All these difficulties can be obviated only by organization of the consumers, which is difficult and often comparatively expensive and unsatisfactory in operation."

The method used under the Amity canal in Colorado is typical of that of many of the older companies. The laterals are run along ridges and serve distinct areas averaging over 2,000 acres each. The Amity canal constructed the laterals and turned them over to the lateral company as soon as there were three users under the lateral, the title being retained by the Amity canal. The lateral company cannot sell or dispose of the lateral, but is responsible for its maintenance and operation. Stock in the lateral was issued to the water-right holders and was appurtenant to certain described land, the stock for any unsold water rights being retained by the Amity canal.

These somewhat conflicting instances serve to show that practice is not uniform in regard to such lateral associations. In general it can be said that they are not desirable unless the lateral association has a definite organization and that such organizations are economical only where the area under the lateral is relatively large. They do not reduce the total cost of service to the individual but divide it into two parts whose total more frequently exceeds the cost of complete service by one organization.

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CHAPTER V

MEASUREMENT OF IRRIGATION WATER

Hydrographic measurements in connection with the operation of irrigation systems have received much attention in the last few years. On many systems similar arguments are being made in regard to the desirability or need of measuring the quantities of water delivered to individual consumers which have been made on municipal water-supply systems. The same obstacle as to the cost of such measurement or metering is encountered with the additional difficulty for irrigation systems that, even if the desirability is admitted and the funds available for installation, many questions still remain to be solved regarding the type of measuring device to be used and the accuracy of the results which will be secured. In water-works practice a large amount of experience with meters is available from which the results of metering any system can be largely determined in advance; with irrigation practice the conditions on different systems vary more widely and the experience of others cannot be as directly applied.

Irrigation hydrography, or hydrometry as it is sometimes and perhaps more correctly called, can be divided into two main divisions. Certain measurements of the flow in the canals are needed in the operation of the system. These are required by the operating organization for its own use in order to handle the division of water between laterals, etc., and do not directly concern the charges to consumers individually. The second division consists of the measurement of the water delivered to individual consumers. Many canal systems carry out more or less general hydrography without making measurements of individual deliveries. Many bulletins and books are available covering the measurement of water both generally and specifically for different conditions, references to a number of which are given at the end of the chapter. Applications to irrigation practice are discussed in this chapter, avoiding as much as possible general methods or principles, a knowledge of which is assumed.

The use of measurement of both of the above types is increasing. This is the natural result of the increasing value of water. It is only when the value of water saved warrants the cost of closer control of delivery, including measurement, or where the actual damage from overuse, such as from water-logging occurs, that measurement of individual deliveries has been generally adopted. As these conditions are becoming felt on an increasing proportion of irrigation systems, the use of measured delivery is naturally increasing. Efforts to introduce such measured delivery where conditions do not make it actually of definite or immediate advantage to the users have generally been unsuccessful.

Where the services of hydrographers are available it is generally found that they can be used to advantage on more or less special work such as checking measuring devices, special gagings in cases of disputes, canal-seepage tests and observations in connection with drainage such as water-table fluctuations. While at present separate hydrographers are not employed on the majority of systems their use is increasing. In the first years of operation the smaller area irrigated can be supplied without the need of close control of the flow in the canals. In later years the problems of the division of water are more complex and the need for hydrographic work is greater. On systems of over 50,000 acres a hydrographer can be used to advantage if the water supply is limited. On smaller systems part time of an instrumentman may be sufficient to handle the necessary gagings.

Hydrographic work on irrigation systems requires an understanding of hydraulic principles. This should include not only a knowledge of the conditions necessary to insure accuracy in the use of different methods of measurement, but also an appreciation of the effects of variations from such conditions. It is often necessary to use devices under unfavorable conditions of velocity of approach or submergence and an understanding of how far such conditions can be permitted to go before corrections are needed or before the certainty of the entire measurement is materially affected is as essential as a knowledge of the theoretical conditions desired. Hydrographic positions offer an excellent opportunity to obtain operation and maintenance experience as one is brought into contact with all branches of the work. The salaries paid usually vary from $75 to $100 per month for inexperienced men to as high as $125 to $150 per month for experienced men in charge of such work on large systems. Hydrographers may be employed only during the summer season or used on the other work during the winter. On large systems a portion of the hydrographic organization may be used on computations throughout the year.

CANAL HYDROGRAPHY

The use of rating stations on canals varies from no measurements to careful ratings of diversions from the stream and subdivisions between laterals. It is usual to maintain a rating station at the head of the diversion canal. On many streams such stations are required by law for use in connection with the administration of adjudicated water rights. Where the purpose of such a station is merely to satisfy such legal requirements, neither the location or equipment of the rating station are usually as carefully selected or maintained as for stations the results of which are directly used in the operation of the canal system. Rating stations are needed to control the division of water to main laterals within the system. The extent to which such stations are used on the smaller laterals depends on local conditions. If the available supply is to be divided to the different laterals closely in proportion to the requirements of contracts or the acreage served, such measurements will be needed. Where the form of lateral headgate is such that it can be used as a more or less satisfactory measuring or dividing device, a division on such basis is usual. Some systems maintain rating stations at the heads of laterals although this is restricted to the larger laterals in most cases.

The use of measuring devices requiring a free fall for measurement is generally limited by practical considerations to quantities of 100 second-feet or less. Approximate measurements may be secured for larger quantities by headgates or check gates used as orifices, but the number of openings in use or uncertainty as to the correct value of the coefficient renders such results uncertain. Some form of drops such as the notch type may be used for measurement of larger quantities. Weirs for larger flows require conditions not usually obtainable on canals. With large checks or drops the uncertainty as to the proper formula or coefficients makes it practically necessary to rate each such structure in use, the structure serving as a control for the rating rather than as a measuring device itself. For fixed structures such as notch drops, the rating should be permanent; for checks the variations in opening may affect the velocity of approach conditions and consequently the rating.

Records are also kept of the waste from the canals in their regulation. Such waste may occur at spillways placed just below the headgate and used to regulate the amount diverted. For such cases the main rating station may be placed below the spillway, giving the amount taken into the canal system directly. Other waste along the diversion canal or at the ends of laterals may be measured. The sum of such discharges for the season represents the operation waste of the system and is frequently expressed as a percentage of the gross duty. On closely regulated systems it may be quite small; for systems of ample water supply and wasteway facilities it may amount to 20 per cent. or more of the amount diverted.

Requirements of Canal Rating Stations.—A canal rating station depends on the determination of the relation between depth of flow and discharge. To be satisfactory such relationship must be fixed or permanent. Where the relation of depth of flow and discharge is not fixed, methods of correction must be used which increase the expense of operation of a station and reduce the accuracy obtained. Canal ratings are expressed as the relation between the gage height and the discharge. The discharge at any section is the product of the area times the mean velocity. For a given cross-section which is not subject to change the area is proportional to the depth of flow which is represented by the gage height. For a given length of canal in which both the character of the wetted perimeter or coefficient of roughness and the slope do not change, the relation between the mean velocity and the gage height is fixed. In order that the rating of any section may be constant or fixed it is therefore necessary that the cross-sectional area, the slope and the coefficient of roughness remain constant. For such conditions the actual determination of the discharge at a few gage heights distributed over the variations in depth which occur can be used as the basis for determining the discharge at intermediate stages.

In many rating stations on rivers the conditions are such that the ratings remain fairly constant. In canal rating stations such constancy of rating is more difficult to secure. The conditions of use, silting, or the growth of vegetation may affect the rating. The control of the area of the cross-section at the point at which the gage is located can be secured by the use of rating flumes or similar means. The effect of changing canal slope can be overcome in some cases by the location of rating stations closely above control structures of fixed openings. The effect of changes in the coefficient of roughness can also be overcome by locating the station above and close to control stations. Where such controls can be secured they furnish the best locations for stations.

To give good results the control has to be free from the effects of slope in the canal or have a constant relation to such changes. This is secured only where the control itself does not change; a check having variable openings will not control a canal rating. To be unaffected by changes in the canal below, free or nearly free fall at the control is required. Such stations may be obtainable on delivery canals; it is more difficult to secure them on laterals on which the flow is checked for delivery. Ratings near the heads of long flumes or lined sections which are not subject to silt or aquatic growth may not be subject to change. A rating flume of short length controls only the cross-section area and will not have a constant rating unless the other requirements are satisfied by the conditions in the adjacent canal. Rating stations operated under such control differ from those controlled by the flow in canals under the influence of the slope. Such controls are similar in nature to weirs. With a weir the rating curve has been reduced to a mathematical formula; with the usual forms of drops or other control it is necessary to make a field rating, the rating depending upon conditions of free fall rather than of slope. Such free-fall conditions are not affected by changes in the adjacent canal unless such changes submerge the control.

Such rating stations and rating curves are the basis of nearly all stream-gaging stations. On some streams changes in the channels affect the rating curves but on the whole such difficulties are much less in rivers than in canals.

Equipment of Gaging Stations.—Actual gagings can be made at any uniform and permanent cross-section of the canal. To secure such permanence of cross-section a short length of canal may be lined. It is preferable that the section of such rating station be similar to the average of the adjacent canal. The floor should be set slightly above the subgrade of the adjacent canal in order to reduce the tendency toward silting. If such rating flumes are used there is little disturbance of the lines of flow in the canal and a shorter length of lining will be needed. Lengths equal to the bottom width for canals up to 20 or 30 feet bottom width are representative of good practice; a length of 20 feet should be sufficient for larger canals of relatively uniform cross-section. Such stations should be located in lengths of straight canal to avoid the disturbance of flow due to curves. In many cases rating sections of short lengths of vertical sided flumes have been built in canals. These necessarily are subject to changes in the lines of flow at the inlet and outlet and are not as desirable on large canals or with higher velocities. Where relatively long flumes or lined sections are used the rating station can be placed at any point where the alignment is satisfactory.

The actual gagings are usually made from some form of bridge. The use of permanent bridges on which the spacing of the velocity verticals can be marked enables the gagings to be more quickly and conveniently made. For spans up to 40 feet poles having a 2-inch × 12-inch foot plank fastened to the upper side may be used. For longer spans light cable suspension foot bridges are satisfactory. These can be built relatively cheaply and do not cause any obstruction to the canal flow. For the widths of spans found in canal practice such suspension foot bridges are preferable to the cable and car stations used on rivers. Highway bridges are frequently used. This is satisfactory if the other conditions for gaging are favorable. The availability of such a bridge, however, is often used to fix the location of a station where the hydraulic conditions are not the best. If there are piers in the canal, an extension with a foot plank can be built on the upstream side so that the meter can be held far enough upstream from the piers to be free from their influence. Wading measurements may be made for depths of less than 3 feet and for the slower velocities. These are not desirable for permanent gaging stations as the cost of the bridge will be repaid by the saving in the time required for gaging. The resulting accuracy may also be somewhat more uncertain with wading measurements. At a well-equipped station a hydrographer is usually able to set up his meter, read two points in 8 to 12 verticals, secure gage heights and other notes for a gaging, and be ready to leave in about 1 hour's time. The time spent in going from one station to another is often more important than the time spent in actual gaging.

Rating Stations Not Subject to Control.—The method of handling canal rating stations subject to the influence of checks and of aquatic growth, developed by Mr. J. S. Longwell on the Minidoka project, while somewhat cumbersome to apply, will enable fairly satisfactory results to be obtained in sections affected by both of the above influences. On portions of this project there is little fall to the land away from the canals so that checking is required for delivery. Also, aquatic growths materially affect the value of n during the season. Such changes in the control of gaging stations make it necessary to use correction methods. In this method the rating stations are located in uniform sections of the canal and as far from the influence of checks as possible. In addition to the gage at the rating station, a second gage is also used located downstream but within the same checking influence. The two gages are set with their zeros at the same elevation relative to the subgrade of the canal. The mean of the two gages at any time will then give the mean depth between the gages and is used for the hydraulic functions at that time. The distance between the gages is also determined.

A standard canal cross-section is determined, which is used as the mean for the length of canal between the gages. This can be determined from a number of actual cross-sections. If the canal is sufficiently uniform in section to be suited to use for canal rating, the cross-section at the actual gaging station can be used. From this mean cross-section the wetted perimeter, area and hydraulic radius for different depth are determined. From these properties and the discharge and water surface slope as measured at each gaging, the value of n in Kutter's formula can be computed for each discharge measurement. The value of n will usually vary during the season due to the effect of aquatic growths. What is called the normal value of n is assumed, being usually the value found in the early part of the season when the canal section is relatively free from growth. For this normal value of n a rating curve is computed for different depths using the slope of the water surface as observed during the period of minimum checking. This normal rating curve is plotted in the usual form, curves for the area of cross-section, hydraulic radius and mean velocity also being plotted on the same sheet as shown in Fig. 13.

As each gaging is made during the season, the result is plotted on the normal rating curve sheet. The vertical distance of the plotting from the normal rating curve is used to give the gage-height correction. Such corrections depend on both canal checking and the value of n. If the value of n is constant, the

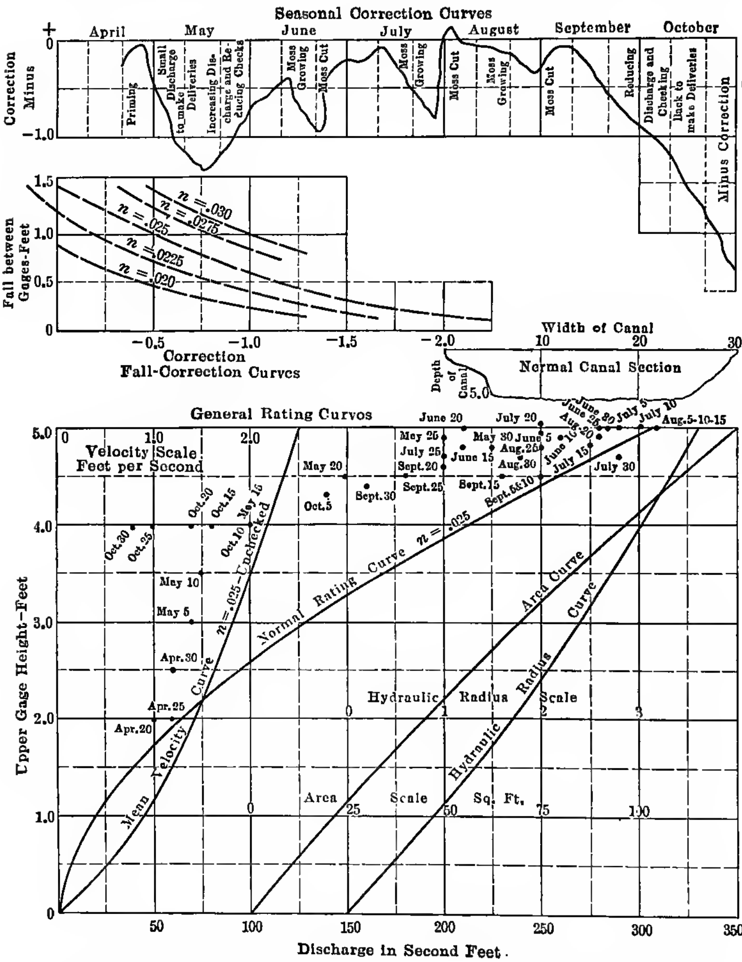


FIG. 13.—Curves used for rating stations not subject to control.

correction will depend on the conditions of checking. The effect of checking shows in the change in the slope of the canal-water surface which is determined from the readings of the two gages. For any value of n, the fall between the gages and the correction for different amounts of checking, will, if plotted, fall on a smooth curve. Such a curve for the value of n found in the earlier season can be determined, as at that time the value of n varies more slowly and the corrections are mainly due to the effect of checking. Gagings at weekly periods are required to give close results under such conditions. For each gaging the value of n is computed. The fall and correction for each gaging are plotted on the general fall and correction curve. A series of fall-correction curves, generally parallel in direction, are thus developed for the various values of n. The corrections for the daily gage readings are secured by using the fall-correction curve for the value of n found at the last gaging, entering with the observed fall for the daily gage readings and taking off the corresponding correction. This correction is then applied to the mean of the two gage readings for the day, the corrected mean gage being applied to the normal canal rating to give the corrected discharge. As an additional check, the daily corrections are plotted on a time curve for the operation season. The corrections due to checking are greatest at the beginning and end of the season when small discharges are checked back for delivery. At the height of the season the full slope of the canal will usually be required to carry the water needed. Corrections due to changes in the value of n will depend on the growth of moss or other aquatic vegetation. Such corrections may increase until it is necessary to cut the growth in order to be able to carry the desired capacity. Following such cuttings the value of n may be as low as the normal value and the correction correspondingly small. Using this method about 20 rating stations can be handled by one field man. This includes weekly gagings and the keeping up to date of the records of such stations.

Current-meter measurements have been used in the delivery of water from the main-canal system in the Imperial Valley. Owing to the large amount of silt carried and the resulting rapid changes in conditions at orifices or other devices no other method has been found to be satisfactory for large quantities. Daily gagings are made on deliveries to some canals such frequency of rating doing away with the need of special correction methods for rating curves. A special current-meter rating station is used as it has been found that the wear on the bearings of the meter, due to the silt, make frequent meter ratings desirable.

METHODS OF CANAL MEASUREMENT

The methods of use of current meters in irrigation canals are similar to those used in rivers or other channels. These methods are fairly well standardized and are discussed in a number of bulletins and books. The greater uniformity in cross-section and in character of wetted perimeter usual in irrigation canals gives a somewhat more uniform velocity distribution than is found in many natural channels so that more accurate and consistent results are to be expected in canal gagings. These conditions also enable some slight modifications in the methods used in general channels to be made. Available comparisons of the accuracy of different methods of canal gaging with current meters have been made only on the basis of the consistency of such results as with larger canals, other comparative methods at practicable cost are not feasible. From a large number of carefully detailed gagings of the U. S. Department of Agriculture for all types of irrigation channels comparisons of the different index methods have been made. These results were published in the Journal of Agricultural Research, Vol. V, No. 6, and the numerical results in the following discussion are based on these experiments. The U. S. Geological Survey has also secured a large amount of similar data on natural channels giving generally similar results, which, however, are not as directly applicable to irrigation conditions.

Current-meter Practice.—The usual index methods of gaging are the two-point and the single-point observations. In the two-point method the meter is held at 0.2 and 0.8 of the depth on each vertical, the mean of the observed velocities being used as the mean for the vertical. In the single-point method the meter is held at 0.6 the depth below the water surface. The integration method is also used. This consists in moving the meter vertically through the depth of water at each interval so that the velocity at each portion of the depth is integrated or averaged in the resulting mean velocity. The vertical movement, if too rapid, has a tendency to cause rotation of the cup type of meter so that the vertical velocity of the meter should not exceed 10 feet per minute. The meter should be given an even number of complete vertical trips to secure a proper mean. These conditions introduce to some extent a personal element on the part of the observer which makes the other more empirical methods preferable for general practice. The use of the two-point method is limited to depths of over 1.5 to 2.0 feet depending on the form of meter used, as good results will not be secured if the meter is set within 0.3 foot of the bottom or of the water surface. The single-point method can be used for smaller depths. Both of these methods are based on the fact that the normal vertical velocity curves have the form of parabolas. Where the conditions of flow are such that the vertical velocity curves are not normal, more detailed methods, such as the multiple-point or integration, are preferable although such conditions are necessarily unfavorable for good rating stations. The integration method is limited to velocities of less than 4 feet per second due to the difficulty of using rod or cable meters without guys with higher velocities.

The equipment of the meters used varies with the conditions. For larger canals cable suspension with weights is usual, particularly where one is working from a bridge several feet above the water. More firm support can be secured by the use of a rod meter with foot piece where the observer is within 6 or 8 feet of the bottom of the canal. The use of rods with the meter at the

TABLE X.—VARIATION IN DISCHARGE IN PERCENTAGE BY THE TWO-POINT, THE SINGLE-POINT, AND THE INTEGRATION METHOD, COMPARED WITH THE MULTIPLE-POINT METHOD

Type of canal cross-section	Two-point method			Single-point method			Integration method		
	Number of observations	Mean difference from multiple-point	Average variation of a single observation	Number of observations	Mean difference from multiple-point	Average variation of a single observation 5 per cent. correction applied	Number of observations	Mean difference from multiple-point	Average variation of a single observation
Rectangular flumes....	27	+0.68	1.45	27	+4.90	2.21	17	+1.06	1.36
Concrete-lined trapezoidal sections........	15	+0.86	1.42	15	+4.21	1.94	4	+0.72	0.93
Shallow earth canals, sloping sides.........	13	−0.38	1.08	13	+3.11	3.42	9	−0.81	2.44
Shallow earth canals, steep sides..........	25	+1.05	1.74	25	+5.02	2.44	18	+0.36	2.15
Earth canals, relatively deep sections........	16	+1.07	1.70	15	+6.32	3.18	7	+3.06	3.78
Mean of all......	96	+0.73	1.51	95	+4.80	2.54	55	+0.76	2.07

lower end of the rod can be employed for smaller depths at low velocities or for integration. Current meters can now be secured equipped for each of these three forms of suspension and such general purpose meters are to be preferred for canal work. For high velocities light wire guys are used to hold the meter in place.

Table X, taken from the article previously referred to, gives the results of comparisons of these different methods of use of current meters. This shows both the two-point and integration method to give average results within 1 per cent. The single-point method gives results about 5 per cent. too high in canals; when a correction of this amount is made, the results of individual measurements have a somewhat higher probable error than with the other methods. Further detailed comparisons indicated that the two-point method gives equally good results for different velocities, depths and values of n. The results with the single-point method appeared to vary slightly with the velocity. The integration method gave the best results for velocities of from 2 to 3 feet and for the greater depths.

Another practice occasionally used is the three-point method, observations being made at depths of 0.2, 0.6 and 0.8. As the 0.6 observation is less accurate than the mean of 0.2 and 0.8 observations, its inclusion with them will reduce the average resulting accuracy, so that its use is not to be recommended. A greater number of verticals with the two-point method is preferable to a fewer number with the three-point method.

Use of Surface Floats.—A number of observations were also made with surface floats. Such observations, while rough, are frequently of use where other methods are not available. For divisions between canals or turnouts where the sum of the parts can be compared with the total, such rough methods may be used. It is customary to apply an assumed coefficient to the observed maximum surface velocity to secure the mean velocity. Such coefficients depend on the size of the canal and its value of n and may vary from 0.60 to 0.90 under extreme conditions. The effect of the area for cross-sections of over 20 square feet is relatively small. Table XI gives the mean value of such coefficients for the values of n found in irrigation channels. Small surface floats which offer little exposure to the wind, such as small chips or leaves, should be used. Several should be thrown into the canal and the time of the most rapid one used. They should be timed over a length of 100 feet or more. The discharge is secured by multiplying the area of cross-section by the observed velocity as reduced by the use of the proper coefficient. To select the coefficient an estimate of the value of n must be made. While such methods are rough, where the cross-section is known as in flumes the resulting discharge may be secured with a probable average error of 10 per cent. For earth sections the probable error in estimating the area of cross-section may increase the error in the resulting discharge above this amount.

TABLE XI.—COEFFICIENTS TO BE APPLIED TO VELOCITIES OF FLOATS TO OBTAIN MEAN VELOCITY IN CANALS

Area of water cross-section	Value of n in Kutter's formula									
	0.012	0.014	0.016	0.018	0.020	0.022	0.024	0.026	0.028	0.030
Square feet										
2.....	0.85	0.80	0.76	0.73	0.70	0.67	0.65	0.63	0.61	0.60
4.....	0.86	0.81	0.77	0.74	0.71	0.68	0.66	0.64	0.62	0.61
6.....	0.87	0.82	0.78	0.74	0.71	0.68	0.66	0.64	0.63	0.62
8.....	0.88	0.83	0.79	0.75	0.72	0.69	0.67	0.65	0.63	0.62
10.....	0.88	0.83	0.79	0.76	0.73	0.70	0.68	0.65	0.64	0.63
15.....	0.89	0.84	0.80	0.77	0.74	0.71	0.69	0.66	0.65	0.64
20.....	0.90	0.85	0.81	0.78	0.75	0.72	0.70	0.67	0.66	0.65
25.....	0.91	0.86	0.82	0.78	0.75	0.73	0.71	0.68	0.66	0.65
50.....	0.91	0.86	0.82	0.79	0.76	0.73	0.71	0.69	0.67	0.66
Over 50	0.91	0.86	0.82	0.79	0.76	0.73	0.71	0.69	0.67	0.66

Number of Points of Observation.—Comparisons were also made to determine the effect on the accuracy due to the use of varying number of observation verticals. In the detailed gagings averages of 16 verticals were used; these were compared with the results using only alternate and also only every fourth vertical. The use of 8 verticals gave an average difference of about 2 per cent. and the use of 4 verticals of about 6 per cent. from the results secured with 16 verticals. The results, however, varied with the form of section as shown in Table XII. The errors due to the use of fewer verticals are less in flumes and lined sections than in earth canals. This is due both to the errors in cross-section due to the use of fewer depths as well as to errors due to fewer velocity observations. For equal accuracy about twice as many verticals should be used in earth canals as in flumes.

Just as two points in the vertical velocity curves have been found to give the mean, it was thought that possibly two points

TABLE XII.—EFFECT ON THE ACCURACY OF CURRENT-METER GAGINGS OF VARYING NUMBERS OF VERTICALS

Type of canal	Number of detail gagings made	Average number of verticals in detail gagings	Comparisons using one-half of observed verticals. Variation (per cent.)		Comparisons using one-fourth of observed verticals. Variation (per cent.)	
			Average	Minimum and maximum	Average	Minimum and maximum
Flumes, vertical sides..	23	15	0.9	+0.05 to −3.82	2.9	0 to −7.50
Concrete-lined canals; steeply sloping sides..	11	14	0.9	−0.04 to −2.95	2.9	−1.08 to −5.85
Concrete-lined canals, wide and flatly sloping sides..................	6	17	1.4	−0.37 to −3.22	3.8	−0.70 to −6.52
Average earth canals, sloping sides........	18	16	2.9	+0.1 to −8.3	9.2	−1.5 to −17.6
Average earth canals, steep sides..........	21	16	2.5	+0.1 to −7.3	9.0	−0.4 to −21.1
Earth canals, relatively deep sections........	10	16	2.7	−0.5 to −5.5	7.7	−0.6 to −19.4
Mean of all.......	89	16	1.9	....	6.2	

in the horizontal velocity curve could be found which would give the mean velocity. It was found that in sections with vertical sides, two verticals located from one-fifth to one-sixth the width from the sides gave results within an average of 2.5 per cent. of that obtained from 16 verticals. In lined sections with sloping sides similar results were secured at from one-fifth to one-fourth the width of the water surface from the sides, if the area of the cross-section were secured from the known cross-section. In earth canals such methods gave much larger errors.

Gages.—Staff gages used by the operating force are more usually graduated in feet and hundredths than in feet and inches. Readings are made to the nearest hundredth or two-hundredths on small deliveries; on large canals this is also usual, although half-tenths may be used. To avoid the confusion of fine graduations, gages similar to standard yard or meter sticks may be used, as shown in Fig. 14. These can be read easily to the nearest 0.02 point. Where used on large systems in quantities these can be made with power saws and painted at a cost of about 6 cents per foot. For small gages such as are attached to gate stems for the purpose of giving the height of opening, small graduated brass strips about 3/4 inch wide perforated for nailing may be used. Enamelled gages have also been used on some systems, with various marking schemes. For weirs of different lengths the gages may be graduated to read discharges directly instead of heads. The length of weir to which each gage applies should be plainly marked on the gage.

Automatic gages are used at more important points in order to secure continuous records. The fluctuations which such gages have to cover are less than in river practice so that full-scale readings are usual. There are a number of such registers on the market, varying widely in quality and price. The sheets generally supply a week's record. The time scale is usually about 2 inches per day. The price of such registers varies from

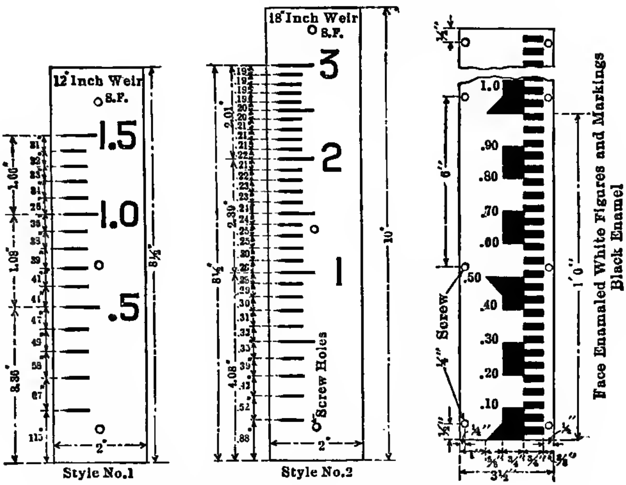


FIG. 14.—Forms of staff gages.

$25 to over $100 each, depending on the character of the clock mechanism and mechanical workmanship. Cheaper gages giving 24-hour records can be devised locally from ordinary clocks.

Notes and Records.—Hydrographic field notes are preferably taken in loose-leaf books due to the danger of loss or wetting. Current-meter notes can be taken on ordinary instrument note sheets, specially ruled and headed paper being used where many gagings are being made. The forms used by the U. S. Geological Survey are well suited to canal work. Where many seepage tests are being made a form (Fig. 15) similar to that used by the Twin Falls Canal Co. may be of use.

A blank form on which the daily distribution of water between laterals can be shown is used on many systems. This may be arranged for either weekly or monthly periods. The gaging stations may be listed vertically with the dates horizontally or the reverse arrangement may be used. Where gage heights are telephoned to the main office each day, double columns are used, one to record the gage height as received and one for the corresponding discharge. Such a tabulation shows the division of water between laterals and is used in making changes to meet

HYDROGRAPHIC OPERATIONS TWIN FALLS CANAL CO.
Twin Falls, Idaho

Date__________ Sheet No.______

Diversions and Intakes Between
Station __________ and Station __________

DIVERSIONS		INTAKES		NOTATIONS
NO.	SEC.FT.	NO.	SEC.FT.	
TOTAL				

		NOTATIONS
Sec.ft.discharge at Sta.(upper)		
Sec.ft.discharge at Sta.(lower)		
Difference		
Diversions less Intakes (sec.ft.)		
Seepage and Evaporation in Section(sec.ft.)		
Seepage and Evaporation per mile(sec.ft.)		
Per Cent. Loss per mile		

Fig. 15.—Form used for seepage tests, Twin Falls Canal Co.

the next day's demands. On some systems each ditch rider may make a daily report in which each delivery for the day is listed. This serves a similar purpose within the individual beats that the summary form does for the whole system.

Various forms for summarizing the results of records secured are used. The monthly sheets for each station may be totalled and a seasonal record compiled showing the total flow at each station expressed in total acre feet or reduced to acre-feet per acre irrigated. The records may be assembled to show the total diversions into the system, its division to laterals and to individual deliveries, waste from canals in operation and other data. The water not accounted for is generally listed as seepage and evaporation; the term "invisible loss" which is sometimes used is perhaps more descriptive, as such items include any errors in records as well as actual seepage losses.

MEASUREMENT OF INDIVIDUAL DELIVERIES

The conditions of delivery to individual farms are not generally favorable for either accurate or convenient measurement of the water used. The difficulty of securing dependable records at costs within the value of the results has retarded the use of such measurements beyond the time when their advantages and desirability have been recognized.

Conditions Affecting Accuracy.—The requirements of accuracy vary. Greater accuracy is needed where the supply is limited, or where operation and maintenance charges are based on the records of quantities supplied, rather than on the acreage irrigated. Actual accuracy may be secondary to consistency where the measurements are used only to divide available supplies proportionately among those entitled to receive water. It is probable that what may be called consistency is usually more important than technical accuracy. If weirs are used on all deliveries and are all subject to about the same extent of silting of the pools during the season, so that the discharge for any given head on the weir is increased, due to the increase in the velocity of approach, the division of the water to the different users may still be consistently proportional. If some weirs silt and others become submerged, due to natural checking below the weirs from weed growth or other causes, inconsistent results will be obtained, as some will over-discharge due to silting and some under-discharge due to submergence.

Records of individual deliveries and of many canal rating stations are computed from gage readings secured once per day or sometimes twice per day. Over long periods of time it is probable that little error results, as daily fluctuations may tend to balance. Where under rotation methods of delivery only from one to three or four gage readings per run may be secured for individual farms, such errors may not balance. Under some conditions there may be periodic daily fluctuations. Gage readings taken at a regular time each day may not be representative of the mean. Gages are usually read by the ditch riders. Honesty of reading can be obtained and filling in of missed readings practically prevented by proper supervision. Errors in reading cannot be avoided. These may tend to balance.

On individual deliveries measurements are usually made at the time water is turned in. With some types of orifices this may give erroneous results. For submerged orifices delivering into relatively large or long farm ditches some time may be required until the ponding back on the orifice becomes stable. This results in reading too low a gage on the lower side and giving too great a discharge reading. Another condition frequently encountered is to have the irrigator begin irrigating on the checks next to the delivery which are often higher than those further in the field. This may cause checking back on the measuring device, which, if a submerged orifice headgate type, will not draw as much water from the ditch as will be the case later on the lower checks. Measurements when checking back will show less than the average discharge.

These various errors in securing records are a necessary condition with any device dependent on gage readings, no matter how accurate it may be in its hydraulic properties. It is questionable if one is warranted in attempting to secure hydraulic accuracy out of proportion to the practical accuracy of use. The elements of error in use cannot, from their nature, be reduced to percentages; hydraulic errors more often can. The resulting seasonal records on any individual delivery which are within 5 per cent. of correct can be considered very satisfactory. If average errors of 5 per cent. with ordinary maximum errors of 10 or 12 per cent. can be obtained on a system as a whole, the results would be fully as good as those now secured under present actual practice.

Cost of Operation of Measuring Devices.—Besides first cost the expense of operation must be considered in selecting measuring devices. Maintenance of the structures themselves is similar to the maintenance of other small structures on the system. Cleaning of approach channels during the season may be needed for those devices requiring low velocities of approach. The principal costs of operation are those connected with securing and computing the records. It is usually found that the ditch tenders can secure the gage readings needed without any additional cost. If such readings are taken at the time of his regular visits to the turnouts, the additional time required to read and record gages is such a small proportion of the time required to reach and adjust the turnout that no reduction in the area covered per ditch rider is required on account of such readings. The additional cost of measurement is then mainly the office or computing cost. The number of turnouts whose records can be computed and notices kept up by one man varies with the type of device and frequency of readings secured. Where submerged-orifice headgates are used under semicontinuous flow or informal rotation methods, one computer should handle about 400 turnouts, including the making of monthly statements to each user of the water received each month. Such devices require more time and labor in computing than devices such as weirs. For submerged devices the difference of two gage readings is used to secure the discharge. If an orifice is of the headgate or variable size of opening type, an additional reading, from which to secure the size of opening, is required. Some examination of the height of opening and the lower gage to make sure that the orifice is actually submerged may be necessary. This detail requires time and reduces the number of turnouts for which one man can make the computations. Where deliveries are made by methods giving water to each turnout about one-half the time over weirs or fixed opening orifices, one computer should compile the records and monthly statements for about 700 turnouts where daily readings are secured. If readings are not secured daily 1,000 turnouts may be handled.

Other types of devices are not in use in sufficient numbers on large projects to make available data in regard to the number which can be handled by one computer. Any device requiring the use of weekly charts, such as an automatic register, will require much more labor in placing the chart and reducing the record. Such registers are used on canal rating stations. The expense of reduction of the record will be greater than for single daily readings if the fluctuations on the chart are closely computed. If such fluctuations are not computed, there is no advantage in the use of a continuous chart record over the single readings. The expense of operation of any types of chart recording automatic registers now available will prevent their general use on individual deliveries. The first cost of such registers has also prevented their use for individual deliveries up to the present time.

Devices which integrate the discharge record should be cheaper to operate. Daily readings would be needed only for purposes of checking the rate of discharge, the monthly quantities being taken from the dial or other means used to indicate the total quantity passed, in the same way that monthly quantities are secured on gas or electric meters. Computations of such results would consist mainly of the expense of making out the monthly statements.

Devices which regulate and hold constant the rate of discharge require less labor in computation of results than any devices except the self-integrating type. Only the time elements need to be recorded for such devices. From this point of view such devices should be desirable; from the point of view of canal operation and regulation, they may not be desirable.

The usual rate of pay for computers is about $90 per month. The cost of computing measurements of individual deliveries for different assumptions is shown in Table XIII.

TABLE XIII.—ESTIMATED AREA FOR WHICH COMPUTATIONS OF WATER DELIVERY CAN BE MADE BY ONE MAN AND RESULTING COST PER ACRE

Number of deliveries handled by one computer	Area in acres for which one man can make computations of delivery for average area served per turnout of			Cost per acre per season of 7 months for computer at $90 per month for average area served per turnout of		
	20 acres	40 acres	80 acres	20 acres	40 acres	80 acres
400	8,000	16,000	32,000	$0.077	$0.039	$0.020
700	14,000	28,000	56,000	0.045	0.022	0.011
1,000	20,000	40,000	80,000	0.032	0.016	0.008

The annual cost of depreciation, interest and maintenance for devices of different first costs serving different average areas is given in Table XIV. The annual cost is estimated for both wood and concrete structures. Interest was taken at 6 per cent., depreciation at 10 and 3 per cent. and maintenance at 5 and 3 per cent. for wood and concrete respectively. This gives total annual costs of 21 and 12 per cent. of the first cost for wood and for concrete devices. For the more expensive devices the percentage for maintenance taken may be too high.

These figures give some indication of the annual costs per acre to be expected under different conditions. Separate structures for measuring devices cannot be built under usual conditions for less than $10 or $15, even for small weirs or orifices.

TABLE XIV.—ANNUAL COST OF INTEREST, DEPRECIATION, AND MAINTENANCE FOR MEASURING DEVICES UNDER DIFFERENT CONDITIONS

For a total cost of measuring devices installed of	Wood device, estimated annual cost 21 per cent. of first cost				Concrete devices, estimated annual cost 12 per cent. of first cost			
	Annual cost per device	Cost per acre for average area in acres served per device of			Annual cost per device	Cost per acre for average area in acres served per device of		
		20 acres	40 acres	80 acres		20 acres	40 acres	80 acres
$ 5	$1.05	$0.05	$0.03	$0.01	$0.60	$0.03	$0.02	$0.01
10	2.10	0.10	0.05	0.03	0.20	0.06	0.03	0.02
15	3.15	0.16	0.08	0.04	1.80	0.09	0.045	0.02
25	5.25	0.26	0.13	0.07	3.00	0.15	0.075	0.04
35	7.35	0.36	0.18	0.09	4.20	0.21	0.105	0.05
50	10.50	0.52	0.26	0.13	6.00	0.30	0.15	0.075
75	15.75	0.79	0.39	0.20	9.00	0.45	0.22	0.12

Measuring devices are usually installed by the canal company. This is essential if they are to be properly selected and set. The individual user may be required to bear the expense directly; it is more usual to include it in general cost, however. If built by the canal company it is preferable that the device be located within the right of way in order that a more complete control may be exercised. The advantage in reducing the number of turnouts or increasing the area served per turnout is shown by these tables. Under rotation delivery it is sometimes possible to use one measuring device to measure the irrigation head for several farms. This is possible on laterals where only one irrigation head is used and where the seepage loss in the lateral is small. The cost of measurement can be greatly lessened if structures necessary for other purposes can also be used for measurement. This is done on many systems where the turnout is of a headgate type which can be used as a submerged orifice. These may not be very satisfactory measuring devices from a hydraulic point of view, yet the limitation of costs may make them the only type practicable.

As an example, a system may be taken on which the total operation and maintenance cost averages $1 per acre and on which it may be considered desirable to install individual measuring devices if the total cost will not exceed 10 per cent. of other operation costs. Where 40 acres would be served per turnout, one would be limited to a type of device costing $15 if of wood, for which one computer could handle 700 deliveries, a requirement which might be fulfilled by small weirs if the fall needed for their use was available. For such limiting costs, not over $35 each could be spent for wooden devices for deliveries to 80 acres. For concrete devices higher first costs could be afforded. If, however, the turnout structures are of such nature that they can be used for measurement without additional construction cost, such as tube tap boxes extending through the bank, the cost is entirely that for operation which, even for such turnouts, should be within the limit given. The possible saving in such structure costs may make the use of devices necessary which are undesirable hydraulically if measurements are to be secured at all.

Under present conditions individual measuring devices costing in excess of $25 each are not in general use. For projects having farms of small size, the value of water and land are usually higher and greater costs per acre may be warranted. For such conditions one device may serve more than one holding, particularly for rotation methods of delivery. Under favorable conditions of construction and use, the cost of both fixed charges and operation of measuring devices may not exceed 5 cents per acre per year. They are not now used in many cases where the annual cost exceeds 10 cents per acre. In the future higher costs may be warranted. For a device to be used to any extent on individual deliveries, it must be capable of installation at costs of less than $25. Limited sales at somewhat higher costs may be secured. For extensive use the cost should not exceed $15 each.

Other Requirements of Measuring Devices.—In addition to the restrictions in regard to loss of head required and cost, measuring devices must be of such nature that they are not easily interfered with and their principles must be such that their general action can be understood by the farmers. Interference may be of two kinds: accidental and intentional. Accidental interference results mainly from clogging with weeds or other drift. Devices which permit the passage of drift and which do not need to be protected by screens are much preferable. Weirs are quite satisfactory in this regard, submerged orifices less so, but much preferable to most of the special devices. Intentional interference results from efforts on the part of individual users to secure more water than they are entitled to or to secure some water without having it recorded by the measuring device. Weirs and fixed area orifices are not subject to such interference with the device itself. The quantity received may be affected by changes in the control gates, but this is not directly the fault of the measuring device. The discharge through orifices can be affected by changes in the submergence. Any device depending for its action upon floats is subject to tampering unless securely housed. Such housing adds to the cost. Various types of floating weirs have been devised which will give constant discharges with varying levels in the supply ditch. It is doubtful if such devices will give satisfactory results under general conditions of use as the discharge can be increased by adding to the weights of the float. To be really successful a measuring device must be acceptable to the users. This will retard and probably prevent the general use of more complicated devices, even though their cost could be reduced so as to bring them into direct competition with weirs and orifices.

On many systems the fall available for measuring devices is limited. Unless there is considerable fall to the land, there will be little excess fall between the canal-water surface and the land when delivery is being made unless the canal banks are carried higher than is required for other purposes. A device which can operate on a small and variable head or fall has a distinct advantage. The amount of fall required is the principal disadvantage of weirs. The ability to operate on small available heads is an advantage of submerged orifices which often overbalances other disadvantages of operation. Some loss of head through turnouts is always required; it may be possible to use this loss as a basis for measurement with orifice types of headgates.

These various requirements of use, particularly that of cost, have practically limited the use of irrigation devices, up to the present time at least, to some form of weir or submerged orifice. Under special conditions other devices are used, but considering irrigation practice as a whole, measurement is limited to weirs and simple submerged orifices as separate structures or combined with the turnout structure. Many special devices are constantly being developed, both for measurement, recording quantities and for controlling the rate of discharge, some of them of merit and much ingenuity, but as yet none of them has possessed a sufficiently complete combination of low cost, simplicity, and dependability to enable it to secure any general adoption. The conditions of use vary too widely for any one device to be suited to all of them. For a given set of conditions there is usually some one form of weir or orifice which is the best for such use. It is not to be expected that any special devices will ever have as wide a field as these more standard types.

WEIRS

Weirs which are used in irrigation practice are of three types: Cippoletti, rectangular contracted and rectangular suppressed. There are other types, such as triangular weirs, which are accurate for purposes of measurement. For the quantities of water used in irrigation the loss of head required by triangular weirs is too great to enable this type to be used.

The Cippoletti weir (Plate VI, Fig. A) is the type most generally used. Its formula is based on having a discharge proportional to the length, the outward slope balancing the effect of the contractions. The discharge of the rectangular contracted weir is usually computed by the Francis formula, the length being reduced by an amount equal to 0.2 of the head as a correction for the two end contractions. If, as is necessary if the Francis formula is used, the head is limited to not over one-third the length, this correction for contraction will be a maximum of 6.6 per cent. For weirs used in irrigation, recent exact measurements by Mr. V. M. Cone show little difference between the Cippoletti and rectangular contracted weir in regard to accuracy.

If the head on the weir exceeds one-third the length of the weir, numerous experiments have shown that the usual formulas give discharges smaller than the actual, the error increasing as the ratio of head to length increases. It is preferable to choose the length of the weir, so that for maximum expected discharges

Table XV.—Capacities of Weirs of Different Lengths

Length of crest in feet	Discharge in second-feet when head is equal to one-third the length			Depth required on 90° triangular weir to give the same discharge as Cippoletti weir, feet	Minimum fall in feet required for satisfactory use of Cippoletti or rectangular contracted weirs to capacity given
	Head in feet	Cippoletti weirs	Rectangular contracted weirs		
1.0	0.33	0.64	0.58	0.58	0.50
1.5	0.50	1.78	1.65	0.87	0.60
2.0	0.67	3.69	3.41	1.17	0.75
3.0	1.00	10.01	9.32	....	1.00
4.0	1.33	20.66	19.07	....	1.25
5.0	1.67	36.33	33.53	....	1.50

FIG. A.—Eighteen-inch Cippoletti Weir.

FIG. B.—Weir with gage graduated to read discharge directly, Twin Falls Salmon River System.

(*Facing page.* 148.)

Plate VI.

Fig. C.—Headgate with sharp edged orifice set in front wall, Minidoka project.

Fig. D.—Dethridge Meter installed in laboratory of California Experimental Station at Davis.

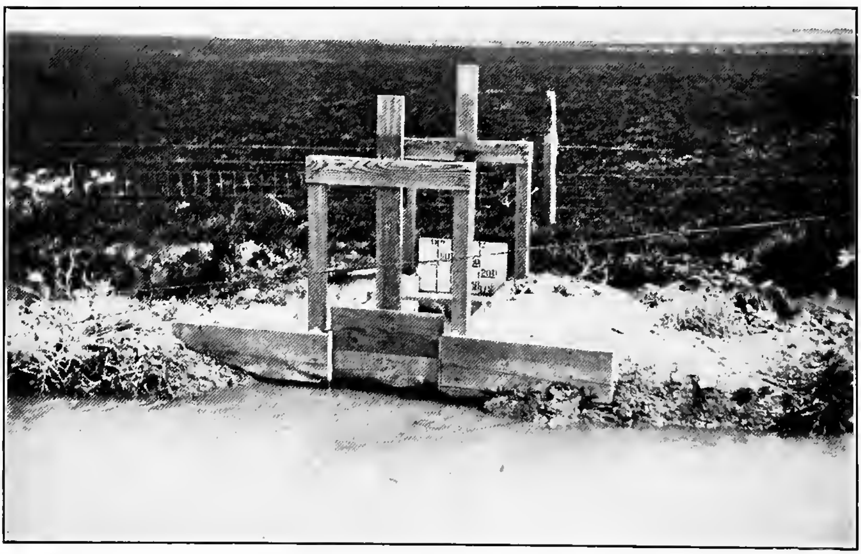


Fig. E.—Double orifice headgate graduated to show discharge in miners, inches, used in Idaho.

the head will not exceed this limit, although tables are now available for actual discharges at higher heads. Table XV shows the maximum discharges of weirs of different lengths when the head is one-third of the length.

The loss of head required for a weir without submergence for such conditions of maximum discharge will be equal to one-third the length. If the water surface in the ditches below the weirs could be exactly located or was uniform during the season, weirs might be built with their crests at such elevations that this minimum loss of head could be realized. Practically, of course, this cannot be done. Weirs can be submerged to a considerable percentage of the head without seriously affecting the result. The correction for different percentages of submergence as usually given is shown in Table XVI.

Table XVI.—Correction in Discharge of Weirs Due to Submergence

Submergence, per cent. of head	Corrections to be applied to discharge for same head, unsubmerged, per cent.
10	− 1
20	− 2
30	− 6
40	−10
50	−16

These figures indicate that submergence up to one-fourth the head can be permitted without exceeding a correction of 5 per cent. This permits the weir crest to be set lower than would otherwise be the case. By having a gage below the weir on which submergence can be read, submergence up to 40 per cent. of the head, particularly if not of usual occurrence, may be permissible. Estimated minimum falls which should be available are also given in Table XV. For small weirs at least 6 inches should be available. For the larger weirs some submergence may be permissible. In case less fall is available than is needed for the measurements of quantities suited to a given length of weir, longer weirs will reduce the fall required for the same discharge. This is shown in Table XVII.

Rectangular weirs with contractions suppressed are desirable types if considered from the hydraulic point of view alone. In irrigation practice they are more directly affected by silting, which changes the height of the crest. The smaller sizes also

Table XVII.—Length of Cippoletti Weirs in Feet Required to Carry Different Discharges without Submergences, Lengths above 1.5 Feet Varied by Feet

Fall available, feet	Discharge to be carried, second-feet				
	1.00	2.00	4.00	6.00	10.00
0.50	1.5	2.0	4	5	9
0.60	1.5	1.5	3	4	7
0.75	1.5	1.5	2	3	5
1.00	1.5	1.5	2	3	3

require more material for their construction, except when used in rectangular channels such as flumes. It is usual with Cippoletti and contracted rectangular weirs to build the weir notch in the upstream wall of the structure and to enlarge the ditch above to reduce the velocity of approach. The weir structure then consists of the wall containing the weir notch with such length of flume on the downstream side as may be required to prevent injury from the falling water.

This difference in material required for the different types can be illustrated by the standards used by the U. S. Reclamation Service. These are made for the use of 2-inch planks and 4 × 4 posts. The use of 2-inch plank is desirable for all structures set in the ground, and is particularly so for weirs where the rigidity of the structure is relied on to keep the weir crest true. For Cippoletti weirs, up to 3-foot crests, the length of structure is 4 feet; for crests of from 4 to 10 feet, it is 6 feet. In firm soil with good cutoffs shorter lengths may be used. The structures for suppressed weirs are of similar material and twice the length of those for Cippoletti weirs. The data taken from the Reclamation Service standards is shown in Table XVIII.

Cippoletti weirs require slightly greater amounts of lumber than rectangular contracted weirs, due to the greater width of box made necessary by the sloping ends. For small weirs considerably more material is required for suppressed weirs than for either of the other types. For the larger sizes the stilling pool of the Cippoletti and rectangular contracted weirs becomes so wide that the additional material needed in the upper wall exceeds that used in the longer box of the suppressed weir. Expressed in terms of capacity the material required for suppressed weirs is always greater than for the other two types. For the

TABLE XVIII.—COMPARISON OF MATERIAL REQUIRED (U. S. RECLAMATION SERVICE STANDARD TYPES OF WEIRS) AND CAPACITY OF DIFFERENT WEIRS

Length of weir crest in feet	Approximate quantity of material required for different types of weirs, in feet, B.M.		
	Cippoletti	Contracted rectangular	Suppressed rectangular
1.0	130	120	175
1.5	130	130	190
2.0	145	135	220
3.0	250	250	355
4.0	640	630	665
5.0	750	715	705
6.0	785	765	750
7.0	905	875	785

heights of crest obtainable under usual ditch conditions, less depth on suppressed weirs can be secured, giving less capacity for the larger sizes of this type of weir.

The pools above weirs should be sufficiently large to effectively reduce the velocity of approach. Where weirs are set below headgates, at least 20 feet distance from the headgate outlet to the weir is needed even with wide pools unless baffles are used. For purposes of control by the canal company it is preferable to place the weirs within the right of way. Where this is done it may limit the length of pool which may be secured. The width of the bottom of the pool should be at least 2 feet greater than the length of the crest.

Costs for small weirs cannot be figured in terms of the unit quantities, such as lumber or excavation. The proportion of the cost represented by the assembling of material and men is necessarily a large proportion of the total. Where large numbers of weirs of standard types are to be used, it is profitable to install a central yard with power saws, at which all the material required for a single structure can be assembled and cut to proper lengths. The structure may be partly erected before hauling if the expense of hauling is not increased. Crews for placing small weirs usually vary from 3 to 6 men. Weirs up to 2-foot crests can usually be installed for $15 each; 3-foot crests for about $18. The cost may be divided with about 30 per cent. excavation and backfill, 40 per cent. material and erection, and 30 per cent.

overhead and setting gages. These figures are taken from costs on systems where several hundred have been built under average conditions of cost of material. For the actual material used in small weirs the costs run from $60 to over $100 per M., B.M. if excavation and all other costs are divided by the lumber used. On larger weirs the unit cost figured on the basis of the lumber used will be less.

SUBMERGED ORIFICES

The orifice was the earliest type of measuring device used in the West, the miner's inch being the legal unit of measurement in most of the States. While still retained in use, the miner's inch, or inch as it is more frequently called, is now defined as a certain proportion of a second-foot, which in reality makes the second-foot the standard. The old miner's measurements were made with unsubmerged orifices. Where there is sufficient fall available for an orifice without submergence, other types, particularly weirs, are preferable.

Submerged orifices have the advantage of requiring a smaller loss of head than weirs and of not being affected by conditions which affect the depth of submergence without changing the difference of head, such as checks, in the ditch below the orifice. Where the elevation of the water surface above the orifice is fixed, changing the water surface below the orifice changes the difference of head acting on the orifice and affects the discharge. Orifices may have a fixed area or an adjustable opening. For measurement purposes the fixed area is preferable, as this can be given sharp edges which result in more definite coefficients and computations can also be more easily made, as one variable is eliminated. Fixed openings where variable flow is to be measured have the disadvantage that for small discharges the difference of head may be less than sufficient for satisfactory measurement if the opening is made large enough to handle the larger flows.

In many cases delivery gates are used as submerged openings for purposes of measurements. This is done to save the cost of separate structures as well as to utilize the head necessarily lost through the headgate and thus avoid the additional loss of head necessary for separate devices. Such measurements are less dependable than those made at special structures; they are much more cheaply secured, however. The cost of installation and maintenance, which is shown in Table XIV to be the principal cost of measuring devices, is avoided, as the turnout would be required for delivery, whether measurements are needed or not. For many conditions of use the increase of accuracy of separate measuring devices over what may be obtained by properly constructed orifice headgates may not be sufficient to justify the expense.

Discharge through orifices is based on the formula:

$$Q = AV = CA\sqrt{2gh}$$

where C is an experimental coefficient; h is the difference in elevation of the water surface above and below the orifice when submerged, and the elevation of the water surface above the center of the opening for free fall; A is the area of the opening. The greatest difficulty in the use of this formula is in the proper selection of the coefficient of discharge. For sharp-edge fully contracted orifices, the value is fairly consistent and has been found from many experiments to be about 0.61. Under field conditions values as high as 0.65 have been found. Where the orifice is placed near to the sides or bottom of the approach channel, where the edges of the orifices are not sharp, where the length is too great in proportion to the height of opening, as in gates set with small openings, or where the difference in head is sufficient to produce velocities sufficiently high through the orifice, so that for the depths available the water below the orifice is unduly disturbed, it has been found that the coefficients are higher than for standard sharp-edged orifices and that for such conditions the coefficient tends to vary for different gates apparently similar but affected to different extents by such uncertain elements. For ordinary headgate orifices a mean value of the coefficient of from 0.70 to 0.75 is usually found with rather wide individual variations. For headgates set in openings in the bank, a coefficient of 0.70 is probably representative; for gates set at the upper ends of tubes extending through the banks, a value of 0.75 may be preferable. Where the conditions are such that a gradual increase in the velocity as the water approaches the gate is secured, the coefficient may have values as high as 0.80. Where gates are used as orifices, they should all be made as nearly similar as possible and a sufficient number rated under the conditions of use to determine the mean coefficient.

In general where the available head is sufficient for the use of a weir, it will be used in preference to an orifice, if separate measuring devices are to be built. An available difference of head of 0.2 is needed for orifices. Orifices are not generally used for small deliveries if falls over 0.50 are available or for larger sizes for falls over 0.75 feet. The discharge of sharp-edged orifices (coefficient 0.61) for various areas of openings and differences in head are shown in Table XIX. These figures can be used as a basis for the selection of the size of orifice for different conditions. For orifices having higher coefficients, the capacity will be increased in proportion to the increase in coefficient.

TABLE XIX.—DISCHARGE IN SECOND-FEET OF SHARP-EDGED ORIFICES UNDER DIFFERENT CONDITIONS ($C = 0.61$)

Area of orifice in square feet	Discharge in second-feet for differences in head of			Approximate quantity of lumber required in feet, B.M., for standard orifice structures of U. S. Reclamation Service
	0.2 feet	0.5 feet	0.75 feet	
0.25	0.55	0.86	.....	150
0.5	1.09	1.73	.....	150
1.0	2.19	3.46	4.24	170
1.5	3.28	5.19	6.36	170
2.0	4.38	6.92	8.48	200

This table indicates that the quantity of lumber required for such orifices is not very different than that shown in Table XVIII for weirs of similar capacity when heads of more than 0.5 feet are available. For small available falls, larger sizes of orifices or longer weirs are needed and more material required than for devices of similar size operated under greater falls.

For the same available head, a given error in reading the gage produces less error in the resulting discharge for orifices than for weirs. This is due to the fact that the discharge for orifices depends on the one-half power of the head, where for weirs it is the three-halves power of the head. For similar capacities, the actual difference in head on an orifice will usually be less than on a weir, so that the actual errors are in favor of the orifice but to a less extent.

Several different types of orifice headgates are used. In some of the open types, the gate is set at the front of the turnout structure (Plate VI, Fig. D). For such gates the lateral from which water is taken serves as the stilling pool to reduce the velocity of approach. In others the gate is set 3 or 4 feet back from the front of the structure; the channel of approach, while permitting more velocity, is definite in area and if coefficients are determined for the actual conditions of use, perhaps preferable. The coefficient is liable to vary with the rate of discharge unless velocity of approach is taken into account.

Variable coefficients introduce complications in computation which are hardly warranted by the accuracy obtainable in any case by such devices. Setting the gate back from the front of the structure gives a better opportunity for making it tight when closed, as earth can be placed in front of the gate. On some systems the gate sill is level with the floor of the turnout, suppressing the bottom contraction. In others, the gate rests on bottom boards 4 to 8 inches high. The sides are usually flush with the sides of the box, except for the projection of the guide cleats. One or 2-inch thicknesses are used for the gates, giving edges of those widths. A check board may be inserted below the gate to insure submergence at all stages.

The height of gate opening is read on the gate stem. Some system of marks or a scale can be fastened to the gate stem and set so as to read zero when the gate is closed. The reference mark for reading this height of opening is usually the top of the gate frame.

A combination headgate and sharp-edged orifice has been used on the Minidoka project in Idaho. A fixed-opening orifice with metal edges is set in the upper face of the turnout. The headgate, of the usual type, is set about 3 feet back from the orifice. Measurement is made through the upper fixed orifice, the gate being used for regulation purposes. When the full capacity of the orifice is required, the gate can be raised so as not to obstruct the flow. The necessary loss of head in the turnout is then used to furnish a large part or all of the loss of head needed through the orifice. The cost is but little greater than for the ordinary headgate alone. Where it is difficult to secure sufficient fall for measurement this type of device should prove of much use, as it has the advantages over the headgate alone resulting both from the fixed opening and the sharp edges.

For relatively small deliveries through canal banks the tube type of turnout is more usual. This enables the canal bank to be used as a road more easily, and for large banks is cheaper. Gage readings for such devices are taken above the inlet and below the outlet, the head lost being that required for the orifice and for from 8 to 12 feet of tube. The coefficients do not differ materially from those found for other similar orifices, being in general somewhat higher. The more usual sizes are 10 × 12, 12 × 12, and 12 × 18 inches.

Any fluctuation in the supply canal affects the discharge through the orifices. To partially control such fluctuations, double orifices may be used. The controlling gate may be set at the front of the turnout with a similar gate at the lower end. The effect of any fluctuation in the level of the supply canal will be divided between the two orifices. Where sufficient loss of head is available for this method, closer regulation may be secured.

Pipe turnouts are sometimes used as tube outlets for measurement. The variation of the shape of the opening for partly raised gates and the necessity for using special tables for these partial areas make them less satisfactory for measurement than rectangular openings. Such outlets more usually have metal gates with sharp edges which is an advantage in measurement. For full openings the disadvantages mentioned are not so important.

SPECIAL MEASURING DEVICES

Much thought and ingenuity has been spent in the design of measuring devices for use in irrigation. Although a great variety of such devices have been developed, none, as yet, has been able to combine accuracy, general adaptability and low cost to a sufficient extent to enable it to secure any general adoption. While the large number of such devices that might be used on large systems, should they be adopted, appears to furnish an attractive commercial opening for any such successful device, the price which such systems feel justified in paying for measurement does not leave a margin over actual cost for devices which have been suggested up to the present time. An increasing demand for the measurement of water together with a willingness to expend larger amounts for the devices used for that purpose may in the future supply a commercial demand for devices other than weirs and orifices. New devices are being developed continually, tests of which are being made available. While these are of interest, those responsible for the selection of measuring devices for any system will do well to give their attention to the adaptation of some of the forms of weirs or orifices to their particular conditions rather than in looking for new devices. Information regarding both these more standard devices and many special ones is given in various texts and bulletins, references to which are given at the end of the chapter.

The Venturi-meter principle has been adapted to irrigation conditions. The cost of construction and of the recording device has prevented its use to any extent. It is adapted to use with pumping plants as the excess cost is less where the meter can be built into the pipes used with the pumps. The cost can be somewhat reduced by depending upon single readings instead of using a recording device. The loss of head is small; it can be used over a considerable range of discharge or with water carrying silt; the meter itself has no parts to get out of order and the accuracy is relatively high. Efforts to reduce the cost by using rectangular sections have been made such as by contracting the area vertically in flumes.

Several measuring devices which control the rate of discharge have been devised. Under some conditions such devices may be desirable. Where relatively small streams are delivered continuously or where the head is limited to a certain maximum rate, a controlling device may be preferable. Where, however, the taking of water is not closely controlled so that water may be turned back into the canal, devices which do not increase their discharge when the canal stage rises may lead to breaks in the banks. If other use is not available for such excess water it is preferable to have it distributed among the other turnouts instead of passing down the canal to overload lower sections.

Although the orifice with a free discharge was the more general type in the earlier mining development, it is used to only a limited extent at present in irrigation practice. The larger amount of fall required for free discharge makes the use of submerged orifices more general. Where water is delivered through pipe lines carrying light pressures, deliveries can be made through such orifices. This condition exists on such systems in southern California and various types of orifices with free discharge are in use there. For very small deliveries, meters, such as are used in water-works practice, can be used. This is done in a few cases although such use is very limited in extent.

The Dethridge meter (Plate VI, Fig. D) is in use to a considerable extent in Australia. It consists of a drum on which there are projecting blades, the wheel being revolved by the water and measuring a given quantity of water at each revolution. The total quantity discharged at any given time is secured from the number of revolutions of the wheel as recorded by a counter and the rating of the meter. This device has the advantage that its action is easily understood and that the cost of securing the record is relatively small. The cost of installation is somewhat high; the cost of the type used in Australia has been about $40 each when built in relatively large numbers. The rating is also somewhat affected by the conditions of checking or depth of flow on the meter.

RECORDS OF INDIVIDUAL DELIVERIES

Computations.—Tables for the discharge of weirs and orifices of several kinds and of corrections for use where the conditions differ from the standard have been printed in many bulletins and books. These are necessarily more or less general in character and expressed in different units. In order to reduce computation tables to the minimum size so that they can be used more quickly it is desirable to prepare special tables covering only the types and sizes of devices used on any system expressed in the units in current use. These can be prepared as tracings and prints supplied for office and field use.

In order to regulate deliveries, the ditch riders need to make computations of the discharge in the field. These do not need to be carried to as close a result as is usual with the office computations; condensed tables which will fit into the field note books are preferable. In some cases these may also be distributed to consumers. Such tables can be very conveniently arranged for weirs of different lengths or for orifices of fixed areas. For orifices of variable area, more columns are needed if field multiplication is to be avoided and the tables become larger. The fewer the sizes and types of devices in use, the more simple are the tables needed. Such simplicity is of material advantage to the ditch riders.

Tables for office computation are needed both to secure the rate of flow and also the total quantity delivered in any time. Both computations may be combined in one table such as for any given length of weir a table may be prepared showing the head on the weir in the left-hand column and the discharge in acre-feet for various periods of time in the remaining columns. The changing of rates of flow in second-feet per day to acre-feet is comparatively simple as 1 second-foot flowing for 24 hours equals nearly 2 acre-feet (1.983 exactly) or 1 second-foot equals 1 acre-inch per hour.

Tables are usually preferable to curves for routine computations as they can be used more quickly and the results of the same measurement will always be the same. In taking quantities from curves, the interpolations may result in slightly different results from the same measurements as taken off at different times.

The computations for standard conditions are relatively simple. Any condition requiring the use of a correction factor not only reduces the accuracy but also materially increases the cost of computation due to the additional time required. Velocity of approach corrections for weirs are particularly troublesome to make, the necessity for such corrections should be avoided wherever practicable. Corrections for submergence require the determination of the percentage of submergence. This involves the use of two gage readings. The discharge that would result with the depth given by the upper gage when not submerged can be corrected by the proper percentage or the amount of submergence can be used to determine the equivalent depth without submergence for the same discharge. This latter method requires a somewhat smaller amount of computation. Curves can be plotted from which for any depth on the upper gage and amount of submergence as shown by the lower gage, the equivalent depth with free fall can be secured. This latter depth is used to secure the corrected discharge directly from the weir tables. Corrections for such conditions as suppression of contraction of orifices are fixed and are made as a certain percentage of all discharges. These can be taken into account in the computations of the discharge tables, the coefficient used being adjusted to the actual character of the opening.

Forms.—Nearly all the forms used in irrigation practice relate to the delivery of water or its measurement. The records of the ditch riders are very largely of this nature. Among the types of forms used are the various forms of ditch riders' reports to the company showing records of delivery, filing forms for office records, and computation forms. The purpose of a printed form is to standardize the record and reduce the labor and time required in securing data. Records filled in on forms where each item desired is specifically listed are much more liable to be complete than those taken as memoranda. At the same time, the use of forms should not be carried so far that data not essential or necessary is called for. A clearly arranged, compact blank form calling for the minimum of items is of much assistance in securing good records. The order of the items on the form should be the same as the usual order of observation and record in the field. Forms for application and notices of water delivery are discussed in Chapter IV.

Ditch Riders' Records.—The form of the daily records of the ditch riders depends principally upon the measurement of water. Where no records of individual deliveries are kept, the daily reports are mainly memoranda regarding maintenance, complaints or records of canal gages and in some cases no written reports may be required. Where individual measurements are made the daily reports consist most largely of the records on which the computations of the quantities delivered will be made. It is not generally considered desirable to have the ditch riders make such computations as their selection is based on other qualifications. They should understand measurement, however, in order to be able to deliver specified amounts. It is also not desirable to require or to permit copying of field records by the ditch riders. The original field record should be kept in such manner that it can be submitted to the office and if more than one copy is needed they should be secured by the use of carbons in the field. Such forms are usually bound in small perforated books or used in loose-leaf holders, the former method being more usual.

The field records of individual deliveries may be kept in two general ways. In one of these all deliveries on any day are recorded on a single sheet, or sheets by journal methods. In the other separate sheets are used for each delivery the record being added to each day during delivery. The first method is usually preferable as the records for each day can be removed from the field book and the loss of a field book can cause the loss of only 1 day's notes. The field records are usually posted on individual record cards in the office which show the complete record to each individual for the season. Where deliveries cover from 1 to 4 or 5 days and occur at periods of 2 weeks or more the second method may be preferable as the complete record of each delivery shows on one sheet. This is also necessary if the consumer is required to sign the delivery sheet.

Division ______________________ 7-303 JANUARY, 1914 Date ______________________ 191__

District ______________________

DAILY WATER REPORT

____
Canal Rider or Gate tender

Water user or canal or lateral served	Turn-out No.	Canal or lateral drawn from	Measuring device		Gage		Head in feet	Time Turned		Hrs. Run	Water delivered		Acres irrigated to date*
			Kind	Size	Upper	Lower		On	Off		Discharge in Second-ft.	Quantity in Acre-ft.	
								M	M				
								M	M				
…													
								M	M				
								M	M				
								M	M				
								M	M				

*To Canal Rider:–Unless otherwise directed by Project Manager, fill in this column only on reports for last day of each month, listing on such reports all the water users on your beat whether they receive water on that day or not.

Fig. 16.—Daily water report form, U. S. Reclamation Service.

Water user or canal or lateral served________________ Acres irrigable________________

________________ Sec.______ T.______ R.______

Turnout No.________________ Sec.______ T.______ R.______

Canal or lateral drawn from________________ Sec.______ T.______ R.______

Measuring device, kind____________, size____________ Sec.______ T.______ R.______

DAY OF MO.	GAGE		HEAD IN FEET	TIME TURNED		WATER DELIVERED				ACREAGE IRRIGATED TO DATE*	REMARKS
	Upper	Lower		On	Off	HOURS RUN	SEC.-FEET	ACRE FEET This Run	ACRE FEET To Date		
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						
				M	M						

*Canal Riders will fill in this column only for the last day in each month or as otherwise directed by the Project Manager.

FIG. 17.—Canal riders' book, used by U. S. Reclamation Service.

Various forms are shown in the illustrations. Form 7–308 (Fig. 16) of the U. S. Reclamation Service illustrates the type in which all records for a single day are placed on one sheet; form 7–311 (Fig. 17), the type where one sheet is used for each delivery over a longer period. In case form 7–311 is used the ditch rider may be required to prepare daily reports on form 7–308 by copying from his field records. The forms of the Twin Falls Canal Co., Fig. 18, provide for entering the amount delivered directly rather than the data on which the amount was computed. The charges on this system are not based on the quantity received; the record is used to limit quantities to $\frac{1}{80}$ second-foot per acre average flow. The reverse side provides for reports of

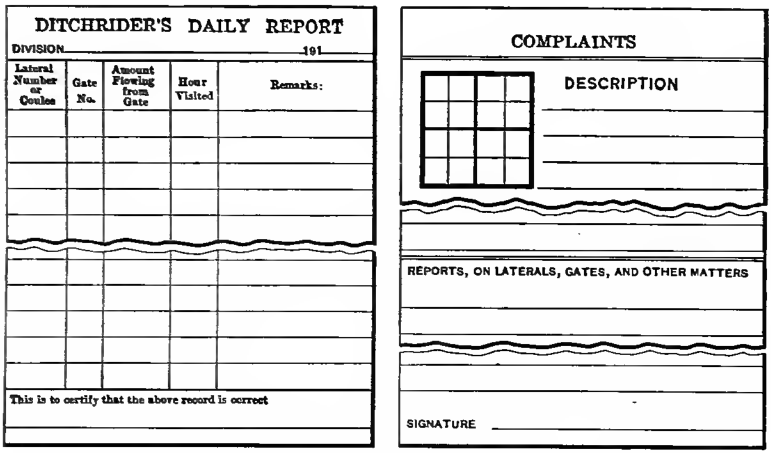


FIG. 18.—Form of ditch rider's daily report, Twin Falls Canal Co.

complaints and maintenance data. The form of the Patterson Water Co. provides, Fig. 19, for measurement either by gate under pressure or by open flow referred to under the column "Water" as width and depth and also includes columns for computation. The form of the Yolo County Consolidated Water Co., Fig. 20, is also arranged so that the charges can be carried out on the field report. Forms for separate sheets for each user are illustrated by those of the San Joaquin and Kings River Canal and Irrigation Co., Fig. 21, and of the Sacramento Valley West Side Canal Co., Fig. 22; the latter is secured in duplicate. The form used by the San Luis Power & Water Co., Fig. 23, is tacked to each weir. Both ditch rider and water user record the flow

PATTERSON WATER CO. — DAILY REPORT

LATERAL__________ DATE__________

NAME	LOT NO.	STARTED			STOPPED			WATER			GATE		HRS. RUN	SEC. FEET	ACRE FEET	CROP
		Hr.	Min		Hr.	Min		Depth	Width		Pres.	Opog.				
									Ft.	In.						

TOTAL__________

RECEIVED__________

DELIVERED__________

__________Ditch Tender LOSS (Explain on back)__________

FIG. 19.—Form for ditch rider's daily report, Patterson Water Co.

and time whenever the weir is visited, the gages being graduated to give quantities direct. At the end of each week the water

YOLO COUNTY CONSOLIDATED WATER COMPANY

Daily report by ________________ 1913____

WATER USER	TURNED ON Date	Hour	TURNED OFF Date	Hour	Head in Feet	Total Hours	Price per Hour		AMOUNT		ACRES	CROP

Fig. 20.—Ditch rider's daily report, Yolo County Consolidated Water Co.

user signs the card which is then turned in to the office. The ditch rider also keeps his own record in his field book.

FORM 948 20M-7-12 V & G

Section ________________ County ________________

Canal ________________ Gate No.________________

Water ordered by ________________________________

For account of ________________________________

T	R	SEC	LOTS	ACRES

Crop ________________ Distance from Canal ________________

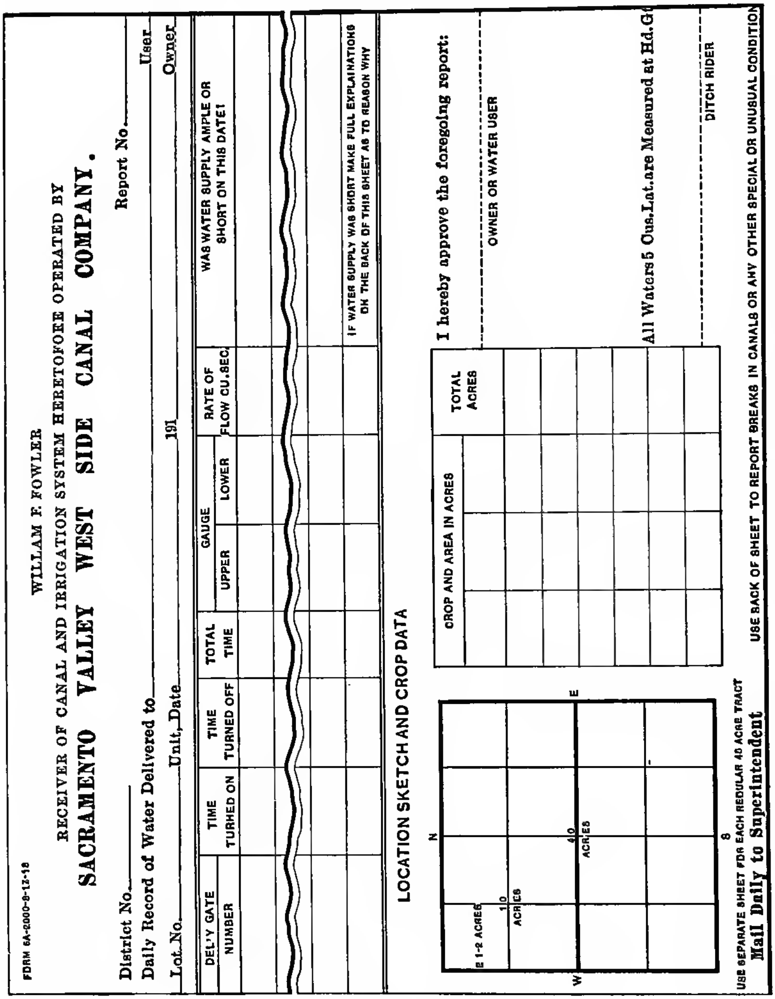
Soil ________________ Condition of Ditch ________________

	Date 191	Hour	Hours Flow	MEASUREMENTS Upper	Lower	Depth	Width
Turned on		M					
Measured		M					
"		"					
"		"					
Turned off		M					

________________ ZANJERO No.

Fig. 21.—Ditch rider's report of individual deliveries, San Joaquin and Kings River Canal & Irrigation Co.

In some cases books containing a number of different forms may be bound for use by the ditch riders. These may be used for the data for a definite period, usually a week, or the leaves may be removable as filled. In addition various tables of measurement of water or rules and regulations of the canal company may be bound with the forms. The forms of the Idaho irrigation district are well suited to systems handled with



FORM 6A-2000-8-12-18

WILLAM F. FOWLER

RECEIVER OF CANAL AND IRRIGATION SYSTEM HERETOFORE OPERATED BY

SACRAMENTO VALLEY WEST SIDE CANAL COMPANY.

District No.______ Report No.______

Daily Record of Water Delivered to______ User

Lot No.______ Unit, Date______ 191__ Owner

DEL'Y GATE NUMBER	TIME TURNED ON	TIME TURNED OFF	TOTAL TIME	GAUGE UPPER	GAUGE LOWER	RATE OF FLOW CU. SEC.	WAS WATER SUPPLY AMPLE OR SHORT ON THIS DATE?

IF WATER SUPPLY WAS SHORT MAKE FULL EXPLAINATIONS ON THE BACK OF THIS SHEET AS TO REASON WHY

LOCATION SKETCH AND CROP DATA

N, S, E, W; 2 1-2 ACRES; 10 ACRES; 40 ACRES

CROP AND AREA IN ACRES		TOTAL ACRES

I hereby approve the foregoing report:

______ OWNER OR WATER USER

All Waters 5 Cus. Lat. are Measured at Hd. G.

______ DITCH RIDER

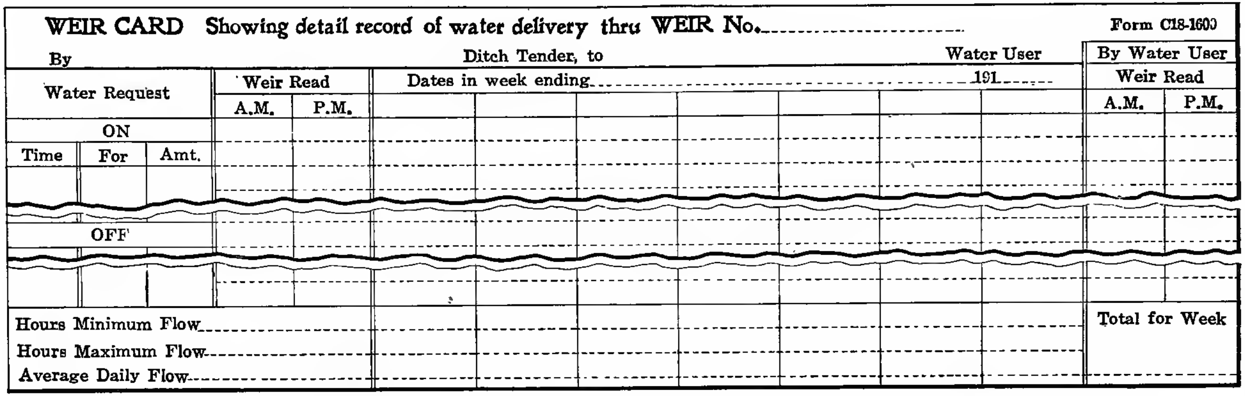
USE SEPARATE SHEET FOR EACH REGULAR 40 ACRE TRACT

USE BACK OF SHEET TO REPORT BREAKS IN CANALS OR ANY OTHER SPECIAL OR UNUSUAL CONDITION

Mail Daily to Superintendent

FIG. 22.—Ditch rider's daily report of delivery, Sacramento Valley West Side Canal Co.

less detail than is used with some other forms of organization. A sheet, Fig. 24, is used for each gate for each month, the record for the remainder of the month being on the reverse side. Deliveries are made on request from the water user on the form



WEIR CARD Showing detail record of water delivery thru WEIR No.____________ Form C18-1600

By Ditch Tender, to Water User

Water Request			Weir Read		Dates in week ending_______________191___							By Water User Weir Read	
ON			A.M.	P.M.								A.M.	P.M.
Time	For	Amt.											
OFF													
Hours Minimum Flow____												Total for Week	
Hours Maximum Flow____													
Average Daily Flow____													

FIG. 23.—Card for recording measurements of delivery, San Luis Power & Water Co.

THE IDAHO IRRIGATION DISTRICT

1912	JULY	1912

AMOUNT OF RIGHT GATE NUMBER

Name

Description of Land Served

GATE LOCATION

DAY	Received Order Number		Complied With Order No.		Quantity Running Before	Quantity Running After	Quantity Running	
1								
2								
10								
11								
12								
13								

Fig. 24.—Monthly record sheet for each water delivery, Idaho irrigation district.

TO THE WATERMASTER
OF THE IDAHO IRRIGATION DISTRICT:

Turn {ON / OFF}------inches of water for the undersigned at this gate (No.)------, on the---------- day of --------------------- 1914

Water User

Dated------------------1914

No.-----------
Received at Gate No.-------
Date ---------------------1914
Time Received --------- {A.M. / P.M.}

Complied with the within order by turning {ON / OFF}-----inches on the ----------day of--------- 1914

The amount of water running at the above gate after complying with this order is------------- inches

Signed ----------------------
Water Master

Fig. 25.—Form for request for water delivery and record of ditch rider, Idaho irrigation district.

7—309
January, 1914

WATER RECORD

Owner..
Address..
Tenant..
Address..
Division.................... District....................
Canal or Lateral..
Measuring device, Kind.............. Size..............

Irrigation season of 191.....
..............Sec.............T............R..........
..............Sec.............T............R..........
..............Sec.............T............R..........
..............Sec.............T............R..........
Irrigable area of farm..............................acres
Cultivated area of farm..............................acres

Turn-out No.	Dates		Length of run		Dis-charge in sec.-feet	Acre-feet delivered		Acres irrigated to date	Acre-feet per acre to date	Turn-out No.	Dates		Length of run		Dis-charge in sec.-feet	Acre-feet delivered		Acres irrigated to date	Acre-feet per acre to date
	On	Off	Days	Hrs.		This run	To date				On	Off	Days	Hrs		This run	To date		

FIG. 26.—Water ledger card, U. S. Reclamation Service.

shown on Fig. 25. The water master fills out the reverse side of the request giving a record of that delivery. The record of the ditch rider's book is also filled out. For each month the record sheet and cards for each gate are filed together and furnish a record of the delivery for that period.

Water Ledger Cards.—Various forms of individual water records are used. The data required for any one season can usually be contained on a 5 × 8 card and such card systems are generally preferable to book systems. The cards can be filed by land descriptions, key numbers or owners' names. Owners' names are usually preferable as the charges are carried to the ledgers under such names. Change of ownership requires a change in filing order of the record if names are listed alphabetically. This can easily be done with card systems. On large systems it is more convenient to subdivide the water-record files by ditch-rider beats, arranging all owners under each beat alphabetically. The field records are received by such beats and are more easily entered by using such divisions. Key maps showing each turnout, owners' names and divisions between beats are used with such systems. The form used by the U. S. Reclamation Service, Fig. 26, for such records is typical. This is ruled for use on both sides of the card, with a place for monthly summaries on the reverse side.

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CHAPTER VI

RULES AND REGULATIONS

The majority of the larger canal systems find it desirable to adopt a set of rules and regulations covering the operation of their systems and to print these for distribution among the water users. This is also done by a number of smaller systems. The laws of some of the States require that this be done in the case of irrigation districts. The public utility commissions also have jurisdiction over the character of service as well as the rates charged by public utility irrigation companies. The Railroad Commission of California in several cases has outlined rules which were considered to cover the essentials of good service on particular systems. Printed rules and regulations are used by some systems in all the States although their use is probably more general in California due to the greater number of commercial companies and irrigation districts operating there.

On large systems, some uniform practice in the delivery of water and control of the canal is required. Such practice can be embodied in the rules and regulations so that each land owner under the system may have a basis for judging whether he is receiving the service to which he is entitled. Such rules may also be of much assistance to the ditch riders when refusing to permit violations of the rules, as a definite policy as shown by the regulations eliminates much chance for favoritism and usually results in greater uniformity of service.

Rules and regulations should be clear, concise and to the point. They should be confined to the more essential points as too many minor regulations tend to reduce the relative importance of the more essential rules. The rules usually adopted can be divided into two general classes: those governing the relations between the users and the company, and those specifying the duties of the ditch riders. Copies of the latter class are frequently supplied to the users, as they have an interest in the extent of the authority and the duties of the ditch riders with whom they come directly into contact. The by-laws and in some cases the articles of incorporation of the company, particularly for coöperative companies and irrigation districts, are frequently printed with the rules and regulations. In some cases the rules of operation may be included in the by-laws although it is preferable to confine the by-laws to such matters as the place of business, meetings of officers, and the election, titles, and duties of the various officers, leaving the preparation or modification of rules and regulations to the officers selected for their enforcement. With commercial companies certain of the more important points involving delivery of water and operation of the system may be included in the water-right contracts. This is desirable from the consumer's point of view as they do not have control over the officers of these companies such as they do have in the various coöperative forms of organization. Where commercial companies come within the classification of public utilities under commission control such contract provisions may not be as essential.

In the following discussion, the rules and regulations in more general use are given in considerable detail. From these rules a selection of those desirable for any given system may be made, the rule itself being drawn to meet the local needs. No one system will require rules on all the points given and some systems may require special regulations in addition to those mentioned.

In the appendix the complete rules and regulations of four typical systems are given. The rules of the Idaho irrigation district are brief, the addition of the reasons making each rule necessary being somewhat novel but effective. Such rules are suited to those systems operating under relatively simple conditions. The rules of the Turlock irrigation district are also brief. They are suitable for a system using rotation delivery with large delivery heads and water supplies which become less than the demand during the later season. The rules of the San Luis Power & Water Co. are typical of those used by such companies in the mountain States. The rules of the Fresno Canal & Irrigation Co. represent the practice required for utility companies by the California Railroad Commission.

Control of Canal System.—A general rule used by practically all systems states that all canals, structures, gates or other company property are under the exclusive control of the canal company and its officials and that no others are permitted to interfere with or change any canals or gates. Others state that no gates shall be changed by any one except the ditch rider. This provision may be inserted even where it is the intention to permit changes by users under certain restrictions as having such a rule gives a basis for refusing permission to make such changes to those that abuse the privilege. In many States it is a misdemeanor for any one to interfere with or change gates or to take water unlawfully and such statutes are frequently appended to the rules. The complete control of gates by the ditch rider is necessary where canals are operated at maximum safe water levels or where closely controlled and uniform delivery of water is attempted. On some systems, particularly the older ones, the land owner may be required to either install or to pay the cost of installing his delivery gate. In such cases the control of the gate should be specified as the ownership of it by the land owner may exempt him from penalties for changing it. The penalties for violation of rules regarding changing of gates should be given. Reliance may be placed on the statutory penalties of fine following prosecution or the canal company may enforce other penalties such as the loss of the next turn in rotation or charging for double the quantity of excess water procured. Prevention is preferable to reparation. The rules of the companies given in the appendix are typical. Many rules state the practice of the company in regard to locking headgates. The following rule of the Orchard Mesa irrigation district in Colorado is representative:

"From and after this date, all headgates on delivery ditches shall be forthwith fitted with locks on the installation thereof, and all headgates to such ditches now in existence shall forthwith be fitted with locks so as to aid the Board of Directors, its officers and agents, in regulating the flow of water therethrough."

Obstructions to canals may be specifically prohibited. Such rules include fences across ditches, gates, and bridges on private roads. The following is a typical rule:

"No fences, bridges, ditches, buildings or other obstructions shall be placed across or upon, or along any canal, ditch, right of way or property of the Company without first obtaining the written permission of the Chief Engineer stating the time, conditions and other regulations governing the same."

Access to Land.—Nearly all companies reserve the right to have access to the land irrigated both for purposes of inspecting the crops, use of water and condition of farm ditches and also for the purpose of crossing or using the land adjacent to the canal in the case of emergency repairs. The rules given in the appendix and the one which follows are typical:

"The ditch riders or other agents of the company shall have free access at all times to lands irrigated from the canal system, for the purpose of examining the canals and the flow of water therein, or for any other purpose connected with the distribution of water or the operations of the company."

Location of Gates.—A rule covering the location of delivery gates is frequently used. Such rules may specify the conditions, if any, under which more than one delivery per farm may be permitted or the maximum distance from the farm at which delivery may be made. Instead of specifying the conditions under which gates may be installed, it is perhaps preferable to require permission for the installation and secure such control through the granting of the permission in each case as may be suited to the particular conditions. The rules of the Turlock and Idaho irrigation districts are in point.

Rights of Way.—Various rules regarding the use of canal rights of way by adjacent land owners may be used. The following rules of the Sacramento Valley West Side Canal Co. cover all such conditions which need to be met:

"No trees, vines or alfalfa shall be planted on the right of way of the irrigating system controlled by the Receiver, and all such growing on such rights of way shall belong absolutely to the utility. Permission, however, may be granted by the Receiver, under such restrictions as may be deemed expedient, to raise annual crops thereon, or to use such rights of way for other purposes.

"When any right of way is plowed or cultivated for any purpose the furrows shall always be turned or thrown toward the embankment.

"No cattle, horses or hogs will be allowed to graze upon the right of way of any canal operated by the Receiver, but an irrigator may, upon proper application being made to the Superintendent and approved by him, fence the right of way of any canal crossing his land and may have free use of the same for the pasturing of sheep or goats.

"No fences or other obstructions shall be placed across, or upon, or along any canal bank or right of way of any canal or ditch operated by the Receiver without his special permission. Whenever such special permission shall be granted it shall always be with the distinct understanding that proper openings or passageways for teams shall be provided, and that such fence or obstruction must be removed whenever requested by the Superintendent.

"Persons are prohibited from crossing canals and laterals operated by the Receiver with wagons or other vehicles which may cause any injury to the embankment of such canals, and should a canal bank be injured from this cause, the cost of repairing the same will be charged to the land owner through whose land the injured portion of such canal may pass.

"Bridges may be constructed by the land owner at his own expense across canals or laterals operated by the Receiver, under the supervision of the Receiver's representative, upon proper application being made and approved. Such bridges shall be maintained by and at the expense of the land owner. Should the flow of water in a company lateral be obstructed or retarded by a bridge constructed by a land owner, such bridge shall be removed by order of the Receiver, or the Receiver may remove the same at the expense of said land owner."

Maintenance of Laterals.—Where water is delivered to the heads of laterals only, a rule permitting the main-canal company to refuse to make delivery to any lateral not in proper condition is usual. Similar rules applying to farm ditches are also frequently used where delivery is made to individuals. The rules for the four systems given in the appendix are typical. The rule on the Fresno Canal & Irrigation Co.'s system is suitable for those systems where the operation of the laterals is being gradually taken over by the main system. On some coöperative systems the land owners under each lateral may maintain it although delivery is made to individuals by the main-canal organization. A similar rule requiring the lateral to be in good condition before water will be turned into it is necessary in order to secure proper maintenance in such cases.

The following rules are typical of those used by different systems:

"Before water is furnished to any private distributing ditch the land owners receiving water therefrom must agree upon and sign rules and regulations satisfactory to the Board of Directors, providing for the repair, maintenance and distribution of water from such ditch, authorizing some one to represent the users in all conferences with the ditch tender, and providing for the apportionment of water, subject to all rules and regulations of the district." Modesto irrigation district.

"The Receiver will not be liable for any damages resulting directly or indirectly from the water flowing in any private ditch, but the responsibility of the Receiver shall absolutely cease when the water is turned into the same. At the beginning of the season, and before water will be turned into any private or party ditch, such ditch shall be put in good repair and vegetation shall be removed so that water may be conducted with as little loss as possible. Such work shall be done to the satisfaction of the Superintendent." Sacramento Valley West Side Canal Co.

"If the irrigator desires to take water through a private ditch which, in the opinion of the Zanzero, is too dirty or badly constructed to carry water without unusual loss, such loss will have to be borne by the irrigator; that is, the water will be measured before it enters the ditch." Anaheim Union Water Co.

Delivery of Water.—The rules governing delivery of water are the most important ones dealing with the relations between the irrigators and the canal organization. The character of the rules used for any system depends on the method of delivery used and as such methods vary widely the rules required differ materially.

The rules of the Turlock irrigation district are suited to rotation delivery on a time schedule per acre. The rules of the Fresno Canal and Irrigation Co. are in more detail, particularly in regard to delivery during times of less than full supply. More detailed and specific rules are usually desirable in the case of commercial companies than for those operated by the land owners. The rule IX of the Idaho irrigation district is representative of the greater simplicity possible for continuous-flow delivery.

The rule of the Coneland Water Co. is to the point:

"Water will not be delivered in continuous run, but will be delivered in heads as large as the water user can handle, in no case less than 40 miner's inches; the time of use being reduced in proportion to the head delivered. Water in excess of the contract amount will not be delivered."

A clear explanation of the method of delivery is given in the following rules of the Sacramento Valley West Side Canal Co.:

"For convenience and in order to facilitate the distribution of water, the lands under the canal system are divided into lateral districts.

"Each lateral district is divided into rotation sections, each section comprising as many irrigators as can be served by one irrigating head. Rotation sections may be changed by the Superintendent from time to time in accordance with the increase or decrease of the acreage of land under irrigation.

"The water will be apportioned to each lateral district and in case of shortage in the supply the apportionment shall be made in accordance with the acreage actually being irrigated in each district.

"Water will be furnished in serviceable heads in turn or rotation to each consumer in a rotation section, except that when agreeable to the Superintendent, consumers within a rotation section may exchange turns for mutual accommodation, provided such exchange will not alter the schedule of rotation for other consumers.

"The Superintendent will give notice of the beginning and duration of each run of water as far in advance as possible, and will notify each consumer in advance when the water will be available to him during each run, and further notify him of any change in the time of delivery. A consumer who fails, through his own fault, to use his allotment or irrigation head during any rotation period will not be entitled to any extra allotment during a later rotation period.

"Each consumer will be allowed not to exceed 6 acre-inches for each acre under irrigation during any rotation period, for crops other than rice. Water will be furnished under serviceable irrigation heads, the size of which will depend upon the character of the crop and the area of the land under irrigation of each irrigator.

"The time of use shall begin when the gate is opened, turning water from the canals or laterals operated by the Receiver into the farm ditches of the consumers, and water must be used continuously night and day until the quantity has been delivered.

"Water will be furnished for rice lands under such heads and for such periods as may be required for proper irrigation of this crop up to the full amount applied for."

The following rules apply to rotation delivery among small holdings such as in orchard areas:

"It shall be the duty of the distributing Zanzero to deliver water in regular runs beginning with the lower ditches, and deliver up in regular order. In case there is a surplus of water, the Zanzeros may suspend the run by direction from the Ditch Committee, which, however, must be resumed as soon as the surplus ceases. The Ditch Committee shall determine the order in which the main distributing ditches shall be served. The Zanzero may pass an irrigator, who is unavoidably prevented from taking water in his turn, and afterward return to him, when this can be done without injury to the interests of the company.

"The Zanzero is to give the irrigator 24 hours notice of the delivery of water.

"It shall be the Zanzero's duty to see that water arrives, and continues to flow to the land being irrigated (as per notice previously given) in as uniform stream as possible.

"A less head than 50 inches shall not be delivered, except when the irrigator is willing to accept his measurement at the main distributing ditch. In such cases any head down to 25 inches may be delivered."

A rule used by a Colorado system is as follows:

"The periods of rotating water delivery to all persons shall be charged against them by day and night, and no extension of time will be granted to any person by reason of the fact that he does not wish his water delivered in the night time."

Application for Water.—The methods used for handling applications for water differ widely. For delivery under continuous flow no application may be used. The same may be true for fixed schedule rotations. For irregular rotation on demand, an application is needed. The rules governing such applications generally specify the form of application, the place or officer to which the application is made, and the period of notice required in advance of delivery. In some cases seasonal applications are required. These are needed to secure the acreages of different crops in planning rotation schedules. Commercial companies require such advance applications in order to secure themselves for the payment of charges.

The rule of the Turlock irrigation district applies where the acreage is required in planning rotation schedules. Rule 3 of the San Luis Power & Water Co. is suited to delivery on demand controlled by a maximum amount of use. The last portion of this rule will be of material assistance in operation, particularly during the earlier years of a system when the irrigated areas may be scattered.

A rule used by one public utility company is as follows:

"Parties requiring water for irrigation must make application therefor in writing to the company's canal superintendent at least ten (10) days before the water is needed, designating particularly the land and number of acres for which water is required. Payment for the water applied for must be made in advance at the time of application."

The period of notice required in this rule is longer than that usually specified. Three days notice is typical. Such periods represent the maximum with most systems; if 3 days notice is required, the company may delay delivery for this period but usually endeavors to comply with the request in a shorter time.

The rule of the Idaho irrigation district given in the appendix is suitable for continuous-flow system. The need for such a regulation is also tersely expressed.

Seasonal applications for commercial companies usually include the area to be irrigated, its location, the character of crop and in some cases an estimate of the amount of water which it is expected will be used. Such applications are generally required by some date in advance of the operation season if service for that year is to be secured. Arrangements for the payment of charges must usually be made at this time. In case of a shortage in the supply, preference may be given in order of application. In cases where such application was not made and service is later desired, the following rule is used by one company:

"If such application has not been made according to this rule, the irrigator must make application in writing to the Chief Engineer at least 10 days before the time irrigation is desired, and such irrigator shall only be alloted water as is consistent with the deliveries arranged for by the Company under applications theretofore made."

Where land is rented an authorization must be filed by the owner to enable the tenant to make application for water.

Minimum Period of Delivery.—Where water is delivered on demand some limit to both the minimum time of delivery and the minimum quantity are needed and a rule specifying such limits is frequently used. The usual limit of time is 24 hours; the limit of quantity for irrigation ½ second-foot, except on systems supplying orchards. Smaller quantities may be delivered for stock use. For such small quantities a minimum charge per delivery which is at a higher rate than that charged for average conditions is usual.

"This company will not deliver water for a shorter period than 24 hours, nor for a less amount than ¼ second-foot, 12½ inches, except stock water, and the minimum charge of 25 cents will be made when the amount does not exceed ¼ acre-foot." Imperial Water Co. No. 1.

Measurement of Water.—Rules regarding measurement of water cover the location of the point of measurement, the character of the devices to be used, the records to be kept and the furnishing to the land owner of statements covering the amount of water he has received. In addition a number of systems print with their rules, principally for the use of ditch riders, tables for the discharge of various devices in use on the systems and instructions for making measurements and computing the result. The rule of the Fresno Canal and Irrigation Co. given in the appendix is typical of those suitable for a system delivering mainly to laterals rather than to individuals. On systems using flat acreage or stock assessment rates, measurement is not usual and rules regarding it are not needed. Some rule requiring the user to sign a receipt for delivery is, however, frequently used on systems delivering on rotation. Such receipts are evidence that water was delivered and where fairly uniform heads are used, the time during which water is given to any farm is a rough measure of the quantity received.

Apportionment in Time of Shortage.—In case of actual deficiency in supply some regulation regarding the division of such supply is needed. On many systems the late season supply may be less than the demand in all years, in others such shortage may occur only in years of less than normal runoff. The available supply may be prorated or the preference given to certain crops. The rules of the Fresno Canal and Irrigation Co. are quite complete and drawn to prevent discrimination between users under this commercial company. Prorating when used may be based on the irrigated area for the year or on the basis of the amount of canal stock or shares held. Some companies give the canal officers authority to enforce rotation during periods of shortage where continuous flow or delivery on demand may be used at other times. Such rotation may extend to the parts of the canal system as well as to individuals.

The following rule of the Modesto irrigation district gives preference on the basis of the kind of crops:

"In case of shortage in water priority will be given first to garden crops; second, to first-year trees, vines and cuttings so far as such water may be necessary to keep such trees and vines alive."

Interruptions in Service.—When delivery is made in rotation or on demand some method of adjustment of delivery schedule is required when service is interrupted due to canal breaks or other causes. The rule of the Turlock system is typical; for breaks on the individual delivery ditch the water is placed to the next irrigator in order; for breaks on the lateral the schedule is advanced for the time lost.

Stock Water.—Where water is not delivered continuously some arrangement for the delivery of small streams for stock use during the regular irrigation season may be required. Such deliveries may in some cases also require winter operation of the system. In some cases extra charges may be made for such service at a certain rate per head for various kinds of stock or at a fixed charge per delivery.

"Upon written request, the superintendent may permit pipes, where a check is not required, not to exceed 2 inches in diameter, to be placed in the banks of the canal for the purpose of drawing water for stock and domestic use, and a minimum charge of $6 per year per pipe will be charged, payable in advance by all stockholders so served." Imperial Water Co. No. 1.

Waste.—A rule giving the canal company the right to shut off water which is being wasted is usual. This is necessary if the supply does not exceed the needs.

Rule III of the Idaho irrigation district given in the appendix covers the wasting of water into lower canals.

The following rule used by one of the California irrigation districts covers this matter in detail:

"Persons wasting water on roads or vacant land, or land previously irrigated, either wilfully, carelessly, or on account of defective ditches or inadequately prepared land, or who shall flood certain portions of the land to an unreasonable depth or amount in order to properly irrigate other portions, will be refused the use of water until such conditions are remedied."

Terms of Payment.—The terms of payment both as to amount and time, are particularly important in the case of commercial companies. Questions of assessments and payment are more usually covered in the by-laws of coöperative systems.

The rules of one commercial system having both a flat acreage and a quantity rate are as follows:

"Cash or certified check covering 10 per cent. of the estimated total charge for the season based on the rates established must accompany each application. The balance to be paid in five equal monthly installments; such payments may be evidenced by promissory notes, dated the first day of each month, beginning May 1, 1916, all payable Nov. 1, 1916. Such notes to be secured by a crop mortgage which shall be a first lien on the crop, or in case such crop mortgage cannot be given, then other security shall be given to the satisfaction of the Receiver. Notes to bear interest at the rate of 7 per cent. per annum.

"The Receiver will discontinue the service of water to consumers during such time as the above terms are not complied with.

"In case of measured service the application must be accompanied by cash or certified check for 20 cents per acre for agricultural crops and 70 cents per acre for rice crops, and notes shall be given for balance to be paid on the basis of flat rates. Before any water is delivered in excess of the amount the consumer is entitled to by the payments made and notes given, he shall give a promissory note, secured as above, for the additional amount estimated to be delivered. Should the amount of water delivered as determined at the end of the season be less than that to which the consumer is entitled by payments made and notes given, a rebate will be made to him covering the difference."

The following rule is used by the Imperial Water Co. No. 1, a coöperative system using a quantity rate:

"All water accounts are due on the first day of each month. Any user of water who has not paid by the 15th of the month for water used for the preceding month will be placed on the delinquent list. His delivery box will be locked by the Zanzero in charge and no water will be delivered to him until such delinquent charges have been paid."

The greater number of coöperative companies levy assessments against the stock, the stock being sold when delinquent. As delivery is based on the ownership of stock, no operating rule regarding delinquencies is required. For irrigation districts the charges are generally levied as taxes against the land and the district handles delinquencies through tax-sale methods rather than by refusing delivery. The Oakdale irrigation district in California has a rule, however, that no water shall be furnished until the charges for the preceding year have been paid. The right of commercial companies to refuse delivery due to non-payment of previous charges involves many legal points, so that such rules may not always be enforceable.

Complaints.—Some rule defining a regular procedure for handling complaints is desirable. The general subject of complaints is discussed on page 218. Requiring the complaints to be in writing and to be presented within from 10 to 15 days of the occurrence of the cause are usual rules. The following rules are typical:

"Any claims for shortage or irregularity in any run must be made in writing to the superintendent of this company within 5 days from the completion of the run.

"Complaint from the decision of the Zanzero should be made to the superintendent; from the action of the superintendent, appeals may be made to the board of directors." Imperial Water Company No. 1.

"No complaint will be considered by the Receiver unless made in writing and filed with him within 10 days of the time the acts complained of have occurred.

"Appeals may be made from decisions of ditch tenders to the Superintendent; from the action of the Superintendent appeal may be made to the Receiver of the company.

"Any complaint regarding service or application of rates may be referred to the California Railroad Commission." Sacramento Valley West Side Canal Co.

Liability of Company.—Rules defining the extent of liability, or what is more often the lack of liability, for damage caused by water after its delivery from the canal; for failure to deliver due to breaks or deficient water supply; and for such other points as local conditions may require, are frequently used. The responsibility for a failure of the water supply itself is usually defined in the water-right contract of commercial companies rather than in the rules. For coöperative companies available supplies are divided under rules discussed under apportionment in periods of scarcity.

The rules of the Turlock irrigation district and the San Luis Power & Water Co., given in the appendix, are typical. Other rules are:

"As the company has no control over ditches constructed by farmers and land owners on their property, or of the water after it has left the discharge gates in the canal, the company will not be responsible for any damage accruing from waste or overflow over public roads or the lands or crops of others, and the takers of water alone are liable for such damage." San Joaquin & Kings River Canal & Irrigation Co.

"The Coneland Water Co. will not be responsible or liable for any damages resulting directly or indirectly from the overflow of water on adjoining lands unless the same is caused by neglect on the part of the company."

Liability of Irrigator.—A statement of the liability of the irrigator for acts which may result in injury to the canal system is desirable. The extent of such liability or the injuries to be avoided differ on different systems. The following rules are typical:

"All water users will be held to a strict accountability for damage to company canals caused by their turning a head of water being delivered to them back into the company canals. No one except the Zanzero has any authority to turn water into or out of the company's canals." Imperial Water Co. No. 1.

"Each water user will be responsible for all damages caused by his wilful neglect or careless acts to the property of the Company or others and upon his failure to repair such damage, after notification by the

Company or its representatives, such repairs will be made by the Company, at the irrigator's expense, and the water will be shut off until payment is made." Coneland Water Co.

Penalty for Breaking Rules.—In order to secure the enforcement of rules, penalties for their violation are required. Such penalties are usually either a loss of water or an excess charge.

"Refusal to comply with the requirements hereof, or transgression of any of the foregoing rules and regulations, or any interference with the discharge of the duties of any official, shall be sufficient cause for shutting off the water, and water will not again be furnished until full compliance has been made with all requirements herein set forth." South San Joaquin irrigation district.

"Any violations of the law or the foregoing rules must be reported by the Zanzero to this office. The company reserves the right for any violations thereof to cease supplying water to the person so offending until satisfaction is made." Fairview Land & Water Co.

Miscellaneous Rules.—Various miscellaneous rules may be required by local conditions. Where the water is used for domestic or stock purposes, a rule against pollution may be needed. Such rules prohibit allowing any refuse, manure, dead animals or other offensive material to get into the canals.

A rule permitting modification of the general rules for emergencies or special conditions may be used. This is not generally desirable as the right of the officials to make such modifications is generally understood and to specifically call attention to it may serve to weaken the force of the other rules.

CHAPTER VII

PAYMENT FOR CONSTRUCTION AND OPERATION CHARGES

The charges against the lands under an irrigation project are of two kinds: those for the cost of construction of the system, and those for its operation. Both of these charges must be met by the lands irrigated either directly by repayment, or as under some public utility systems, by the payment of interest on the construction cost. The methods of distributing these two kinds of charges and the terms of payment differ, so that they can be discussed separately.

CONSTRUCTION CHARGES

The construction or building charge covers the cost of the construction of the canal system and is only paid once; the payment usually extending over a period of years. Usual improvements are generally classed with maintenance or betterment work. Supplemental work, such as the provision of storage or extensive betterments, may be handled in some cases in the same way as the original construction work and its payment extended over several years.

With systems constructed by the land owners the construction charge is equal to the actual cost of building the system. This applies to coöperative companies and to irrigation districts which carry out the original construction themselves instead of purchasing systems already built by other forms of organization. In the past such forms of organization constructing systems for their own use without profit have been in the majority, both in actual numbers and also in total extent of area covered. At present the new developments in large units are being made more largely by other forms of organization which eventually plan to transfer the control of the system to the control of the users. The construction charge may include a profit, as in Carey Act projects or systems constructed by private corporations where the cost of construction is less than the price received. It may, and in some cases has, included a loss where the cost of construction or the time required for settlement has exceeded the estimates.

Apportionment of Construction Costs.—There are two general methods by which the total construction charge may be distributed to the irrigable land: one being at a uniform rate per acre of irrigable land; the other on the basis of the benefits received or at a variable rate per acre.

The uniform rate per acre method is the more usual. It has the advantage of simplicity in application. On any given system the actual cost of construction for the different parts of the system naturally varies; the headworks and diversion canals are common to all the lands, the cost per acre of the distribution system will vary with the topographic conditions. Lands nearer the upper portions of the projects may be served at a low cost. It would not be practicable to fix the charges on the actual cost of construction to each area, as those lands most difficult to reach might require a charge in excess of the benefit received. A difference in construction charge is sometimes made between distinct units of large systems which have been constructed at different times or at different actual costs. There are other systems where the actual cost of construction between different portions of the project may vary to a considerable extent and yet a uniform charge be made to all lands. This is the case in some pumping systems where more than one lift is used.

Effect of Form of Organization.—The construction charge may be assessed directly or indirectly against the lands. In coöperative organizations, such as mutual or stock companies, the charges are assessed against the stock rather than directly against the land. However, the owners of the stock are the owners of the land, the stock being held in proportion to the irrigable area owned, such as in companies issuing stock, one share of which entitles the owner to water for 1 acre of land. This is essentially a uniform rate per acre basis, although in some cases one owning land with porous soil or otherwise requiring excess amounts of water might also own or rent excess stock.

On Carey Act projects the construction charge is fixed by contract between the State and the constructing company. This has generally been on a uniform rate per acre basis. In some States the rate fixed is the maximum which can be charged by the company. This enables the constructing company which also handles the colonization to reduce the price on the poorer lands if desired. Such differences in price that may be made are due to differences in the value of the lands, such as roughness, poorer soil or other factors rather than to a variation in the price of the water right. Such a method would represent an approximate charge on the basis of benefit. The purchasers of Carey Act lands have generally paid uniform rates per acre for their water rights, however. On the projects of the U. S. Reclamation Service, the construction charges are made at a uniform rate per acre for each unit of the different projects.

The irrigation district laws in Idaho, Nevada and Washington require that assessments shall be made on the basis of the benefits of the land. In California, Nebraska and Texas an ad valorem basis must be used, lands being assessed for their value, the improvements being exempted. The other seven States having irrigation district laws (Arizona, Colorado, Montana, New Mexico, Oregon, Utah, and Wyoming) provide that all lands shall be assessed at the same rate per acre. In California the ad valorem basis was originally adopted, due to uncertainty as to the legality of other methods. In practice the ad valorem basis may be similar in result to the benefit basis. It resembles the flat rate per acre in some districts where values are based on distance from towns rather than water requirements or production. On systems built by private companies the price of the combined land and water may be varied in different parts of the system or for different individual farms. This variation is more usually due to differences in the value of the lands, rather than variations in the construction charges.

Comparison of Flat Rate and Benefit Charges.—These examples indicate that the uniform rate per acre is the more usual basis for assessing construction charges. This is particularly true of the smaller systems where the variation in soils and topography is usually less. On the large systems this method is also generally used except for projects divided into separate units. Within such large projects the soil and topography naturally vary more widely than on smaller systems. On the more porous soils or rougher lands the returns per acre from cultivation may be less and the cost of construction greater than for the lands having more uniform topography. In such cases the basis of benefit or value of the water to the land—an application of the principle of "what the traffic can bear"—may be necessary, rather than the average cost of construction. When such conditions are extreme, it is better to exclude such lands from the irrigable area.

The adoption of a benefit basis for the payment of construction charges has been retarded by the difficulty of its application. The benefits are not fixed amounts, but change with changing conditions of ground water and other factors. Their determination at the beginning of the operation of any system involves elements of prophesy as to future conditions which render the results uncertain. Some of the States requiring the use of the flat acreage rate for assessment in irrigation districts also require a benefit basis for drainage districts. Such a basis can be applied much more easily to drainage districts as the damage done to the land is a measure of the benefit that will result from its drainage.

The cost of construction on the more expensive systems may exceed the value of the water to some of the poorer lands under the system. The exclusion of such lands would increase the cost per acre of serving the remaining better lands, so that it may be profitable to sell rights to the poorer lands at prices somewhat lower than the average cost of construction. On the earlier and less expensive projects, the value of the water to all irrigable lands was generally greater than its cost. In the more expensive systems now being built this may not be the case and the uniform rate per acre basis of construction charge may need modification to fit these conditions. Among such methods may be the division of projects into units, the lands within which have similar conditions and which are charged similar amounts per acre or a charge based on actual estimated benefits to each tract. Such methods can be most easily applied where the organization fixing the construction charge also fixes the price of the land, as in colonization projects handled without public control or for systems handled under irrigation district laws where the method of assessment is fixed by law.

Up to the present nearly all charges are based on the irrigable area with some limit as to the maximum amount of water which will be furnished per acre. Charges per acre with a specified rate of supply, such as 1 second-foot to each 80 acres, or a delivery of a certain maximum number of acre-feet per acre make the area, rather than the water used, the basis of the charges.

Such rates of use are usually sufficient for the more porous soils; land requiring less than average amounts of water secures no advantage in the construction charge. On projects supplied from storage where the cost of construction consists more largely of the cost of storage, a construction charge based on water used would more nearly represent the cost of service. Where stock in coöperative companies is held in proportion to the water requirements of the lands, the construction cost is more nearly based on the water used than on the area of the land. Where the water available rather than the amount of land is the limiting factor in development, a building charge based on the extent of use without regard to the area on which it is used may be desirable.

Classification of Irrigable Area.—Both construction and operation charges are generally based on the net irrigable area. In some States irrigation districts assess against all lands within the district which may, as in California, include town lots. Provisions, are, however, made in all States for excluding from the districts lands which are not physically irrigable. The classification of the land in a system becomes of importance in many cases. In the smaller systems, more common in the past where the cost per acre of construction was usually less than in the systems now being built, the total difference in the charge to any farm due to minor classifications of the irrigable area were not as important and the gross area was more often used. With the higher costs now more usual on the large systems, closer classification is demanded.

If the total irrigable area is to bear the total cost, the exclusion of those areas which affect all farms to about the same extent will not materially affect the cost per farm. Such might be the case in regard to roads which for farms of about the same size will be a small and usually fairly uniform proportion of each farm.

The rules for the classification of irrigable land vary with different systems. Among the methods used are the following. The areas as shown by the U. S. Land Office plats are usually accepted unless actually known to be in error by some minimum percentage or acreage, such as making no correction of less than 1 acre. Land which is rocky, alkali, seeped, high, or consists of borrow pits or creek channels may be deducted if the cost of clearing, reclaiming or levelling exceeds some figure of cost approximating the value of the land when made irrigable. Such costs will vary widely with different systems and localities. Land having slopes of over 10 or 20 per cent. may be deducted, steeper slopes being included where the soil is relatively deep. Lands having less than a certain depth of soil, such as 1 foot, over rock or hardpan may be deducted. The extent of high areas is determined by running out grade contours from the delivery box on flat grades which for small ditches are taken from 0.05 to 0.10 feet per 100 feet. All deeded rights of way such as roads, canals and railroads are usually deducted, rights of way consisting of easements more usually are not. Rights of way for canals over a certain capacity or width of right of way may be deducted and smaller ones included. Private roads are not deducted. If the total non-irrigable land does not exceed some fixed amount such as 1 acre or some percentage of the total area, no deduction is made. Individual areas are determined to the nearest 0.2 to 1.0 acres in different systems. The methods used vary on different projects, due to differing local conditions. A method relatively fair to different farms is more essential than one actually exact. The irrigable area on any farm is not a fixed quantity. It may gradually be increased as land values increase by the levelling of borrow pits, grading of knolls, etc. It may also be decreased by new roads or water-logging.

Terms of Payment.—The terms of payment by the land owners vary with the form of organization. Where the systems are constructed by the organized owners of the individual farms, as in districts or coöperative companies, the collective credit of such owners may be used to finance construction and the time of payment extended over relatively long periods of time by means of bonds. Interest must be paid on such funds. The usual rate on the face value of irrigation district bonds is 6 per cent. The terms of sale for such bonds have been such in many cases that the actual rate has materially exceeded this rate. In some States the laws permit the payment of interest for 1 or 2 years to be made from the funds secured by the bonds themselves. Irrigation district bonds are issued for periods of from 20 to 40 years and are usually retired at a graduated rate during the second half of their life. With coöperative companies borrowed funds are more usually secured on notes for shorter periods of time. In many cases the full or a large part of the construction cost is assessed directly to the stock and the individual stockholders required to finance their own portion of the cost.

On systems built for sale with the lands the terms are often based upon the condition of the land market and resources of the constructing company. The present tendency is to make the terms of payment as liberal as the condition of the constructing company will permit, interest at usual rates being charged on the deferred payments. Payments extending over periods of from 6 to 15 years, graduated in some cases, are used by different systems. The payment during the first years after purchase may be made low, in order to enable the settler to use his resources in improvements on the land.

The experience of the U. S. Reclamation Service has been of interest in this regard. The original act provided that the building charge should be paid in 10 equal annual installments without interest. This was found to be too burdensome for the settlers on many projects and in 1914 a law was passed granting a total of 20 years for the repayment of the building charges on a graduated scale. For new entries this is to be 5 per cent. at time of entry, with no further payments for 5 years, 5 per cent. per year from the sixth to the tenth year, and 7 per cent. per year for the remaining 10 years. As no interest is charged, this is equivalent, at usual rates of interest, to reducing the cash value to the settler at the time of entry to about one-half the face value. The inability of settlers on many systems to meet the annual payments on the construction charge where the period of payment has been made short has led to much agitation in favor of some form of rural credits. It is now well recognized that much capital is required to develop an irrigated farm. Either the development must be left to those possessing such capital or the conditions for borrowing must be made favorable for those lacking in capital. On funds secured from bonds by the land owners, repayment does not usually begin for 10 years or more. Where land is purchased from the constructing company, a first payment is required. The amount of this payment usually varies from 10 to 25 per cent. of the total. It should be equal to the cost of securing the purchaser which has been as much as 20 per cent. of the price in some cases. The tendency is toward a smaller initial payment in order that the settler may use his available funds more largely in the development of his land to a productive basis.

OPERATION AND MAINTENANCE CHARGES

The two general methods by which operation and maintenance costs are charged to the land are the flat rate per acre and the quantity rate. In the flat rate per acre method, the charges are based on the area irrigated without regard to the amounts of water actually used, except as this is limited to some maximum quantity by the terms of the water right. In the quantity or metered method, the charges are based more or less completely on the amounts of water actually delivered to any tract of land, more usually the actual charge, however, consists of a minimum charge per acre plus a rate per acre-foot for water used in excess of a certain amount. There is much difference of opinion at present as to which is the better method. Where the policy of the system and methods of charging are determined by others than the actual users of the water, the quantity rate is frequently used; where the users of the water control the system, the flat rate per acre is more usual. Both of these statements are, however, subject to many individual exceptions. There are certain conditions for which either method is better suited than the other; there are other conditions for which it will be more difficult to make a choice.

The flat rate per acre is the older method in this country. It is the natural outgrowth of the coöperative company where all costs were assessed uniformly against the stock of the company, which was usually held in proportion to the irrigable area of each owner. It is also the outgrowth of the earlier developments where the water was entirely secured by direct diversion from the stream and the cost of service was more largely a question of the maximum rate at which water was taken and the total length of season than a question of the actual amount of water used per acre. Where the area of a project is fixed and fully developed and where the available water supply is ample, a reduction in the quantity used due to a change in the method of charging may have little direct financial value to the system, as it may have no other opportunity for using such water. There is, however, a direct public interest in such reductions of the quantity used. On systems supplied from storage or by pumping, the cost of operation may be determined more largely by the amount of water used than by the area covered. A more economical use of water on systems covering bench land may enable the systems to be extended to cover additional areas. More economical use may be required after the first few years of operation, in order to furnish water for the additional areas prepared each year. Better and cheaper methods of measuring the water to individual farms are being developed; the damages to the land from overuse of water are becoming better understood and more attention is being paid to better farm irrigation practice.

Limits of Beneficial Use.—Legal rights to the use of water acquired by appropriation are based on the requirements of beneficial use. The laws of several of the States or the rules of the State engineer's office give the maximum rates of use which will be considered beneficial. In Wyoming, Nebraska, Utah and New Mexico this is 1 second-foot to 70 acres; in Idaho, 1 second-foot to 50 acres; in Oregon, 1 second-foot to 80 acres; and in Nevada, 1 second-foot to 100 acres at the land. In Wyoming there is no limit, other than beneficial use, to the length of the time of use or total quantity to be taken per acre in any year, except as limited by the maximum rate of diversion; in Nebraska the total quantity is limited to 3 acre-feet per acre; in Utah the total quantity is similarly limited, and the period of the year during which the water is to be used must also be stated; in Nevada, total use and rates of use per month are specified. In Colorado and Montana there is no statutory limit to the use which will be considered beneficial, the determination in each case being left to the courts. The States at first followed the Colorado method; Wyoming then passed the laws limiting the maximum rate of diversion, and the other States have enlarged these statutes as outlined above, the law in Nevada being the most recent and also limiting the use more nearly on a quantity basis, rather than a rate-of-flow basis. There seems to be a rather definite tendency in water-right regulation to more closely restrict the maximum rate at which water may be used and also to limit the total amount per acre which can be diverted per season, or an approach to determining the extent of beneficial use in terms of the quantity used per acre, rather than the maximum rate of use.

Factors Affecting Use of Water.—The amount of water used on any farm or under any irrigation system depends on the soil, topography, ground-water conditions, crops, method of preparing land and care used in applying water. These factors vary on the different parts of a system or even on adjacent farms. Certain of the factors are fixed, such as soils; others may change, such as ground-water conditions and crops. Some of the conditions of use can be controlled by the irrigator, such as the care used in preparing land and applying water; the fixed factors and some of the variable ones, such as changing ground-water conditions caused by use on higher areas, are not subject to control by the individual land owner. If the variations in use resulted only from the factors under the control of the individual land owner, the quantity rate would be preferable, as under such a method of charges those carelessly preparing their land or using water wastefully would be penalized for their neglect to the benefit of the careful irrigator whose charges would be correspondingly reduced. If the variations in use result from the factors which the irrigator cannot control, the quantity rate increases the cost of production on lands of high-water requirements and tends to depreciate their value. That the relative water requirement is an actual element in the value of lands is coming to be recognized although as yet it is not as important as several other elements of value except for extreme soil types. The same elements of soil character which increase the water requirement may increase the cost of other cultivation operations.

Effect of Rates on Measurement of Water.—The use of a quantity basis makes necessary the measurement of water to individuals. The conditions of delivery on many projects are such as to make accurate measurements very difficult, and this has been one of the principal reasons for retaining the flat rate per acre method of charges. If the cost to the user depends on the records of water delivered to his land, a more careful and accurate measurement will be demanded than where the users interest is limited only to securing water sufficient for his needs. The cost of such measurement need not be excessive. The gage readings on which the records are based can usually be taken by the ditch riders in the course of their other duties without reducing the extent of their beats. The computation of results is an added expense. The cost per season of securing and computing measurement records of individual deliveries, but not including the cost of installing and maintaining the measuring devices, should not exceed 5 cents per acre, and for systems supplying large farms with infrequent deliveries may be less. The interest on the cost and the depreciation of the measuring devices varies more widely. Costs of measurement are discussed in detail in Chapter V.

FLAT RATES

The adjustment of flat rates for operation and maintenance is relatively simple. Where the charges are based on acreage, the total charges divided by the acreage gives the rate per acre. The irrigable area, determined as in the case of construction charges, is generally used. In some cases the charges may be made only to lands actually irrigated. The assessment of operation and maintenance against the irrigable area is preferable as it tends to limit speculative land holdings and to increase the rate of development. Where the charges are assessed against stock in coöperative companies, the basis is equivalent to assessing the irrigable area.

In some cases the rates may be different in different parts of systems using flat acreage rates. Some coöperative systems have more than one class of stock. This may be due to a large area coöperating in the construction of the diversion canal, storage or other common works with separate organizations handling the distribution systems in the different divisions or districts.

QUANTITY RATES

Where the quantity basis of charges is used, the rate generally consists of two parts, the demand and the service or delivery charge. The demand or standby charge is usually a fixed amount per acre of irrigated or irrigable land, the payment of which entitles the owner to a certain minimum amount of water per acre, such as 1 or 2 acre-feet. For water used in excess of the minimum a certain rate per acre-foot is charged.

In determining rates for different forms of utilities two general methods are used. In one, the rates for different classes of service are made proportional to the cost of supplying such service; in the other, the rates are adjusted among the different classes of service so as to produce the desired total earning the rates to each class being based on the value of the service rather than its cost, a method frequently referred to as charging "what the traffic will bear." An irrigation company usually has only one class of service. These two methods have their application in irrigation, however, when the rates are based on the quantity of water used. If the rates are to be based on the cost of service, those items of cost which are not proportional to or dependent upon the quantity of water used should be returned by the minimum charge, and those items which are more nearly proportional to the quantity of water used should be returned by the rate per acre-foot for quantities used in excess of the minimum. If the rates are to be based on the value of irrigation or the benefit to the irrigator, the rates may be made proportional to the quantity of water used and the service portion of the rate made to return a large part or all of the total cost.

Classification of Operation and Maintenance Costs.—The cost of operation of irrigation systems can be divided into four general classes: (1) fixed charges, (2) operation, (3) maintenance, (4) general expense. Each of these is an actual part of the cost of service; in many systems owned by the users the construction cost may have been paid in the original price of the water rights so that interest charges are not included in the annual rates.

If each user has repaid his proportion of the cost of construction, the annual charges will consist of the annual expenditures for operation and maintenance. Depreciation may be met in the maintenance as it occurs in such cases instead of by reserves. The annual rate for operation and maintenance can then be based on any desired division of the cost between acreage and the use of water. Fixed charges are properly an acreage charge. Maintenance is also dependent on acreage rather than on use per acre. General expenses are more largely an acreage cost than a quantity cost although they may be distributed to operation and maintenance in some cases. Operation depends on both acreage and use and its cost should be segregated to these two divisions where quantity rates are to be fixed on the cost of service. Even if the rates are not based on the cost of service it is desirable to know the demand and service portions of such costs if they are to be departed from intelligently. The cost of operation, such as ditch riders and water masters, is not entirely a delivery cost. If a system is to be operated at all the cost of operation or delivery will not be proportional to the water used. A certain delivery organization will be required in any case and a considerable part of the cost of such distribution force can be considered a demand charge rather than a direct delivery cost. The relative use of water may not affect the construction cost. Where water is secured from direct-flow rights in streams, the cost of construction is mainly controlled by the maximum rate or peak load of use which determines the canal capacities and cost of construction. The service or direct quantity costs are the cost of part of the actual delivery force and the cost of securing water such as storage or pumping where such occur. The cost of the measurement of water to individuals should be included in the delivery cost.

Such an analysis places the fixed charges, maintenances, general expenses and a portion of the operation costs in the demand charge and leaves only the cost of securing the water, its distribution and measurement as the direct delivery or service costs. The actual and relative amounts of these different items vary with each system. In all but commercial companies it is not usual to include interest on the value of the system in the fixed charges although other systems may partly meet such charges through interest payments on outstanding bonds, which may, however, be carried as distinct accounts. Also, the greater number of systems at present secure their supply by direct diversion so that the development cost for the water itself such as storage or pumping may be relatively small. Such an analysis will usually show a relatively small delivery cost per acre-foot. Some general figures on the relative amounts of these different items are given in the following discussion.

Ratio of Demand and Service Costs.—In the 13th U. S. Census figures were obtained on the average cost of operation and maintenance for about one-half of the area irrigated. These costs included the majority of the systems except those classed as individual or partnership enterprises. For these two classes operation and maintenance are handled incidentally by the users without definite records or charges. The average cost of operation and maintenance for all the States was $1.07 per acre, varying from $0.63 in Idaho to $3.25 in Texas. The average cost of construction per acre actually irrigated in 1909 for all States was $22.41, the average cost per acre which completed systems were ready to supply in 1910, $15.92. Using the latter figure as the average construction cost and assuming 8 per cent. for interest and depreciation, a relatively low figure as the cost of interest alone may exceed this for newer systems, the fixed charges become $1.28 per acre. The total cost would then be $2.35 per acre of which operation and maintenance would form only 45 per cent. These fixed charges are relatively low as the cost of construction is figured on the total area irrigable and also includes the construction cost of individual and partnership systems which the census found served about 40 per cent. of the irrigated area and had an average construction cost of less than one-half of the mean for all systems. The average cost of construction of the systems for which operation and maintenance costs were secured would exceed the figure used giving a correspondingly higher fixed charge and lower proportionate expense for operation and maintenance.

As a result of its investigations in rate cases, the California Railroad Commission has determined the operating costs for a number of systems in that State. The average of 16 systems scattered over the State gives the following division of the total expenses: general salaries, 17 per cent.; other general expenses, 10 per cent.; taxes, 6 per cent.; operation expense, 37 per cent.; maintenance and repairs, 30 per cent. These do not include the fixed charges such as interest and depreciation which have been found to average about 60 per cent. of the total cost. The direct operation expense of 37 per cent. of the total expenses other than fixed charges would on this basis be only 15 per cent. of the entire rate which such companies would be entitled to earn. In addition to the cases actually coming before the commission for rate-fixing, all irrigation utility companies report their expenditures annually under a standard form of accounts. In 1914 the reports of 26 companies show an average of 34 per cent. of the expenses other than fixed charges to have been for operation, a practical agreement with the figures in the actual rate cases.

In Bulletin 229 of the Office Experiment Stations, U. S. Department of Agriculture, "Delivery of Water to Irrigators," by Frank Adams, the cost of delivery alone for a number of systems is given. For six systems outside of southern California the cost of delivery to individual farms averaged 16 cents per acre per season; for seven systems delivering to the heads of laterals only the cost averaged 10 cents per acre per season. For nine systems in southern California delivering to 10- to 20-acre holdings where small measured heads are used during a long irrigation season the average cost per acre for delivery was 71 cents. These costs include only delivery of water and the superintendence directly chargeable to such delivery. If the census figure of $1.07 per acre for total operation and maintenance cost is used and 13 cents taken as the cost of delivery alone, the percentage of cost of service to be returned by the quantity rate is quite small.

The reports of the U. S. Reclamation Service give costs of operation and maintenance separately. For all projects the costs to June 30, 1916, are given in Table XX.

TABLE XX.—TOTAL COST OF OPERATION AND MAINTENANCE ON ALL PROJECTS OF U. S. RECLAMATION SERVICE TO JUNE 30, 1916

	Operation	Maintenance	Total	Per cent. of total	Operation per cent. of total
Storage	$176,000	$234,000	$410,000	8	43
Pumping for irrigation	344,000	45,000	389,000	8	89
Canal systems	439,000	859,000	1,298,000	25	34
Lateral system	850,000	1,681,000	2,531,000	50	34
Undistributed expenses	147,000	316,000	463,000	9	32
Total	$1,956,000	$3,135,000	$5,091,000	100	38

The use of the quantity rate has long been advocated by those responsible for the general policies of the U. S. Reclamation Service. This method was used to some extent on projects operated on a rental basis prior to 1915, and was made general at that time under the terms of the Extension Act, passed in 1914. As these various projects are distributed throughout all the Western States, the rates used in 1916 represent the wide variations required to meet different conditions. The following information has been taken from the public notices for the 1916 rates issued for the different projects.

The initial charge was made relatively high, in order to discourage speculative holdings, usually 1 to 2 acre-feet per acre being furnished for the initial charge, which applies to all irrigable land, whether water is used or not. The rates per acre-foot for water in excess of that furnished for the initial charge varied from $0.10 to $0.75 on the different projects. On these projects having the greatest variety of soil types, the lowest rates on excess water were used. On the Truckee-Carson project the rates were 90 cents for the first acre-foot per acre and 10 cents per acre-foot for the additional amounts used. Rates of this type are required in order not to unduly penalize the owner of porous lands for a condition which is beyond his means to remedy. On the basis of the average use of water in 1915 and the rates for 1916 the initial charge was equal to about 80 per cent. of the total charge on lands using the average amounts of water. Including the collections from land not irrigated, probably more than this proportion of the total operation charges were derived from the initial charge. The charges for excess water, while furnishing only a minor part of the total charges, act as a restriction on excess use. Various special rates were required on the different projects, such as different rates for direct flow and storage water, and for extreme types of soil.

The annual statements of different irrigation companies are not all made on the same basis or in the same detail so that it is difficult to pick out the items which represent the demand cost and those which represent the service cost. An examination of a number of such reports was made, the general ratio between operation, maintenance and general expense being similar to the other figures given.

The examples indicate that the delivery costs do not average over one-third of the total operation and maintenance cost exclusive of fixed charges. If rates are based on cost of service and do not include interest on the value of the system, the minimum charge should be adjusted to return from two-thirds to three-fourths the total cost, and the remainder be secured from the delivery charges. If interest on the value is included in the rate, the minimum or demand charge should cover four-fifths to five-sixths the total payment. As the minimum charge is practically an acreage charge, such rates are more nearly on a flat acreage basis than on a quantity basis.

Variations in Rates from Cost of Service.—In many cases it may not be desirable to base the rates on the cost of service. For the same reasons that power companies or railroads may find it preferable to base rates on the value of the service, canal companies may find it preferable to increase the quantity rates so as to furnish a larger proportion of the return. A quantity rate based on the cost of delivery may be so low as to offer little incentive to careful use. This results in charging higher rates per acre-foot for excess water or in a reduction in the quantity furnished for the minimum charge. When the conditions are uniform so that the value of an acre-foot of water to the land on which it is used is similar for all parts of the system, higher quantity rates are desirable. This is also true where the supply is less than the amounts which it may be desirable to use; in such cases a high quantity rate will tend to restrict use to the crops of higher return. Where, however, the supply is ample and a canal system has little opportunity of disposing of water which may be saved by a high quantity rate, there would seem to be little advantage in quantity rates higher than the cost of service. A high quantity rate may indirectly reduce the need of drainage if it acts to restrict use. Where late season water is secured from storage a higher quantity rate for such water, proportional to its actual cost, which is on a quantity basis, may be used.

The principal advantage of the quantity method of charges is the incentive to more careful use. The annual cost of water to any farm depends upon the amount used, and careful use produces a direct return in the reduction of the charges. If the annual operation cost is determined wholly by the area irrigated, as in the flat rate per acre method, there is no direct saving to the individual on such charges due to a careful use of water. In many localities the cost of water is less than the cost of its application to the land. In such cases, the cost of application acts to some extent to prevent unnecessary use. This is true to a greater extent in regard to the number of irrigations than to the amount applied at each irrigation.

It is usual also to furnish a certain quantity of water per acre for this minimum or initial charge, more often 1 acre-foot. This minimum charge may be assessed against all irrigable land, or only against land actually irrigated in any year. It is preferable to assess all irrigable land. This discourages speculative holdings and requires any land supplied by subirrigation or waste to bear a portion of the cost. The cost of this "readiness to serve" is more largely a factor of the irrigable area under the system than of the area which may be irrigated in any year. Charging all irrigable land with this minimum cost may work a hardship on some settlers during the first year of settlement when they are unable to prepare all of their land for irrigation. However, if the total cost of service must be met by the total charges, the assessing of an initial charge against all irrigable land will reduce the rate for excess water, so that the total cost to the average farm may not be materially changed. The quantity of water furnished for the minimum charge should be somewhat less than the quantity used under better practice on the system. This penalizes any excess use over the amounts actually needed. On many systems which have been handled on the flat rate per acre basis, changes to the quantity rate are being agitated. Such changes from a method which is understood to one involving measurements with which the usual farmer is unfamiliar are naturally opposed more or less actively by the users. This is largely a prejudice against any change, the results of which are not understood.. For this reason it may be desirable to make the rates on excess quantities of water quite low, at least for the first few years after the adoption of the quantity rates, so that the added charge for less economical use will be relatively small. An initial charge, which practically will return the cost of operation with a rate on excess water, which will somewhat more than return the added cost of measurement, may be used. This may have a good effect in causing the users to give attention to the quantities of water used and in securing data on the actual use without at first giving sufficient added cost to those using excess amounts to cause active opposition. The charges may later be developed to penalize wasteful use to a greater extent and so have a greater effect in reducing its amount.

In some cases special rates may be given for the first 1 to 3 years' irrigation on new lands. It is recognized that raw lands usually require more water than the same land after it has been in use for a longer time. The interest of the canal system is more largely in stimulating development, rather than in forcing the most economical use at first.

Variations in Rates Due to Soil Conditions.—Where the conditions on different parts of a system vary and where the value of the crops limits the price which can be paid for water, various special forms of rates will be required if the quantity basis is to give equitable results. This is particularly true on systems where all lands have been handled on a flat acreage basis for construction and operation charges and a change to a quantity rate is made. The more usual variations in use which occur are those due to differences in soils, a factor largely beyond the control of the irrigator. Where the areas of the different types of soil are relatively distinct, district or zone rates may be used for the different conditions. Usually, however, such soil variations blend into one another so that the divisions of the zones will not be distinct. If the larger proportion of the land is uniform and the number of farms requiring special rates relatively small, the method of rebates used on the Boise project will give good results. On this project when the total charges for any farm under the usual rates exceeds $2 per acre irrigated, provision is made for an examination of the land by a committee of water users. If the ditches are found to be in good conditions, the land well-prepared and the water carefully used, a rebate of the charges in excess of $2 per acre may be made.

The experience of the gravity unit of the Minidoka project is of interest in this connection. This system was operated on a flat acreage rate until the passage of the Extension Act requiring the use of the quantity rate. In 1914 the rates were 75 cents per acre. In 1915 the minimum charge was 60 cents per acre for which 1 acre-foot was supplied plus 5 cents per acre-foot for any excess water used. The actual average use varies from 2 to 8 acre-feet on different soils on this system, so that even the very low rate for excess water made a material difference in the charges. In 1916 a zone system was established. Three zones were used, the minimum charge in each being 75 cents per acre, for which 1, 3 and 6 acre-feet per acre respectively were supplied in each zone. For excess water a uniform rate of 15 cents per acre-foot was used. While some hardship may result from this rate along the division of the zones which were necessarily fixed to fit average conditions, for the system as a whole the 1916 rate should be much more equitable than that used in 1915.

On the Okanogan project a flat rental charge of $3 per acre was used in 1914. In 1915, three zones based on the quality of the soil were used. A minimum charge to all lands of $1.75 per acre was used for which the better lands were given 1 acre-foot per acre, the medium lands 1½ acre-feet and the poorer or sandier lands 2 acre-feet, all lands paying $1.50 per acre-foot for any water used in excess of these minimum amounts. This system of charges provided a sufficient revenue and at the same time caused an actual decrease in the amount of water used.

The need for recognizing variations in soil in fixing rates on the quantity basis has been felt by the U. S. Reclamation Service since the passage of the Extension Act. The following quotation from the 15th Annual Report after 2 years operation of all projects on a quantity rate is instructive:

"Additional experience gained during this period further indicates the desirability for reasonably close classification of the soils on some of the projects with respect to the duty of water on the various types. An acre-foot of water delivered to porous or sandy soil will not perform the same duty as the same amount delivered to non-porous soil and the value of the water is correspondingly less to the irrigationist. Such a classification of soils has been fairly well worked out on the

Minidoka project in Idaho, where the Department of Agriculture made soil classification and duty of water studies during the season of 1915. Pending a proper classification of soils, the fixing of operation and maintenance charge schedules in such manner as to approximate a flat rate per acre will prevent serious inequities among water users on projects where the types of soil vary considerably."

A quantity rate is not suited to localities where irrigation is only supplemental to the precipitation and where the use of irrigation water varies widely from year to year. The returns to the irrigation company in such cases are uncertain. Unless the land can be held by some form of contract to pay the demand charges whether water is used or not, either as a flat acreage charge or as the minimum charge in a quantity rate, there is little assurance of an adequate earning for the system. Flat acreage rates are preferable for such conditions.

TERMS OF PAYMENT

Operation charges may be paid monthly or at one payment for the whole season, the latter method being more usual. Monthly payments are used on some systems delivering on a quantity rate. In case water received during the previous month is not paid for by some fixed date in the month following, further delivery may be refused. On many systems payment is made at the end of the season after the crops produced with the water have been harvested. With coöperative systems, the assessments are made at various times during the year as need arises, and amount to a payment in advance in most cases. In irrigation districts the expenses for the following year are estimated, so as to be collected with the other taxes during the preceding winter, which is also a payment in advance. With the Reclamation Service payments are now due on March 1 of the year following. This enables the crops to be both harvested and sold before payment for the water used in their production is made. Most private systems owned by others than the users cannot carry the accounts to this extent. This can be done by the Reclamation Service, as their funds are not subject to interest rates. Advance payments can be more easily made where the flat rate per acre basis is used, as the amount of the charge can be determined in advance.

Interest on delinquent payments is usually charged at rates varying from 6 to 12 per cent. For irrigation district assessments, the penalties on overdue taxes are equivalent to such interest charges. The Reclamation Service now charges the users 1 per cent. per month on delinquent accounts, but also gives a rebate of 5 per cent. for payments made before due.

SUMMARY

In general it may be concluded that some form of quantity rate is preferable although the preference for this type of rate comes more largely from other causes than its relation to the cost of service. Even where the quantity rate is only sufficient to cover the added cost of measurement of individual deliveries, its use may be of benefit in causing a realization among the users of the importance of care in the use of water and in furnishing a basis for later changes in rates so as to more largely penalize wasteful use.

The result of the change to quantity rates on the U. S. Reclamation Service projects is well expressed in the 15th Annual Report:

"While the basing of operation and maintenance charges on the amount of irrigation water used per acre has worked some disadvantages due to varying types of soil, this plan has worked economies in the handling of project works as the water has been used more conservatively and more timely irrigations have been effected. The irrigationists are now studying the use of water, which is beneficial to both the land and the land owner."

Two tendencies toward improvement in methods are noticeable in irrigation operation, the tendency toward rotation methods of delivery and the tendency toward the use of rates based at least in part on the quantity of water used. While neither rotation delivery or quantity rates are suited to all conditions encountered in irrigation, they are adapted in many situations where other methods are now used and the extension of their use is to be expected and should be encouraged. Quantity rates, however, should not be adopted without a full understanding of the local conditions and of the effect which the rate selected will have upon the use of water and the charges to individuals for the conditions found on the system. A well-chosen division of costs between the minimum charge and the service rate should be better than flat rates on the large majority of systems; a poorly chosen division may result in a permanent reversion to flat rates.

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CHAPTER VIII

GENERAL OPERATION

USE OF CHECKS IN CANALS

Where the water surface of a canal is not sufficiently above the adjacent ground surface to permit direct delivery, checks must be used in the canals. This condition occurs for many canals when operated at capacity; it also occurs with nearly all canals from which deliveries at part capacity have to be made, a condition that occurs at the beginning and end of the irrigation season. If the land does not have a regular slope away from the canal it is difficult to cover all the land below the ditch, unless the ditch is carried in fill. It may be cheaper not to attempt to serve small areas of high land than to try to hold the ditches sufficiently high to cover them.

Main canals cannot be divided and the flow taken into main laterals without checks unless excessively large gates or considerable fall into the lateral is available. Checking the canal from which the lateral diverts gives greater pressure on the gates so that smaller sizes can be used. Checking main canals gives unfavorable conditions for canal rating; the methods of handling such stations are discussed under canal hydrography in Chapter V.

The use of checks decreases the velocity in the canal and may cause silting. This can be lessened near the checks by having openings near the bottom; the effects of such sluicing may extend only short distances, however. By operating the canal as a whole without checks at the beginning or end of the season when delivery is not required, it may be possible to sluice out such deposits.

It is not usually necessary that checks be water-tight, as they are more often used to control the delivery of a portion of the water by raising the water surface than to stop the flow entirely. This is particularly true of the larger canals. Gates having heights somewhat less than the depth of the canals or flashboards can be used. Flashboards can be made small enough to be handled by one man. Sliding gates are usually operated by hand through some form of levers or gears. Taintor gates can be operated by one man. Check gates may be made to operate automatically so as to hold the water surface at a constant level. The automatic regulation is applied usually to only one bay or division of the checks, the others being hand-operated.

Checks may pass the water either at the bottom or at the top of the canal section. If the drop at the check is more than 1 foot, the velocity through undershot checks may be sufficient to cause erosion in the canal below, unless lining or other preventative methods are used. With overpour checks this fall can be more easily controlled in the stilling basin at the fall. A combination in which some openings act as undershot and some as overpour checks may be preferable to all of either. Overpour checks are less affected by fluctuations in the discharge of the canal as the discharge is proportional to the three-half power of the head instead of the one-half power of the difference in head as with submerged orifices.

Delivery gates should be placed as near the bottom of canals as practicable in order that delivery can be made at low stages of the canal. Where such deliveries are only a small proportion of the water being carried in the canal, diversion can be made through such gates without checking the main canals if the delivery gate does not serve land too high in relation to the canal. The elevation of the canal should be adjusted to that of the land to be served so that checking for small deliveries is not required on main canals or larger laterals. On smaller laterals where each delivery receives a large proportion of the total flow, checking for delivery is usually required.

When the canals carry water only part of the time or where a check is used only for a few days per month to make certain deliveries, less freeboard may be needed than where the banks are under continuous strain. On the other hand, the danger from breaks on such banks, due to gopher or squirrel holes, is greater than on those where the water is held at a constant elevation.

WASTE WATER FROM FARMS

There are two kinds of waste which may occur after water has been delivered to farms. One of these is the surface runoff or visible waste. The other is the deep percolation loss or invisible waste. The farmer is responsible for the disposal of the first of these as it can be traced to its source and the responsibility fixed. The second class, from its nature, can hardly be traced to its individual source and while accumulated seepage often causes more damage to lower lands than surface waste the responsibility cannot be directly fixed.

Surface waste will occur to some extent under all conditions of irrigation. It cannot be entirely eliminated any more than waste in canal operation can be entirely avoided. Surface waste from the irrigated lands may amount to 20 or 30 per cent. of the water applied to some fields; it should not exceed 10 per cent. for any farm or 5 per cent. for any canal system. The amount of surface waste depends on several factors among which are: (1) ability to dispose of the water, (2) method of irrigation and preparation of the land, (3) value of water, (4) kind of soil, (5) skill of irrigator and (6) size of irrigation head.

Where the use of water is obviously wasteful it can be shut off. Most canal systems include such a rule in their regulations. This is used, however, only where the waste is of such extent as to attract attention and cannot be expected to prevent ordinary waste. The laws of most States also provide means for the closing of canal headgates served under appropriation rights if water is not being used beneficially. Most States have laws making it a misdemeanor to permit the running of waste water onto county roads. An occasional prosecution under such laws will have a beneficial effect. Where roads are well crowned and have good side ditches, waste water may be carried along the right of way of the road until it reaches an outlet without damage to the road.

Rights to waste water are still the source of much legal controversy. In general, waste water is subject to appropriation if taken before it reaches a natural drainage channel or stream, after which it becomes subject to the rights in the stream. Such waste-water rights, however, do not compel the one whose waste water is thus appropriated to continue the waste. Where laterals are run around the slope of the land instead of down the steepest grade, provision may be made for picking up waste from higher lands. This is of questionable benefit, however, as the amounts received are usually too variable to be dependable and may at times be sufficient to overload the lateral. It is more usual for the land owner to provide his own outlet to the nearest drainage channel. Where closed drainage systems have been built, it is not usual to permit surface waste to be discharged into them as the capacities of the closed drains are inadequate for such use.

WASTEWAYS

Wasteways serve two principal purposes: (1) relief in case of a canal break below the wasteway: (2) regulation of the supply carried. For the second purpose, the wasteways or spillways are located just below the point of diversion, at the ends of canals and laterals to give an outlet for unused water and at points within the system where outlets can be secured. For the first purpose wasteways should be located above dangerous lengths of canal to enable the flow to be turned out quickly in case of breaks. In sidehill locations liable to breaks, wasteways may be desirable at distances of from 3 to 5 miles. The actual damage caused by a break is usually proportional to the time which elapses before water can be shut off, which, in turn, depends on the distance of the break from the nearest wasteway above. Such wasteways are more essential on main canals than on laterals. When breaks in laterals occur, the water can often be crowded into other laterals.

Speed and ease in operation are essential in wasteways used for relief in case of breaks. Taintor gates have this advantage. Ordinary geared slide gates are slow in operation unless power-driven. Such wasteways should be set low enough to draw the full flow from the canal or a check should be built across the canal below the wasteway. Control of the high-water line may be secured by using lip spillways set at the full-supply water surface. If the water is raised, due to clogging of screens or similar causes, partial relief may be secured by such spillways. For close control an excessive length of crest is required, for this type of spillway. This disadvantage may be overcome by the use of siphon spillways, where the conditions are suited to their use.

In some cases provision is made for carrying cross-drainage into or through the canal. Waste gates may be placed in both the upper and lower banks. In flat country it may be difficult to locate the canal so that such drainage can be taken either under or over the canal, although such methods are usually preferable. Drainage during the non-operating season may be carried directly through the canal. During the operation season it may be used or wasted depending on the relative amounts of such drainage and the capacity of the canal.

Some wasteways are designed to be automatic in their action, opening when the canal either rises or falls below certain limits. Such devices, if not tested frequently, are liable to fail to work when desired. For canals in unstable locations it will be desirable to have low and high-water alarms connected with the patrolmen's quarters so that they can be called out at any time.

STOCK WATER

Irrigation systems may be used to furnish water for stock and even for domestic use as well as for irrigation. In some localities, particularly for the larger systems covering bench lands, the expense of drilling the deep wells required and the uncertainty as to the supply which will be secured, make it necessary to use canal water for such purposes. Little can be said in favor of the direct use of canal water for domestic purposes except in those limited areas where the supply is pumped from the ground water and conveyed without pollution. Even if well supplies cannot be secured, the canal water can be filtered into a cistern for house use. Such filter and cistern should be regarded as one of the improvements the settler is expected to make if no other domestic supply is available.

Stock water may be supplied both during the main irrigation season and also after crop use is ended. Where continuous-flow delivery methods are used stock water requires little additional delivery during the irrigation season. For demand or rotation delivery to the crops, a small continuous stream may be needed for stock use. The amount of such stock water is generally too small to warrant its separate measurement. If the charges for water are based on the quantity used, a certain arbitrary charge may be added for such service. Where the system is operated for stock use alone outside of the irrigation season, the costs should be borne by those benefited. Winter operation may be necessary where large numbers of feeding stock are carried. For the ordinary work stock and domestic use it may be possible to haul water or to use cisterns. The colder canal water has been found to be less satisfactory for stock than the warmer well water.

It is generally found that after irrigation has been practised for a few years, well supplies become available due to the rise of the ground water, or that the financial condition of the settlers enables them to drill deep wells. Stock-water delivery, particularly during the winter season, should be looked upon as a temporary expedient to be stopped as soon as practical.

NUMBERING CANALS AND TURNOUTS

Some method of numbering canals and turnouts is needed as a basis for reference on maps and in records. Such numbers or names serve as abbreviations.

Main laterals may be designated by names, letters or numbers. On smaller systems all laterals may be given names. Such names may be chosen from the locality served, as the Dry Gulch lateral, or named after some land owner under the lateral, the location of whose land is well known. On large systems similar names may be used for the main laterals. Main laterals may be given the names of letters in order from the head of the main canal, such as the A canal. Laterals taking out from the A canal may be given numbers in the order of their location from the head of the main lateral such as A-1 lateral. This method may be carried through the sub-laterals, alternating letters and numbers as A-1-B-3 for the third sub-lateral taking out from the second lateral on the A-1 canal. Where all canals and laterals are built at the same time such methods can be used to advantage. If it is later found that additional sub-laterals are needed the sequence of numbers is either broken or additional divisions used such as the A-1-B-3½ sub-lateral. This difficulty may be overcome by giving each lateral a number corresponding to the distance of its headgate from the head of the canal from which it is taken, usually expressed in miles and tenths as the A-5.1 for a lateral taking out from the A canal 5.1 miles below its head. This method is used more largely on main canals and laterals than on sub-laterals. For any method, key or index maps showing the actual names should be supplied to the ditch riders and the name marked on the head gate.

For individual headgates or turnouts it may be more convenient to use numbers than names. Such numbers may be preferable in ditch riders' records as they are more likely to be legibly written than names. Such numbers can be branded or painted on the headgate so that the ditch rider does not have to refer to lists of numbers in making his delivery entries. The office records can carry both names and numbers as these are used only in the headings and not repeated for each entry. In some cases the ditch riders fill in both names and numbers in their field record. The legal description of the land may be used, but this is inconvenient and confusing unless some simplified system of description is used. Such a method is used on the Minidoka project and is well suited to lands subdivided according to the U. S. Land Survey into 40-acre areas. A standard plat of a section is used in which each one-sixteenth section or 40-acre tract is given a letter depending on its position in the section. These begin with A in the northeast corner and run alternately west and east across the section in the same way that the sections are numbered in a township, the southeast 40-acre tract being called P. The numbers for each turnout are selected by taking the last digit of the township number, the last digit of the range number, the entire section number and the farm unit letter. Thus the turnout for Farm Unit A, Sec. 26, Tp. 9 S., R. 23 E. would be 9326A; for Farm Unit D, Sec. 9, Tp. 10 S., R. 23 E. it would be 039D. If a farm unit has more than one headgate they may be numbered 1 and 2 if desired (Plate VI, Fig. C). The complete numbers are either stamped or painted on the headgate. On smaller systems covering less than one township the numbers referring to the township may not be needed.

LOCKING TURNOUTS

Practice regarding the locking of individual headgates varies from the locking of all gates against both opening and closing to that of permitting the individual land owners to practically operate their own turnouts. Any practice regarding locking should be uniformly enforced, at least on the different laterals or ditch riders' beats. This is necessary to avoid charges of favoritism. Locking devices may be provided but not used as long as no trouble arises. Some managers prefer to control the taking of water by other means. If complaints arise on a lateral over the distribution of the water, all turnouts would be locked. It may occasionally be desirable to lock turnouts near roads or schools in order to prevent mischievous interference by others than the water users.

A lock may remove the sense of responsibility for fair dealing on the part of some land owners. The need for locks may depend more largely on the individuality of the ditch rider than on any other factor. A rider who demonstrates his fairness and ability to get water to the users when promised will give much less cause for attempting to obtain water irregularly. There are statutes against changing gates and the unlawful taking of water which can be used where the responsibility for any such taking can be fixed and where public opinion will support such action. The example of a few cases of active prosecution resulting in fines may have a greater effect than many locks. Locks may be provided and used only during the time of maximum demand. At the beginning and end of the season the supply may be ample in proportion to the demand and close regulation not necessary.

Locks may be arranged so that while the gates can be lowered they cannot be raised beyond a certain point. This can be done by placing a lock or clamp on the gate stem which will not pass through the guides. Such locks permit the water to be shut off by the user but prevent the taking of an excess. They are not desirable on canals run to the maximum level as such turned back water may overload the canal below. On closely controlled systems it is not usual to permit one user to turn back water without notice to the ditch rider or arrangement with some other owner for its use.

The method of delivery influences the need for locks. Where only one rotation head is run in a lateral, all of which is given in turn to each user, locking is not needed as the taking of water out of turn can be detected. Locking would also make necessary night ditch riding where changes are made at less than 24-hour periods. Where several users are taking water from the same lateral under continuous-flow or demand methods it is more difficult to detect night raising of the gates and locks may be desirable. Locks similar to car seals have been used in some cases on the Truckee Carson project. These permit the operation of gates in cases of emergency, such as breaks, but leave evidence of such operation when the seals are broken.

Locking of gates or checks in the canals may also be needed, more usually on laterals than on main canals, however. A turnout can be made to deliver extra water by adding a flashboard in a canal check and increasing the pressure on the gate. On larger canals for checks consisting of gates the difficulties of operation may prevent meddling.

WINTER OPERATION

By winter operation is meant the running of water in canals for stock or domestic purposes during portions of the year when water is not applied to the land. There are some systems in the Southwestern States where crops are irrigated practically throughout the year and where winter operation does not differ from that at other times. It lessens the time available for maintenance work, however. On some systems winter irrigation of orchards or bare lands may be practised in order to use flood waters when available.

It is usually advisable to shut water out of canals as soon as practicable in the fall and not to begin operation, except for canal priming, until irrigation is required in the spring. In the mountain States the open weather available for maintenance work may be limited unless this is done. It has been found on some systems that 20 per cent. of the yearly diversion may take place at the beginning and end of the operation seasons when little actual irrigation is being given. Shortening the operation season also reduces the time the ditch riders are employed. Where a stream is fully utilized through storage, such late- or early-season diversion may reduce the supply available for the main season. Where many wooden flumes are in use it may be desirable to run water until freezing occurs in order to prevent decay from alternate drying and wetting.

The need of winter operation for stock use is discussed under the general question of stock water. Such operation, when used, is the lesser of two evils, the benefits to the settlers being greater than the disadvantages to the canals. In addition to the water required and prevention of canal cleaning there are the further disadvantages of the cost of operation, actual injuries to the canals and structures and the greater additions to the ground water which may increase drainage needs. In some localities muskrats appear to burrow more extensively and cause more harm in canals operated during the winter.

In winter operation it may not be necessary to run water in all laterals or sub-laterals. Daily patrolling may not be needed except at times when ice is moving so that the cost may not be high. Periodic runs at intervals from 15 to 20 days may be made to replenish cisterns. The proportion of the amount which it is necessary to turn into a canal in order to make such deliveries that is actually used is relatively small and the remainder will largely reach the ground water as seepage. It has been estimated that winter operation on the South Side Twin Falls tract added ½ acre-foot per acre to the ground water. Wells were very difficult to obtain on this area when first irrigated and winter operation was necessary. At present, water is being shut out of increasing areas of this system each winter as wells are provided. Winter operation may prevent the natural lowering of the ground water during the winter and add to the resulting water-logging during the following season.

Where canals have to be operated during freezing weather the flow should be kept uniform and at the maximum stage to be run while freezing takes place. After solid ice forms it is not practicable to increase the depth of flow as pressure will be formed under the ice or water will run over its surface, either of which may cause the ice to break and jam at structures. With metal flumes, the capacity will be more largely reduced by freezing as the ice forms around the bottom and sides as well as at the surface. For very low temperatures it may be difficult to operate small metal flumes continuously. Headgates should be adjusted as much as possible before freezing occurs. To open a frozen gate may result in its injury. This is equally or even more true of concrete structures than for wood.

When ice begins to break and move, great care is needed to prevent jams at structures which may act as checks and force the water over the banks. If the ground is also frozen the banks may not be eroded or may resist for some time. At such breakups the only safe course is to shut water out of the canal until the ice has become soft. Some advantage may be secured by closing the side openings in checks, carrying the flow through the center opening at an increased velocity.

Operation during freezing weather should be avoided where possible. One Idaho system has found its maintenance cost to be increased about 15 cents per acre due to the cost of repairs made necessary by the action of ice incident to the running of winter water.

COMPLAINTS

Complaints are not avoidable. The delivery of water to large numbers of farms under the necessary conditions of ditch capacity and water supply cannot always be carried out, even on the most carefully handled systems, without giving grounds for complaint in some cases. The number and seriousness of such complaints can be kept at a minimum by well-planned systems of delivery and prompt attention to the cause when complaints do arise. A policy of operation which gives closer supervision to delivery and a more definite control of use will reduce the number of complaints due to delay in time or inadequacy in amount of the delivery of water. Such methods may increase the expense of operation and cause complaints on the ground of cost.

Complaints can be divided into two general classes: those involving questions of cost, and those involving questions of service. The methods of handling both kinds depend on the form of organization. With public utility companies both rates and service are subject to public control. For such companies, when rates have been fixed or rules of service prescribed, the company is to a large extent relieved of the responsibility for fixing the policy of the system and is responsible only for carrying it out. On systems controlled by the land owners, the general policies are usually determined by elected representatives of the users and the strictly operation officials are held for the enforcement of the policies and economy in expenditures. Complaints on methods or policies can be referred to such elected officers, usually the directors. The complaints due to costs can best be answered by keeping adequate records of expenditures and results so that actual and comparative unit costs will be known.

The complaints regarding service are generally due to failure to deliver water promptly when due, failure to get a sufficiently large irrigation head or damages from breaks. If it is made evident that the whole force is endeavoring to give good service and that such shortcomings as do occur are the result of circumstances and not of favoritism, there will be less incentive to make complaints. The development of a coöperative spirit between users and officials is necessary for the best results and this can only be secured through the understanding of the point of view of the other that comes from a familiarity with the conditions and difficulties in running both an irrigtaion system and an irrigated farm.

The methods of handling complaints should be such as to discourage chronic or trivial kicking and still permit a ready hearing and action in reasonable cases. The most effective method of eliminating trivial or unreasonable complaints is to require that, to be considered, all complaints must be submitted in writing. This will reduce the number received very materially, as the grounds for complaint do not look as serious to many when expressed in cold writing over their signatures where assertions must be definitely made and are subject to verification. On some systems blank forms for complaints are used. These have the advantage of uniformity and greater ease in filing. The use of such forms should not prevent the consideration of written reports if not prepared on the form.

It is also an advantage to settle complaints as near to the source as possible. To "settle on the ditch bank" is good practice. The handling of such informal complaints by each ditch rider is desirable as the remedy can be more easily and quickly given if the user is in the right. Where such adjustments cannot be made, appeal by written complaint to higher officials should be available to the water user. When disputes between the user and ditch rider come to the superintendent with only the unsupported statements of fact by each on which to make a decision, it is usually necessary to support the ditch rider. In case this cannot be done the rider should be changed.

On some of the government projects a grievance committee has been found to be an advantage. On these systems the water users are not directly represented in the operation organization and such a committee becomes an arbitration board between the users and the officials. On coöperative systems the board of directors is, in effect, such a board, complaints which cannot be otherwise settled coming to the directors who also have the power to act. The grievance committees on the government systems do not have such powers to act; however, public sentiment or the willingness of the officials to adopt their findings have resulted in giving their conclusions much weight on some systems.

On the Twin Falls North Side canal red cards are used for complaints which are made to the main office. A rule is enforced that all complaints must be made within 15 days of the occurrence of the cause. This is particularly useful in regard to claims for rebates on charges due to inadequate service. The red cards are filed by ditch-rider beats and furnish a general indication of the work of the ditch rider.

CROP STATISTICS

The crop statistics useful in the operation of an irrigation system are of two kinds: (1) those needed in the actual operation of the system; (2) those useful in determining the financial conditions and progress of the settlers as affecting their ability to meet payments and the general success of the development.

In the first class is included the census of the actual area irrigated in different crops or types of crops. In the second comes such additional data as the yields, average prices received, live stock on the farms, and value of farms and improvements.

Where rotation methods of delivery on the basis of a definite time schedule are used it is necessary to know the area to be irrigated in each kind of crop on each farm in order to plan such schedules. Similar information is needed to properly handle delivery on demand if the rights are proportional to the areas irrigated. With continuous delivery such data are very useful, particularly in times of scarcity of water as the areas of the more valuable crops can be given preference. Many systems now collect data in the spring on the acreage of each crop which will be irrigated on each farm during the coming season. This may be done by the ditch riders in advance of the season or by requiring each land owner to file with the company a statement or application for water during the coming season in which such data is given. Such applications may be made a prerequisite of the right to receive service. These statistics furnish data on acreage only and give no information on yields or profits.

The form used by the Turlock irrigation district, in collecting such data, is shown in Fig. 8, page 115. These are bound in duplicate, the original on white paper and the carbon on yellow.

With some forms of organization a more elaborate census may be taken at the end of the irrigation season. The most complete of these are those taken by the U. S. Reclamation Service. There is little doubt as to the value of such data in comparing conditions and progress from year to year if the data are properly compiled and analyzed. There may be considerable question, however, as to whether the value of such a census to the land owners is as large as the value to the operation organization. The operation organization is in a position to secure such data effectively as the ditch riders are familiar with each farm in their beat and can make the census economically during the less busy period at the end of the operation season. The chief value of any such data is local with each system; comparisons of averages between different systems, as a whole, are of little use owing to the variations of conditions which always occur. On many large systems soil and other conditions vary widely on different portions of the project. For such conditions, the crop census can be very useful in giving data on the average conditions of the land owners

DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
WATER USER CENSUS

THE WATER USER

Name	
Address	
Owner or renter?	
Previous occupation	Previous location
Date of settlement	Number of people on farm
Years experience in humid farming	;in irrigation farming

THE FARM

Subdivision	Sec.	T.	R.	M.	
Subdivision	Sec.	T.	R.	M.	
Subdivision	Sec.	T.	R.	M.	
Acres in farm, total	;irrigable		;seeped		;drained
Acres cleared and leveled		;cost per acre of clearing and leveling $			
Total cost of all other improvements $					
Purchase price of farm without improvements $					
Present value of farm with improvements $					

THE STOCK & EQUIPMENT

KIND	NUMBER	VALUE
Horses		$
Mules		
Cattle		
Sheep		
Hogs		
Fowls		
Hives of Bees		
Total		$
Equipment		
Grand Total		$

THE CROPS

In listing crops (other side): under **BEANS** include white and brown beans raised for market for human food; under **CANE** include sugar and sorghum canes; under **CORN, INDIAN**, include all varieties of Indian field corn; under **CORN, SORGHUM**, include the Sorghum family, such as Kaffir corns, Milo maize, Jerusalem corn and Egyptian rice corn, raised for grain; under **CORN, FODDER**, include stover or fodder harvested either from Indian or Sorghum corns; under **FRUITS, SMALL**, include berries, currants, grapes, cherries, plums, olives, dates and figs; under **GARDEN**, include the family garden and all truck crops grown for market and not given in the printed list; under **PEAS**, include all threshed field peas, soy-beans, cow-peas and the like; under **WHEAT** include all common wheats, macaroni wheats, spelt and emmer raised for grain; under *EACH CROP* include any acreage on which the crop failed and compute the average yield from the total acreage of the crop.

REMARKS

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Water User or Ruler

FIG. 27*a*.

FIGS. 27*a* and *b*.—Form for crop census used by U. S. Reclamation Service.

Kind	Acres	YIELD			VALUE		
		Unit	Per Acre	Total	Per Unit	Per Acre	Total
Alfalfa Hay		ton			$	$	$
Alfalfa Seed		bu.					
Apples		lb.					
Barley		bu.					
Beans		bu.					
Beets, Sugar		ton					
Cane		ton					
Clover Hay		ton					
Clover Seed		bu.					
Corn, Indian		bu.					
Corn, Sorghum		bu.					
Corn, Fodder		ton					
Cotton		lb.					
Flax		bu.					
Fruits, Citrus		lb.					
Fruits, Small		lb.					
Garden		—	—	—	—		
Hay *		ton					
Hops		lb.					
Millet Seed		bu.					
Oats		bu.					
Onions †		bu.					
Pasture		—	—	—	—		
Peaches		lb.					
Pears		lb.					
Peas		bu.					
Prunes		lb.					
Potatoes, C. ‡		bu.					
Potatoes, S. §		bu.					
Rye		bu.					
Wheat		bu.					
Miscellaneous							

Total acreage

Less acreage counted twice

Net acreage cropped

Total Value $

Average Value per Acre $

* Except alfalfa and clover hay.
† Onions raised for market.
‡ Common
§ Sweet

Total irrigated acreage of:

Non-bearing orchard ________ Acres
Young alfalfa (no crop) ________ "
Ground fall-plowed ________ "
Miscellaneous ________ "

Total________

Less acreage of crops grown in non-bearing orchard, young alfalfa ground fall-plowed, etc................ ________ "

Net area irrigated without crop................ ________ "

Net acreage cropped (See above)................ ________ "

Total irrigated acreage................ ________ "

FIG. 27b.

in the different divisions which may be used as a basis of adjustment of payments, either in time or in amount.

The 5 × 8 card used by the U. S. Reclamation Service for collecting such statistics is shown in Fig. 27. This is a general form for use on all projects and consequently contains more items than would be required for any single system. The omission of the items not desired on other systems will enable the size of the form to be reduced. If a copy of each card is given to the land owner a form using only one side of the sheet enables carbon copies to be made and is preferable.

The expense of taking a complete agricultural census need not be high. Where the one collecting the data is familiar with the area covered returns from an average of 20 farms per day should be secured in the field. If many trips over the area are required in order to find those missed at earlier calls the average may be less than this. A personal visit is essential if complete data are to be secured. Inquiries through the mail will not ordinarily bring replies from over 30 to 40 per cent. of those addressed. Proper follow-up letters may materially increase this percentage, but many of the replies received will be incomplete and not on a uniform basis.

Where such a detailed census is not considered warranted, it may be possible to secure data regarding particular crops from other sources. The beet-sugar companies keep quite complete records of all lands under contract to raise beets. Various marketing organizations may have similar records for the crops which they handle. If the areas of each crop irrigated have been secured in the spring, the average yields may be secured in the fall by a canvas of a selected number, such as 75 or 100 of individual farms, the average yield of which is assumed to be typical.

Where financial returns are secured in the census, it is customary to apply a uniform unit price to each crop. This is desirable for such staple crops as alfalfa or grain. For special crops such as fruits the actual prices for each farm may be used.

The interest which the canal organization has in such records depends on the form or organization and stage of development of the system. Where land and water have been sold on long-time payments, the organization carrying such deferred payments has a very material interest in the progress in development of the land owner as the securing of their payments is dependent mainly, on the earnings of the land. Where the system is owned directly by the land owners, such as in coöperative companies or irrigation districts, such data may have much value in securing loans or in selling bonds for improvements, those systems which are able to show a regular progress in development and increase in resources of the land owners furnishing a better security for such loans. Where such data are collected for the use of the land owners rather than in canal operation, the census may be taken by the canal organization with their regular force due to their familiarity with the conditions.

DRAINAGE

Drainage, either partial or complete, is coming to be recognized as a usual necessity on the majority of irrigation systems. Where the boundaries of the drained area are included within or coincide wth those under an irrigation system the operation and maintenance of the drains may be handled by the irrigation organization.

In most cases drainage systems are built and maintained by district organizations separate from those handling the irrigation system. The U. S. Reclamation Service, irrigation districts in some States and a few private systems build and operate the drains needed with the same organization used for the irrigation system. As drains are not usually constructed until actually needed, the construction comes after the irrigation system is completed and in use. The construction of drains on private systems, either for surface waste, deep drainage or both may be more largely as an aid in selling land than as a direct part of the irrigation system.

On Carey Act projects, drainage, when required, has usually been handled by separate drainage district organizations. If such districts include much unpatented land the security behind the drainage bonds is less desirable. With Carey Act projects the price for the construction of the irrigation system is fixed in the contract between the company and the State. The terms of this contract can be fixed for the irrigation system as the work to be done can be definitely specified; for drainage, however, the extent of the work to be done cannot be determined until needed following the actual use of water.

Drainage systems may be built for smaller units of area than that of the irrigation system as only certain parts of the lands may be injured. The area of a drainage district usually includes only the land tributary to a certain outlet. There may be several such outlets within an irrigation system. Drainage district costs are required by law to be assessed on the basis of the benefit to the land in nearly all cases. Where only a part of the area under a canal is injured, only such lands can be included in the drainage district. Higher lands whose deep percolation losses may be the cause of the injury are not made to pay for the costs of the drainage district. For such cases the building of the drains by the irrigation system as a whole as is done within irrigation districts in California or on some government systems is a fairer distribution of the cost.

Drainage water comes from canal seepage, surface waste in irrigation and deep percolation of part of the water applied to the land. The only one of these which comes directly from the canal system and for which it may be responsible is the canal seepage. The conditions under which a canal company may be held responsible for such seepage have been discussed under the head of damages in Chapter I. The deep percolation loss on irrigated fields is frequently a considerable percentage of the amount applied and such percolation, in many cases, is the principal cause of the rise of ground water. The extent of such field losses is not usually as fully realized or understood by the users as the loss from the canals, so that the canals are blamed for drainage troubles for which they may be only partly responsible.

The operation organization may be of assistance in restricting the need for drainage by their influence and control over the use of water in irrigation. Where the systems are still unpaid for and are operated by the constructing organizations, the interest of such organizations is greater than the mere saving of the cost of drainage. Land needing drainage is not in condition to earn the payments for the irrigation system. Assistance in drainage may be necessary in order to protect the irrigation payments.

Possible future drainage should be kept in mind when the location of the irrigation canals is planned. The use of natural drainage channels for canals will interfere with both surface runoff and the construction of drains.

Maintenance is as essential for drainage systems as for canals. The effect of open drains depends on the height of the water in the drain for a given flow. If the drain becomes silted or the growth of vegetation raises the water surface the effect of the drain is lessened. In the slower velocities usual in drains, the condition for growth of moss, pond-weed, tules, or other forms of vegetation are favorable and cleaning or cutting during the irrigation season will probably be required. The methods of removal of such vegetation are similar to those used in canals. The sloughing of side slopes or silting, due to deposits washed in or picked up in the drain, may make periodic dredging or cleaning necessary.

Drains, particularly covered ones, should not be used for surface waste in irrigation. This is particularly true for small lateral drains. The use of such drains to carry the full irrigating head of a farm has, in some cases, resulted in washing in sufficient matter to clog the drain.

DELIVERY OF STORAGE THROUGH STREAMS

With the more complete utilization of stream flow by means of storage, the administration of many Western streams has become quite complicated. The division of water from a large and long main canal to the various laterals presents many problems if the result is to be equitably accomplished. Such canals, however, are subject to control as to the total flow and the rights of the users under the different laterals are generally equal in time and amount. The distribution of water from a stream to the various canal systems along its course is similar to the division within each system but is without the advantage of control of the total flow or uniformity of priority. If, in addition, the return flow is of appreciable amount, the result is a condition which requires an understanding of the characteristics of the particular stream and of river hydrography, if all canals are to receive the water to which they are entitled.

The administration of the diversions from streams is under the supervision of the State engineer in most of the States. The extent to which such supervision is carried out varies in the different States. Such State administration can have effect only where the rights of the different canals both as to amount and as to priority, have been adjudicated. The extent of the administration exercised by the state may not be sufficient for the needs of some more highly utilized streams and a combination of the canals may be effected to supplement such control. This has been done on the Arkansas River in Colorado. Where no direct procedure for the determination of all rights on a stream has been provided by law, the canals may enter into a controlling and binding agreement adopted mainly by mutual consent, such as the present control of the Yakima River in Washington.

The distribution of direct flow does not present such complications as does the mixture of direct flow and storage rights. Where a canal system can procure storage along its canal and below its diversion point, the condition is mainly that of direct use. When, however, the storage for lower canals is provided on the upper drainage area above the diversion points of intervening canals, the conveyance of such water to the canal entitled to its use is a difficult matter. The laws of the different States permit the use of natural stream channels for the conveyance of such stored water. The one owning the storage is entitled to release such water at his desire, let it mingle with the natural flow and be conveyed through the stream to his point of diversion and there divert the amount of such storage less the loss of conveyance in the stream channel. Water, when stored, is reduced to ownership and such storage water is not subject to being taken by earlier rights when being conveyed through the stream. The owner of the storage is liable only for such injury as may be caused to earlier rights by such flow. As such storage is released at low stages of the river such additional flow may benefit rather than injure, due to the increase in the river stage, thus making diversion of the natural flow less difficult. The losses in conveyance are usually determined for each stream although definite determination is difficult. The statutes of Arizona provide that a loss of ½ per cent. per mile of stream used shall be deducted. In some streams there may be a gain due to return flow and the loss in conveyance may be quite small.

Although the legal questions as to the relative rights on a stream may be quite definite, the physical questions as to which water is natural flow and which is storage, and the actual detection or proof of excess diversion by intermediate ditches are ones of much difficulty. Increasing the flow of a stream due to the release of storage has a similar effect on the diversion by canals that an increase in the flow in a lateral has on the turnouts. Unless the headgates are lowered the increased flow, which increases the depth or head on the headgates, will increase the amount diverted at the expense of the stored water being run. If there are a sufficient number of such headgates to be passed, the storage flow may be seriously depleted. Such lowering of headgates may be objected to by their owners and can be done only by those acting under the police authority of the State, such as water commissioners, of the State engineer or of the courts. The expense of such administration is borne by those benefited. Some of the older systems may control the flow into their canals at low water by means of brush or other forms of temporary dams without permanent headgates. For adjudicated rights permanent headgates are generally required as a prerequisite to the right to receive the amount of their adjudicated right.

Water released from storage blends with the natural flow. A sharp increase in the flow at the reservoir will flatten out, the increase at points lower down on the stream being gradual and less marked. If there are tributaries, which may have a variable discharge, entering the stream below the reservoir, or if the rate of return flow is of material amount, the separation of natural flow and storage cannot be made exactly. Even with complete records of inflow at all the points the complications of time allowance for the various effects to be felt at any point will render the resulting estimate subject to uncertainty. If complete records are available for the stream before storage is released and also after a few years of use for the conveyance of storage, the administration of the stream can be developed from the experience acquired in handling it.

Storage both on the watershed and adjacent to the irrigated areas has been extensively developed in northeastern Colorado. In some cases a canal system may own a reservoir site below the level of the lands which they serve. A system of exchanging water has been developed, the water to which earlier direct-flow rights lower on the stream are entitled being diverted by such higher canals and an equivalent amount of the storage released for use by the earlier rights. Such exchanges are carried on extensively and have resulted in the very complete use of such streams. The handling of the exchanges is under the supervision of the water commissioner of the State.

On the Snake River storage has been provided at Jackson Lake in Wyoming for use by some of the more recent systems in the vicinity of Twin Falls, including the Minidoka project of the government. Much controversy with the older canals on the upper Snake River has arisen over the conveyance of the storage water past their diversions. Similar conditions have arisen on the upper South Platte River in Colorado, and others and will probably arise in an increasing number of streams as the construction of storage increases.

OPERATION OF LARGE PUMPING PLANTS

The use of pumping plants for relatively large areas is a development of recent years which has been due to the increase in the value of water and land and to the decrease in the cost of power. It is also partly due to the improvement in the character of pumping equipment used with the resulting increase in efficiency.

While the operation of irrigation systems supplied from pumping is generally similar to that of gravity supplies, certain elements in the cost of operation make it necessary to plan the delivery methods somewhat differently where pumped water is used. The following discussion does not attempt to cover questions of construction or of mechanical operation.

Pumping systems irrigating sufficient area to require the services of an operation organization usually secure their water by pumping from surface sources. In conveying water from a stream to lands adjacent to and higher than the adjoining stream two methods may be used. A canal may be run on grade contour from the river sufficiently high to cover the land or the water may be pumped directly from the stream. The cost of construction and operation of the diversion canal can be compared with the similar costs of the pumping lift. For streams having flat gradients or for locations where the diversion canal passes through difficult country, the pumping plant may be cheaper. That such conditions do occur is evidenced by the number of such pumping plants which have been installed.

Canal Operation under Pumping Plants.—The generally higher cost of pumped water tends to its more economical use. The heads delivered for irrigation to each farm should be those which can be most efficiently handled. This makes the use of rotation delivery more general. Where continuous flow gives an efficient use of water it will also furnish a relatively uniform load on the pumping plants. Delivery on demand is not desirable as it tends to a high peak use and a less constant load. Where rotation is to be used and the delivery heads are relatively large in proportion to the capacity of the pumping stations, the capacity of the units should be selected so that the station output can be varied by multiples of the rotation heads.

For canal systems supplied by pumping the cost of service is more nearly proportional to the quantity of water handled than to the acreage served. For gravity supplies the acreage served is generally the controlling element of cost. Pumping systems resemble those supplied by storage in that the cost may be more largely that of developing the water supply rather than the cost of its conveyance and distribution. This condition makes the use of the quantity basis for charges even more desirable for pumping systems than for gravity supplies.

For gravity systems water may be diverted into the canals and if not used, wasted with but little direct loss or expense. With pumped water this is not the case, as each acre-foot of water pumped into the canals represents an actual cost for pumping. A closer control of the water and supervision of its distribution and use is required in such cases.

It is essential that the pumping season be restricted in length where power is purchased under a minimum monthly rate for each month of use. The cost of attendance is also an added factor. This makes it undesirable to attempt to deliver stock water or to winter operate pumping plants.

Where rates for power are based either wholly or partly on the maximum demand or on the connected load, it is important that the peak demand be reduced to a minimum. This also results in a saving in equipment. This can be done if the crops grown are diversified so that their periods of demand do not coincide, or, if deep-rooted crops, particularly orchards, are irrigated in which the seasonal demand for water is more uniform. The peak demand may be reduced by the form of rates for water. The charge for water may be made lower during the periods of less demand in order to encourage use then and reduce the needs at the height of the season. The maximum rate of demand can be made a part of the water-right contract, such as the agreement for the delivery of 1 second-foot to a relatively large area. Where the water rights are based on the use of a certain number of acre-feet per acre for the season the maximum amount which can be taken in any one month may be specified such as a right to 2½ acre-feet per acre per season not over ½ acre-foot of which is to be used in any one month.

Equipment of Pumping Plants.—In order to operate each pump efficiently, the number of units in a station should be sufficient so that the variations in discharge can be obtained by operating varying numbers of pumps rather than by varying the discharge of each pump. Usually at least three units will be desirable for larger stations although some plants have been built with two, one of which has a capacity about twice that of the other. Larger units have somewhat higher efficiencies although for sizes above 12 or 15 inches for centrifugal pumps such increases are relatively small. It may be desirable to have an extra unit for emergency use. This may not be necessary, however, as with four or more units one can be shut down without material injury except at the short maximum peak of the season.

Foot valves or other sources of loss of head should be avoided. For higher lifts a check valve in the discharge pipe is used, to protect the pump casing from surges when the pump is shut down. Valves are relatively more important on low lifts as the loss caused is a greater percentage of the useful work accomplished.

Where the head pumped against does not vary the pumps can be direct-connected to motors if they are designed for the same speed. Where the head varies during the season or in different seasons belt connection may be used so that the speed of the pump can be adjusted to the lift. Such variations are more usual in pumping from wells. The variations that occur in the stages of rivers from which water may be pumped may also be of importance. For high lifts such variations are of less relative importance and it may not be necessary to change the speed. In one plant provision has been made for changing the pump runners during the season due to variations in the head of about 40 per cent. in a low-lift plant. For the ordinary changes of head, two-speed motors or belt connection with change of speed secured by changing the sizes of the pulleys might be preferable.

Operation of Pumping Plants.—Power consumption is most readily expressed in terms of kilowatt-hours used per acre-foot of water lifted through a height of 1 foot or per foot acre-foot. For 100 per cent. efficiency 1.025 kilowatt-hours would be required per foot acre-foot. In practice, some plants have secured a foot acre-foot per 1.7 kilowatt-hours of power input equivalent to an over-all efficiency of 60 per cent. Small individual pumping plants may require as much as 3 kilowatt-hours or an overall efficiency of 34 per cent. For well-built and maintained plants serving areas of over 500 acres not over 2 kilowatt-hours per foot acre-foot should be needed. This is equivalent to about 50 per cent. overall efficiency.

Continuous attendance is customary at larger plants. Where a series of lifts are located a short distance apart one operator may attend to more than one plant. When continuous attendance is used, large units are more economical in labor cost. In some cases the operator may patrol a portion of the adjacent canal. Whether continuous attendance is used or not, the plants should be equipped with protective devices for such conditions as no voltage and be made as nearly automatic as possible. Two shifts of 12 hours each or three of 8 hours each may be used, the former being more usual except on government systems.

In some systems small pumping plants for lifting water to cover higher areas or for drainage of small areas may be used, their operation being handled by the general operation force. These plants are usually small and comparable with those used for individual land owners. Attendance is not continuous with such plants and they should be planned to operate as nearly automatically as possible. It is often preferable to arrange with adjacent land owners to give such routine attention for oiling as may be needed rather than to use any of the regularly employed force. For such plants electricity is preferable due to the smaller amount of attention needed.

Source of Power.—Electric power is used by the greater number of large irrigation pumping plants. The rates under which this is secured vary both in character and amount. In some cases the power is generated by the irrigation companies; more usually it is secured from the larger power systems. Three general kinds of rates for power are used: the flat rate, the meter rate with a certain minimum and a meter rate plus a certain demand charge. With all forms of rates it is desirable to keep the connected load as small as practicable. This is particularly important with the flat rate. The usual flat rates vary from $25 to $40 per horsepower for 6-month season. Other typical rates would be about $12 to $18 per horsepower demand charges for 6 months service plus an energy charge of about ½ cent per kilowatt-hour. Where a meter rate with minimum charges is used, the meter rate for larger plants varies from less than 1 to 2 cents per kilowatt-hour depending on the size of the plant and the load factor plus a monthly minimum of $1 to $2 per horsepower. One kilowatt equals 1.34 horsepower. In some cases lower rates may be made for use during 19 or 20 hours per day, the pumps being shut down during the lighting load peak in the evening. For medium-size plants the saving in rates may be sufficient to warrant such operation; for large systems the disadvantages in canal operation will overbalance the saving in power cost.

In some cases an irrigation system may be able to generate power at its diversion dam or at drops in its canals. The Minidoka project develops sufficient power at its dam to pump water for about 50,000 acres. Drops are utilized on several systems, among them the Sunnyside and Huntley projects, for pumping a portion of the water to higher elevations. Power generated at drops has a seasonal characteristic similar to that of irrigation pumping and can be used very advantageously for such purposes. Where the drop is located at the point at which it is desired to pump, direct connection of turbine and pump may be made.

Where power is generated at diversion or storage dams, the irrigation system may also carry on a general power business. This can be done directly or by leasing to other power companies. Such power business may be under the general supervision of the manager of the irrigation system; it is, however, distinct from irrigation operation.

Cost of Pumping.—The other items of cost are operation, maintenance, depreciation and interest. Interest in any case can be figured from the amount of the investment. Operation cost depends on the size of the plant and length of season. The larger irrigation plants have not been in use sufficiently long to determine the average cost of maintenance or depreciation. The necessity for using substantial construction and a good grade of equipment has, however, been demonstrated if such costs are to be kept down and satisfactory service is to be secured. Little data on the total cost of pumping has been made available. A number of plants have satisfactory records of expenditures but do not have records of the quantities pumped or the lift, so that unit costs cannot be secured. The cost of power per foot acre-foot can usually be closely approximated where electric power is used as the general efficiency of the plant may be known. If 2 kilowatt-hours are used per foot acre-foot the cost of power, if purchased, will usually be from 1.5 to 2.5 cents per foot acre-foot for plants supplying canal systems. The cost of fixed charges and depreciation are more variable. The acreage cost of the pumping plant alone may vary from $12 to $25 or more per acre, depending on the area, lift and character of the plant.

Depreciation is more uncertain in amount. The labor cost of operation is also variable. In 1914 the cost of pumping on the Minidoka project, a three-lift system irrigating about 40,000 acres, was 0.14 cents per foot acre-foot for operation and 0.30 cents for depreciation. Power was developed by the project under favorable conditions and at low costs. If interest and general expense are included, it would appear that water for irrigation should be pumped by plants of sufficient size to be economical at a cost of 3.5 to 5 cents per foot acre-foot where power is purchased. For 50-foot lifts this would equal $1.75 to $2.50 per acre-foot. Where the power can be generated at a drop or by the canal system the cost may be somewhat less; where the operation season is short or the plant poorly designed or operated, the unit cost may exceed these figures.

RELATIONS OF OPERATION ORGANIZATION AND LAND OWNERS

Colonization.—Colonization is not a regular part of the duties of an irrigation organization, although in the earlier years of systems developed under the Carey Act or by private capital the operation of the irrigation system is under the control of those who also handle the colonization. Distinct personnel may be maintained for each function or there may be more or less overlapping of duties. On smaller systems the members of the operating force may be called on to aid new settlers by giving advice regarding the preparation of land and methods of irrigation. On larger systems a separate adviser may be maintained.

Close coöperation between the colonization and operation forces is necessary. While additional settlers are still being sought it is usual to be more lenient in the enforcement of rules with those already on the ground. The preparation of land plats and checking of payments for water can be handled by the operation force, the plats being made and kept posted by the engineering department. It is necessary to keep in close touch with the land selling in order that the extension of laterals and construction of turnouts may be made as needed.

The operation organization is particularly interested in one policy of colonization which is coming to be recognized as necessary. This is the opening of the project in definite units and the withholding of new units until the old ones are nearly sold out. In some of the older projects, the first settlers have been scattered over large areas making operation difficult and expensive.

Methods of land colonization are improving. It is now realized that more than a purchase contract is involved. Where settlers are to be carried for future payments, those who are capable of success or have capital to make payments are the only types of settlers to whom a company can afford to make sales. The difficulties with delinquent payments, the bad effect on other sales of those who fail and the expense of securing purchasers make a policy of care in the selection of settlers necessary. Land speculators are undesirable from the point of view of the company, as their lands are more slowly developed and their owners more easily dissatisfied. In the past there have been some systems where the first purpose of colonization has been the securing of sales contracts to be used as security for construction work. This condition has now changed as settlers cannot be secured for large systems who will purchase before water is made available. Greater expenditures from their own resources are now required by those developing irrigation systems for land-colonization purposes and this greater investment leads to a more permanent interest in the project on the part of the promoters.

With coöperative companies or irrigation districts the lands are in the ownership of settlers at the time the development is made. For such systems, the land sales are individual in nature and do not involve the operation organization.

The rate of extension of the irrigated area is relatively slow in many cases. The records of the U. S. Reclamation Service show that an average of only one-fourth of the irrigable area is irrigated in the second year of operation and that one-half the irrigable area will not be irrigated before from 4 to 6 years. For many systems the rate of development has been slower than these amounts.

Average Size of Farm.—The average size of farm units is a factor both in colonization and in the operation of the system. Larger farms mean fewer deliveries and less detail in the delivery methods. If the average size of farm is too large, large capital or an excessive length of time are required for its complete development. For the most rapid development of the land and increase of irrigated area small farms are preferable. Such farms may be smaller, when developed, than sufficient to fully occupy or support the farm family. The limiting of the farm to such an area that the capital available will permit of its rapid development, followed by the leasing of other land if the original holding is too small, is to the interest of both farmer and canal company.

The desirability of having fixed sizes of farm units may be questioned. The U. S. Reclamation Service has discretionary powers in fixing the maximum area for which water-right applications will be received. This area has been made relatively small in some cases. The proper size of farm unit depends as much on the financial resources of the settler as on any other factor. While all should be discouraged from taking larger areas than can be developed to advantage, fixing too low a maximum area may restrict settlement to those of limited capital. The size of entry can be fixed only in the case of land within government projects and such limits cannot be enforced in practice after the land and water titles are in private ownership. The economic size of farm varies with the individual, the type of agriculture and the financial resources of the owner. Like other economic questions in agriculture it must be worked out from the point of view of the farm. In irrigated agriculture, the irrigation methods must be adjusted to such conditions on the farm rather than to attempt to adjust conditions on the farm to desired irrigation methods.

Agricultural Aid to Irrigators.—As a part of the realization of the common interest of irrigator and canal operator, or of the new settler and the colonization of irrigation systems, various kinds of agricultural assistance have been supplied to settlers on new systems.

Demonstration farms have been used in some cases. The purpose of these has been to demonstrate the crop possibilities of the locality, mainly for use in land sales. It is now recognized that constructive demonstration work requires many years of experiment under consistent direction and that such results can best be secured under the direction of either the State agricultural colleges or the U. S. Department of Agriculture. While demonstration or experiment farms are now in operation under several systems they are nearly all under such control. Such work is properly handled by State or federal funds as the results are of general public benefit. It is also now recognized that the results on raw lands are not necessarily indicative of future results after soils have been in use.

More effective aid can be given to new settlers directly on their own farms. Some large companies have employed agriculturists for such work, who correspond to the county agents or farm advisors now employed to some extent by the government and counties. Such men can be of much assistance in preventing mistakes by those new to the locality or in improving practice for older communities. From the direct point of view of the operation of the canal system, the advice given on preparing land for irrigation is the most important. The single factor which affects the duty of water to the largest extent is the care used in preparing the land. For permanent crops the character of the preparation of the land largely controls the duty of water and size of irrigation head for several years. If settlers can be given advice on the methods suited to their lands and be induced to plan their ditches and lands so that the most economical size of irrigation head can be used, the problems of delivery of water both in method and amount will be much simplified. Such advisors can also be of much assistance in aiding the settler to choose the crops to be grown and crop methods, in purchasing stock and in selling his products.

The regular operation force may to some extent assist in such work. This can be done through general advice and coöperation. On some systems, instrumentmen employed by the company are used to survey the land, make topographic maps and plan and stake out the farm system. On others, aid is given only to the extent of laying out ditch grades. This may be to the interest of the canal system as the farm takeouts can be planned in connection with the sub-lateral system and arrangements made for using uniform sizes of irrigating heads where other conditions permit.

Ownership of Land by Operation Force.—The ownership of lands under a canal system by members of the operation organization is a question which has given trouble on some systems. This is particularly true of government systems; for other forms of organization the outside activities of employees are not so closely restricted. Any such ownership should be for actual use and not for speculation. The arguments in favor of such ownership are that the experience will give those in charge a better understanding of the difficulties of the land owners, tend to make changes in the management and other officials less frequent and create a better spirit between the operation force and the users.

The arguments against it are that the operation force may favor the vicinity in which they own land in time of water shortage and that they may give time and attention to their farms which should be given to the canal system. There does not seem to be any marked advantage to either argument; if officials desire and have the means to own farms under the system, they should be permitted to do so, but such ownership is not essential.

It may be found desirable to provide ditch riders with houses and small areas of land. This is done as a part of the compensation and as an encouragement to permanence in employment and is separate from the question of ownership of land for general agricultural purposes.

Restricting Use of Water.—The extent to which the operation force can go in restricting excessive use of water is difficult to determine. Where the excess use is practised by only a few or comes within the scope of the rules governing waste, the cases can be handled individually. Where the practice is that of using more water than is required, although surface waste may not be evident, control is more difficult. Generally, the management cannot go beyond the point to which public opinion will support interference with the individual. Such public opinion will usually support restrictive measures against users where waste is noticeable or to the injury of others, either from actual waste or due to the resulting reduction in their supply. Where the water supply is ample in amount, little support can be secured for a policy which restricts use unless the direct injury is apparent. While the operation force may be the actual leaders and organizers of public opinion, their actions in restricting use should appear to come from an outside demand by the users, rather than on their own initiative. To attempt to force a control of the use of water by the operation organization engenders a direct opposition to such control which only increases the time before a more careful use can be secured. The duties of the strictly operation force are administrative; it is not desirable that they be also judicial in regard to policy except in so far as they may be in accord with the users or compelled by necessity. The efforts of operation employees should be educational in nature, calling attention to the results secured by those practising economy in the use of water, keeping records by which the identity of the "water hog" becomes known and advocating diversified crops or crops of lower water requirement where practical.

The quantity of water to which a farm is entitled is determined by the terms of some agreement, such as a water-right contract, or by the number of shares held in coöperative companies, that is, the user is protected in his water supply up to some total rate of use or total quantity. Within the limits of such rights, the user is generally the judge of his needs and restrictive control is more largely a matter of diplomacy than of right.

The size of irrigation head which is used on each farm affects both the farmer and the delivery methods of the system. The interests of both are to have as large heads used as can be handled effectively without waste. The actual size of head used depends on many factors and varies widely. On many systems the earlier practice has developed the use of smaller heads than those which give the greatest efficiency. The change to larger heads can only take place gradually as the enlarging of farm ditches and structures is required. To attempt to force the use of larger irrigation heads before such changes in farm systems have been made will result in direct opposition which will usually delay the actual changes beyond the time when their adoption might have been secured had no attempt to force the change been made.

Determination of Operation Policy.—For about 75 per cent. of the area irrigated, the owners of the land control the canal system. For one-half of the remaining area the control of the system will eventually be turned over to the land owners. On such systems the policies are determined by the land owners through their elected officers, the duties of those directly concerned with the operation being to carry such policies into effect. The responsibility for the policies themselves rests with those having the power over their adoption. This does not mean that the operation officials should not use their influence in advising regarding the policy to be followed, but the responsibility for the choice belongs with those having the power to make it. Where the users and management are in proper accord the recommendations of the management will usually be followed.

On systems not owned or controlled by the users, policies can be adopted by the owners which may not be desired by the users and the operation force may be able to handle the system in ways opposed by the users. Such practices will not be permanently successful, however. The majority of the systems which are not owned by the users are subject to the control of public service commissions both as to rates and character of service. The general character of service and maximum rates on Carey Act systems until they pass into the control of the users are covered in the contract between the State and the constructing company. Even if the users do not actually control the system they are able to exert a very strong influence on the operation policies, as no system can succeed against the opposition of the land owners.

Irrigation may be and is an absolute necessity for crop production in many localities. Given a water supply, however, its use becomes only one of several factors involved in the success of the settlers. The desire of the farmer is to produce crops most profitably, that of the canal system to have the most economical use made of the water in order to reduce the expense of operation. These two objects, particularly on new projects, do not coincide in many cases. In case of conflict the farmer's point of view will generally dominate if the system is to succeed.

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CHAPTER IX

OPERATION AND MAINTENANCE ACCOUNTS

While the advantages of keeping the accounts of different irrigation companies by some uniform system have frequently been pointed out, yet there has been little general progress toward such uniformity although there has been a general improvement in the character of the accounting systems used. Several of the Western States now have public utility commissions whose jurisdiction extends to the accounts of the utilities in these States. The number of irrigation companies which are classed as public utilities is relatively small, however, and the system and subdivision of accounts which have been prescribed for such companies are those required for all water companies and were planned mainly for municipal water systems. The systems of prescribed accounts are quite similar in the different States and furnish a satisfactory statement of the financial condition of the companies. They do not, however, give sufficient detail to furnish all the costs which it is desirable for those responsible for the management of an irrigation company to have and further subdivision should be used. For utilities particular emphasis is placed on the accounts showing the capital investments and conditions; for the non-profit-earning irrigation companies, such as irrigation districts and coöperative companies, these investment accounts are of relatively less importance than the direct operation and maintenance accounts. Uniform accounting methods are used on the projects of the U. S. Reclamation Service. These are carried to more detail than is usual with other forms of organization.

The forms of irrigation organizations owned and controlled by the owners of the lands served comprise much the greatest proportion of irrigation companies. These vary so widely in organization, size and conditions of operation that it would be difficult to plan a system of accounts suited to all systems. A general classification with the detail to which it is carried varying with the size of the system or other factors represents as great uniformity as seems warranted. This is recognized in the prescribed accounts for utilities where three classes of systems are used based on the amount of the operating revenues. These are usually given as Class A corporations for those having average annual operating revenues exceeding $100,000; Class B, for those between $100,000 and $25,000, and Class C for those less than $25,000.

The purpose of any system of accounts is to supply the costs of various operations and the resulting financial condition of the enterprise. The keeping of accounts is a matter of accounting; the following discussion has reference to the kinds of records needed for irrigation systems and not the technical questions of actual accounting itself. Besides the strictly operation and maintenance accounts any system will, of course, have to carry individual ledger accounts with all parties to whom payments are made or from whom revenues are received. It is the classification of the items of expense to show operation and maintenance costs which forms the basis of general accounting systems for irrigation companies.

GENERAL CLASSES OF ACCOUNTS

Accounts can be divided into certain general classes. Those recognized in the prescribed system of the California Railroad Commission are the general asset and liability and balance-sheet accounts; fixed and tangible capital; income accounts; surplus and deficit accounts; operating revenues; pumping, distribution, commercial and general expenses; taxes; amortization of capital; and clearing accounts. Of these general accounts, operating expenses, amortization of capital or depreciation and clearing accounts most directly concern irrigation operation and maintenance.

The division between operation and maintenance is not made in many systems. Such a division is essential if the costs of different years are to be comparable. For given conditions operation costs may be fairly uniform from year to year, maintenance may fluctuate materially. Where the same employees are used for both operation and maintenance the distinction may be more or less arbitrary and the difficulty of making it has prevented many companies from separating these items.

The distinction between routine operation, maintenance or repairs, replacements, and betterments are often difficult to make in actual practice. The public utility commissions of Idaho, Washington and Arizona use the following definition with only slight differences in wording:

"Maintenance should be understood to mean 'upkeep' and should cover all expenditures for current or ordinary repairs, renewals or replacements of property resulting through wear and tear, or through those casualties which are incidental to the nature of the operation and which expenditures are necessary in order to keep up the productive capacity of the plant to its original or equivalent state of efficiency. When, however, a complete replacement of any building or structure, facility or unit of equipment is made necessary regardless of such current expenditures, the uncurrent or extraordinary repairs, renewals or replacements made necessary will be charged to the Depreciation Reserve, accumulated for that purpose."

The classification used by the Pacific Gas and Electric Co. is defined as follows:

"The charges which are made to capital under the general head of Maintenance of Capital, are generally termed repairs, and are thereby more specifically designated as expenditures, necessary to keep the facilities, structures or units of equipment up to the standard of operating efficiency. When through wear and tear or through casualty it becomes necessary to replace or repair some part of any structure, facility or unit of equipment, and the extent of such repairs does not amount to a substantial change of identity in such structures, facility or unit of equipment, such work is to be treated as a repair and charged to the subaccounts under maintenance. Replacements include all substitutions for existing structures, facilities or units of equipment, which have been exhausted, or become inadequate in service, and when the replacement of such structures, facilities or units of equipment must be considered a replacement, and not charged to any of the subaccounts under maintenance, but to Accrued Amortization of Capital —a general account. When a substitution, for existing structures, facilities or units of equipment, has a substantially greater capacity than that structure, facility or unit of equipment for which it is substituted, the value of the original structure, facility or unit of equipment, less the salvage of old material, as junk or stock shall be charged as a replacement and credited to capital. The cost of the substituting structures, facilities or units of equipment, shall constitute an addition and betterment to capital and be charged to appropriate subaccount in additions and betterments of capital—a division account."

The Oregon Railroad Commission gives more detailed classifications as follows:

"Ordinary repairs include replacements of minor or short-lived parts of structures, equipment, or facilities; replacement of minor parts of structures or equipment made necessary by reason of faulty construction, excessive strains, mechanical injuries, or other minor casualties not provided against in charge for depreciation of plant and equipment; rearrangements and changes in location of equipment, etc. Ordinary repairs are not required to be taken into account in fixing a rate of depreciation. Extraordinary repairs include restoring to an efficient or proper condition buildings, structures, or other units of property which have deteriorated; substituting, in order to maintain normal efficiency, new parts for old parts of continuous structures, where such substitutions do not amount to a practical replacement of any considerable length of such continuous structures; restoring the condition of property damaged by flood, fire or other casualties; recovering salvage and removing retired or abandoned property in connection with the above kinds of work. Extraordinary repairs should be provided for by adequate charges to depreciation. When it is necessary substantially to reconstruct or to replace a major portion of any unit of property or any important section of a continuous structure, the cost should be handled through the Capital account; that is, the cost of property removed or replaced should be credited to the appropriate Fixed Capital accounts, and the new property should be charged thereto."

Such routine repairs as removal of vegetation, or control of burrowing animals which may be handled by the operation force can be charged to operation, particularly where the work done is effective for less than one season or is carried on continuously throughout each season. When the repairs are those covered by the usual annual canal cleaning, or minor changes in structures which would be classed as ordinary upkeep, they should be charged as maintenance. When the repairs are of more important nature such as those which would only be made in occasional years or when they constitute either an entire replacement or a substantial renewal of part of a structure they should be handled through depreciation accounts. Where replacement consists of the substitution of a structure of better type or larger capacity the additional cost over that of duplication of the original structure becomes a betterment. These methods are based mainly on the required accounts for public utility companies where the rates charged cover interest on the value and depreciation as well as operation and maintenance. For such companies it is necessary to carry book accounts for the value of the system in use. With non-dividend or non-interest-earning forms of organization, which include the greater number of irrigation systems, such book accounts of value are seldom maintained. Instead of carrying a reserve account for depreciation both replacements and betterments are met as they arise. With mutual or stock companies the assessments are made to cover the annual expenses which may vary widely depending on the amount of replacement or betterment work done. The individual stockholders finance their own assessments in such cases. Where the betterments are extensive, notes or bonds may be issued by the company to distribute the expense over a series of years. Irrigation districts handle their accounts similarly, the use of bonds for larger improvements being more general. The annual assets and liabilities statements of some irrigation districts give the original cost or money expended from bond funds plus inventory accounts on hand as the total assets without attempting to give figures on present value of the system. For such forms of organization this method is satisfactory, as assessments are based on expenditures and not on legal earnings. Many such companies carry a construction fund and a repair fund, which correspond in a general way with betterments or additions to capital and maintenance respectively, although there may be a good deal of difference in the practice in the charges for replacements. Where extraordinary repairs are paid for by loans, secured at the time of repair and paid during ensuing years, the process is the reverse of that used in accumulating a depreciation reserve over a series of years prior to making the extraordinary repair. In irrigation depreciation is principally that of structures. With proper annual maintenance, earth canals will improve rather than deteriorate, and depreciation accounts will not usually be required. The actual rate of depreciation and useful life of structures depends upon the materials used and conditions of service which have been discussed in Chapter II.

ACTUAL ACCOUNTS

Owing to the wide variation in conditions on different irrigation systems certain functional subdivisions are necessary if the operation and maintenance costs are to be at all comparable.

The total annual costs per acre of a system having a long diversion canal is not fairly comparable with one situated more favorably even if the conditions of actual use of water are similar. In the same way storage or pumping costs should be separated. The larger or functional divisions used by the U. S. Reclamation Service are those of (1) development, (2) carriage, (3) distribution, and (4) drainage and flood protection. In addition such accounts as general expenses and depreciation reserves may be separately kept or distributed to these functional divisions. Some companies distinguish only collection or development expenses and distribution expenses which would include carriage and distribution. With some forms of organization drainage and flood protection of the irrigated land are not handled by the irrigation system but by separate organizations. The general operation accounts specified by the utility commissions for water companies are usually (1) pumping, (2) distribution, (3) commercial, and (4) general and miscellaneous expenses, (5) taxes, and (6) depreciation. These are better suited to municipal water-supply systems than to irrigation.

For systems sufficiently large to have definite operation organizations it should be desirable to recognize development, carriage to the irrigated area and distribution. Development would include the cost of storage including canals for filling if such canals are used or of pumping from wells. On many systems diverting directly from the streams such accounts would not be used. Carriage should cover the cost of conveyance to the boundaries of the area of use which may be either by means of a diversion canal or by a pumping lift from the stream. This division may be neglected on smaller systems covering relatively low-lying lands; it is important on systems having relatively long main canals. Distribution should cover the costs within the area served which will be more nearly comparable on an acreage basis. Judgment is of course essential in the selection of these divisions. Some lands may be served from the diversion canal, making the division between carriage and distribution more or less indefinite. Where water is delivered to laterals only or wholesaled, carriage and distribution may be combined. Where the storage is of a regulatory nature rather than for the actual water supply it may be classed either with development or carriage.

It will also be desirable to carry accounts for general office expenses which can be distributed or not, more usually not, to the four general divisions. Accounts of other business may be carried in the same accounting office depending on the nature of the organization. Where the irrigation company carries on power, land sales, or municipal supply such operations should be treated separately in the accounts and in some cases separate incorporations will be made for their conduct.

The distinction between supplies and materials used in repairs may also be made in the maintenance accounts. Supplies are used in the construction but do not become a part of the finished structures, whereas materials do. Also, equipment such as hand tools are generally classed as supplies if their probable life is less than 1 year. Equipment subject to transfer from one division of the work to another may be carried in a general equipment account and the depreciation for actual use charged to the work on which it is used.

Within each of these general divisions of accounts the subaccounts should be chosen to give the costs of similar items under the same accounts. Maintenance and operation should be subdivided. In maintenance it is desirable to group structures of similar length of life particularly if regular depreciation accounts are being used. This would give subaccounts for maintenance of wooden structures, concrete structures, tunnels, steel pipe, lined canal, earth canals and possibly further detail on some systems.

Separate maintenance costs may be kept for special large structures. A large flume on a system may represent a large part of the cost of the system so that it is desirable to segregate its maintenance costs. These will then be of much aid in judging of the economy of the type of structure used when its replacement is necessary. Also, the accounts for particular types of structures such as measuring devices, certain kinds of drops or delivery gates may be segregated if of sufficient importance.

A suggested general outline showing some of the subaccounts recognized by various systems is given in the following tabulation. With many companies all divisions would not be required. With small companies less detail may be needed. Where the expenditures under any division are large further detail may be useful. For special reasons the costs of particular items such as cost of silt removal by different methods, or maintenance of canals under different systems of handling may be kept.

Outline Schedule of Accounts

DEVELOPMENT.

Reservoirs.

Operation.—Gate tenders, watchmen, labor, supplies.

Maintenance.—Repairs to dams, inlet and outlet structures, labor, materials and supplies.

Diversions to Storage.—Detail as for reservoirs.

Diversions from Storage.—Detail as for reservoirs.

Pumping Plants.

Operation.—Supervision if directly chargeable, labor of attendance, supplies, purchase of power or detail cost of generation.

Maintenance of pumping equipment and buildings.

Drainage and Flood Protection.—To development system only.

Administration of Water Rights. Costs of water commissioners, stream patrol, etc., charged to general expenses in some systems.

Purchase of water, such as storage from other systems.

CARRIAGE.

Operation.—Supervision, gate tenders, labor and supplies on diversion, patrolmen on canals, labor and supplies, other operating labor and supplies, such as controlling vegetation or burrowing animals.

Maintenance.—Labor, material and supplies for repairs to diversion dam and headworks, canal breaks, cleaning canals, repairs to concrete, wood and metallic structures.

General.—Damages from breaks and injuries, roads, lands, buildings, distribution of clearing accounts.

DISTRIBUTION.

Operation.—Superintendence, ditch riders, other operation labor exclusive of maintenance.

Maintenance.—Labor, material and supplies, repairing canal breaks, cleaning earth canals, repairs to concrete, wood and metallic structures.

General.—Damages from breaks and injuries, roads, lands, buildings, distribution of clearing accounts.

GENERAL.

Salaries and Expenses.—General officers having supervision of all work, clerical employees, engineering department, general charges, hydrographic work, directors' expense.

Supplies.—Stationery, postage, printing.

Telephone.—Operation and maintenance labor, material and supplies.

Buildings.—Light and heat, rent, repairs.

Taxes.

Insurance.

Interest.

Equipment.—Furniture, engineering instruments, etc.

Legal Expenses.—General costs, legal retainers, etc. Damages charged directly to the division affected.

Undistributed adjustments to balance annual and general inventories.

CLEARING ACCOUNTS.

Storehouse.—Labor, supplies, rent, fuel, light.

Camp Maintenance.—Labor, fuel, light and rent maintaining, moving, repairs, water supply, supplies.

Messes.—Labor cooks and assistants, food, supplies, fuel, light, rent, moving mess, repairs to equipment.

Corrals.—Labor, light and rent maintaining, feed, hay and grain, shoeing, veterinary, repairs to wagons, etc., moving, supplies.

Shop Expense.—Labor shop employees, materials used, supplies for shop, rent, fuel, light, miscellaneous.

Automobile and Motorcycle.—Labor, gasoline, lubricating oil, other supplies, tire renewals and repairs, other repairs.

Equipment.—Inventory and transfer account including repairs and depreciation of equipment subject to transfer from one division to another.

DRAINAGE AND FLOOD PROTECTION OF IRRIGATED LANDS.

Operation and maintenance in detail dependent on extent used.

RESERVES.

Depreciation when used.

Funds for bond retirement.

SEPARATE OPERATIONS.

Commercial power, land sales, water-right sales, domestic use, handled as separate undertakings.

In the segregation of charges to items or accounts it is usual to employ some form of account number or key system. This may be done by giving a letter or number to each of the general or functional divisions, a similar letter or number to each feature under the functional division, and numbers to the individual accounts under each feature. This facilitates both field and office classification and is now in general use on government, railroad and other large work. Key books or sheets of account numbers are furnished to those making the segregations.

The extent to which costs such as construction work on the larger replacements should be kept in detail in the books or by field costs keepers is a matter on which there is much difference of opinion. Where the work is of sufficient size to warrant the use of field timekeepers it is probably preferable to have the detail kept by them, checking against the totals in the books. If all charge vouchers have the nature of the items given in sufficient detail they can be used to make up detail costs if desired without burdening the books with detail accounts. For this it is essential that the filing system for vouchers be such that they can be readily found from the reference in the ledger. Foremen can be instructed to note the character of the work performed in the time book or in daily reports where the crews are small and regular timekeepers are not kept. Where work is handled under contract the company generally finds it desirable to keep a more or less close account of the costs to the contractor. This is usually done by the field inspector or instrumentman in connection with his other duties. Such costs are of much use to the company in determining the financial conditions of the contractor and in judging fair prices for similar future work. It is generally preferable to obtain such details in the more informal field records rather than to raise detail accounts in the books.

New construction works such as extensions or enlargements should be handled as other new work. Such work is distinct from operation and maintenance. There is a considerable amount of construction work which may not have been carried out before operation began so that in the earlier years both construction and operation books will be carried separately. The building of additional laterals will be such an item. Later, such work can be handled as betterments.

In the cases of some large projects it may be desirable to set up books for separate units of the project. This will apply to the functional divisions as well as to the detail accounts, the accounts of each unit being kept as for separate systems except that single accounts for general expenses for all units may be carried.

Various clearing and suspense accounts will also be required in addition to those handled as general expenses. These will include camp, shop and storehouse accounts which can be carried as distinct accounts and distributed to proper features as desired. The extent to which general expenses or clearing accounts should be distributed to features is often a difficult one to decide. Where they are made on a fixed percentage basis there would seem to be little advantage in such distributions. For instance, if the division of the cost of engineering cannot be made directly to features except as a proportion of other costs little is gained by its distribution in the accounts. If on larger work a member of the engineering force is engaged continuously sufficiently long so that his services can be charged directly against the feature such as an inspector on a contract lasting more than 1 month the charge can be made directly against the work. The utility accounts prescribed by Western commissions usually provide for carrying general expenses without distribution to features. In cost statements of construction the percentages represented by engineering and overhead are of as much use if stated as the percentage to which they would have amounted if they had been distributed as if they had actually been arbitrarily prorated.

REPORTS

Annual Reports.—The reports discussed here are the statements prepared from data collected and recorded, not the methods of collection and recording, which have been previously discussed. The main purpose of such reports is to summarize and convey the information regarding the operation and maintenance of the system to those interested, principally those owning the system, who are also more usually the same in identity as those owning the land served. The information may be of two kinds; that relating to expenditures, and that relating to the results accomplished by the expenditures. In the past the first kind of information has been more usual; at present more attention is being paid to the second in connection with the first.

The practice of making annual reports is general. The year may coincide with the calendar year or with the end of the operation season. Many irrigation systems print annual reports for distribution to the stockholders and water users. This practice is to be commended as it furnishes a basis on which the users can form an opinion regarding the efficiency of the management and secure a better understanding of some of the problems of operation. The necessity of making annual reports also tends to improve the keeping of records on which they may be based.

There is much difference in the detail of such reports. The annual project reports for the systems of the U. S. Reclamation Service are in much detail, giving in some cases some of the records as well as the summary and conclusions from them. Such reports furnish a sufficiently complete record of the operations for the year as to be useful directly as a source of information at later times in case of controversy over results. Only a summary of such reports is printed in the annual report of the U. S. Reclamation Service as a whole. Many systems, such as irrigation districts or coöperative companies, print the financial balance sheet showing only the revenues and expenses without comparisons with former years or reasons for the amounts of the different items. Other systems print reports intermediate in nature but without becoming longer than will be read with interest by those concerned.

Where the main purpose of such reports is for distribution to stockholders, certain points in which the stockholders are interested should be kept in mind. The financial interest is largely in the rate of assessment, the necessity for the amounts assessed, the uses made of the funds, explanations why this year's assessment differs from that of previous years, and possibly a prediction as to conditions in the coming year, although this is usually desirable only in case unusually large expenditures are planned. Any means which give the users a better understanding of the conditions of operation, the policies being carried out and the uses made of funds, aid in creating a better feeling in support of good administration.

The annual report of the superintendent of Imperial Water Co. No. 1 for 1915 illustrates the subjects which may be treated. This contained about 18 printed pages, each topic having side heads so as to be readily found, with the treatment to the point, yet giving the necessary facts. Comparisons with the four previous years were also given. The topics were: gross expenditure and average force employed; conditions of water supply for the year; total water used by months; labor conditions; work and results, such as a paragraph each on cleaning, clearing, cutting brush, repairing canals, new construction, reconstruction, wooden and concrete structures, canal V'ing, dredging; crop acreage by kinds of crops; average duty of water; corral account; data on individual canals; cost of operation of automobiles; and inventory. About two pages of water equivalents, general rules regarding water stock, delivery of water and suggestions in regard to irrigation methods were added at the end.

In the 1915 report of the Twin Falls Canal Co. 8 pages of small size are used to give the usual financial statements of receipts and disbursements, resources and liabilities and inventory, followed by 20 pages of what is called explanation and analysis of accounts, giving in greater detail the results secured from expenditures.

The Modesto irrigation district printed a report of their chief engineer in 1916 following the completion of over $500,000 of improvement work. The costs, including overhead, under each contract, with descriptions of the character of construction used, were given, furnishing information from which the water users could secure an understanding of what had been accomplished.

Circulars.—It may be desirable to issue circulars to the stockholders or consumers at irregular intervals. Such occasions may arise previous to voting on expenditures for improvements, giving data regarding the work planned; when changes in the methods of delivery are made; or in notifying each stockholder of assessments. Temporary matters may be handled through local newspapers. Where the information is official or it is desired that it be kept by the landowner, circulars are preferable. Such circulars are, however, different from the more formal and permanent rules and regulations.

Records.—It is important that all records regarding construction and operation be preserved. This can be done in the general files or by preparing a project history such as has been done for each of the systems of the U. S. Reclamation Service. Such records include drawings of all large structures as actually built, records of any material changes made in maintenance, particularly for portions which may be underground, and records of water diverted and acreage irrigated, with other data useful in establishing water rights. The personnel changes from year to year and such facts should be compiled for later use. This involves but little additional time or expense if the routine drawings and records are kept in good form and carefully filed and indexed. The indexing is as important as the preparing of such information, as it is useless unless filed so as to be accessible.

REFERENCES FOR CHAPTER IX

Uniform classification of accounts for water corporations of:
Corporation Commission of Arizona, Phoenix, Ariz.
Railroad Commission of California, San Francisco, Cal.
Public Utilities Commission of Idaho, Boise, Idaho.

Public Service Commission of Nevada, Carson City, Nev.
Railroad Commission of Oregon, Salem, Ore.
Public Service Commission of Washington, Olympia, Wash.

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APPENDIX

RULES AND REGULATIONS

IDAHO IRRIGATION DISTRICT

By-laws

I

Any one desiring to increase or decrease the flow of water in their ditches must give the manager or water master twenty-four hours written notice, before water is to be changed.

Reason.—The Idaho Irrigation system is not provided with ample waste-way; therefore, it is cheaper to be careful, have a steady stream, and not be assessed for damages and breaks.

II

Headgates.—Unnecessary headgates will not be maintained nor operated.

Reason.—It is impossible to regulate with safety and satisfaction, two gates where one gate will answer all practical purposes.

III

Banks.—Patrons are warned against cutting banks of canals or laterals, controlled by the Idaho Irrigation District.

Reason.—Because it is a penitentiary offence, and will be vigorously prosecuted.

IV

Damages to Banks.—Anyone allowing stock to trample, or in any way damage the banks of the canals or laterals controlled by the Idaho Irrigation District, will be held responsible for damages.

Reason.—To protect the District.

Fences.—Persons having fences across the right-of-way of any of the canals or laterals controlled by the Idaho Irrigation District, shall make proper gateway on banks to be travelled by the water master; they shall, also, keep fences from in any way retarding the velocity of the water.

Reason.—To control a canal, means guarding against damage, as well as delivering water; we must ride the banks in order to guard against breaks.

VI

Wasteways.—All wasteways into the Idaho canal system must drop from a box or flume of proper construction, to be approved by general manager before being installed.

Reason.—To prevent the washing down of the banks, and the filling in of the canal.

VII

Structures.—Any person or corporation contemplating the building of any structure over the canals or laterals controlled by the Idaho Irrigation District, shall first consult manager as to the proper plans.

Reason.—To safeguard against cutting down the capacity of the canals.

VIII

Control.—Gates, checks and other property of the Idaho Irrigation District are to be controlled by the manager and water masters thereof. Any person who breaks, or in any way interferes with, the locks, gates or checks, will be punished according to law.

Reason.—The checks, gates, locks, etc., are property of the District; they have hired a manager and water master to look after this property and give the patrons of the Idaho Irrigation District a distribution his or her holdings entitle them to.

IX

Delivery.—Turning the water to which any person or persons, is, or are, entitled to, into the headgates of such person or persons using the water from this system, shall be deemed and considered to be a delivery of such water to any person or persons. The district will not deliver, nor undertake to deliver, water to any person who does not own, or control, a lateral or ditch, connected with this system, which will safely carry the water which any such person or persons may desire to receive from this system.

X

Duty of Water Users.—It shall be the duty of any user of the waters of this system to keep his laterals or ditches, or lateral or ditch, as the case may be, in such order and repair that the same will safely, and without waste, carry the water which such user may be entitled to.

Approved by the Board of Directors.

TURLOCK IRRIGATION DISTRICT

Rules and Regulations

Governing the Distribution of Water in the Turlock Irrigation District

Management.—The maintenance and operation of canals and works of the District shall be under the exclusive management and control of the superintendent, appointed by the Board of Directors, and no other person, except his employees and assistants, shall have any right to interfere with said canals and works in any manner, except in cases of a special order from the Board of Directors.

Ditch Tenders and Other Employees.—The superintendent shall employ such ditch tenders and other assistants as may be necessary for the proper operation of the system. Each ditch tender shall have charge of his respective section, and shall be responsible to the superintendent. From the rulings and actions of the ditch tender, an appeal may be made to the superintendent, which must be filed, in writing, with the secretary, upon request of the superintendent.

Application for Water.—At the beginning of the irrigation season, the ditch tender shall obtain, from each irrigator, a written application, on forms furnished by the District, specifying the number of acres he expects to irrigate, the kind of crops, and such other information, that may be desirable. The ditch tender shall verify this acreage and shall be held responsible for its correctness.

Acreage.—Only land leveled, or otherwise prepared, and actually irrigated, shall be included.

Condition of Ditches.—Upon said application, it shall be the duty of the ditch tender to certify whether or not the applicants' ditches are in proper condition to receive water. All ditches must be kept free from weeds and other obstructions, and the ditch tenders are required to examine the same and order them to be cleaned before water is turned in. Refusal to comply with this rule will be sufficient cause for refusal to turn water into any ditch.

Time Limit for Use of Water.—Each irrigator will not be allowed to exceed one-half hour to irrigate one acre of land in alfalfa and other crops requiring flooding; but for sweet potatoes, trees, vines and gardens, the District will endeavor to supply water as required, provided that the total amount of water delivered to such crops, in one month, shall not exceed the amount of water available for each acre irrigated in the District, for said month.

Water to be Used Continuously, Day and Night.—The time will start upon delivery of water to irrigator and water must be used, day and night, continuously, until time limit expires.

Notice of Delivery.—Each irrigator shall be notified by the ditch tender, at least twelve hours before the water will be delivered to him, and further notice of any change in time of delivery, and the irrigator who fails to use his allotment of water, during an irrigation, will not be entitled to any more water at any future irrigation, than if he had used his full share at the time of allotment.

Water Furnished in Rotation.—Water shall be furnished in rotation to each irrigator, except by agreement between adjoining owners, satisfactory to the ditch tender, and which will not change the time of irrigation to other irrigators, commencing at the lower end of each distributing ditch. When a break occurs in any distributing ditch, the irrigator, to whom the water is given, until such break is repaired, shall be allowed to finish before the water is taken from him and he shall not claim another irrigation for that run.

Breaks in Distributing Ditches.—The party irrigating at the time of a break, must place the water to the irrigator next in rotation and, if it becomes necessary to shut off the water at the head of the ditch, the ditch tender must be notified. If this is done, the party using water at time of break, shall receive the remainder of his time, when the break is repaired.

Water Receipts.—Any person, to whom water is offered, must sign a receipt therefor. If water is used, the receipt must show upon what kind of crop, and for what length of time, it was used; and if it is not used, the receipt must specify the reason.

Apportionment of Water.—The water will be apportioned to each lateral by the superintendent, and the ditch tenders will be in charge of the distribution of the same, and will be held directly responsible by the superintendent.

Diverting Gates or Side Gates.—All diverting gates, or weirs and gates, on all private ditches, are under the control of the District, but the District will not maintain, or repair, gates, or weirs, on private ditches. The District employees, alone, will be allowed to open the diverting gates, and they have full authority to close the same as soon as the requisite amount of water for each irrigation has been discharged. Said gates will be supplied with locks, and the keys shall be under the control of the superintendent.

Access to Land.—The authorized agents of the District shall have free access, at all times, to lands irrigated from the canal system, for the purpose of examining the canals and ditches and the flow of water therein.

Right of Way.—No fences, ditches, or other obstructions, shall be placed across, or upon, or along, any canal bank, or levee of any canal or ditch, belonging to the District, without the special permission of the Board of Directors of said District. Whenever such special permission shall be granted, it shall always be with the distinct understanding that proper openings, or passageways, shall be provided, so that ditch tenders may pass along the banks of said canals without hindrance and, when so constructed, the ditch tender will keep them closed and that such fence, or obstruction, must be removed, whenever requested by the superintendent, or Board. The superintendent shall have the right to remove all fences, or obstructions, constructed, or maintained, contrary to these provisions.

Application for Gates.—No openings shall be made, or gates placed, in any bank, or banks, of canals, without permission from the Board of Directors. Application for the same must be made to the Board of Directors, and filed with the secretary, on blanks furnished by said District.

Liability of District.—The district will not be liable for any damages resulting directly, or indirectly, from any private ditch, or the water flowing therein; but its responsibility shall absolutely cease when the water is turned therein, according to these rules and regulations.

Liability of Irrigator.—Every irrigator shall be responsible for all damages caused by his wilful neglect, or careless acts.

Section 592, Penal Code

"Every person, who shall, without authority of the owner, or managing agent, and with intent to defraud, take water from any canal, ditch, flume or reservoir, used for the purpose of holding, or conveying, water for manufacturing, agricultural, mining, irrigating, or generation of power, or domestic uses, or who shall, without authority, raise, lower or otherwise disturb, any gate, or other apparatus thereof, used for the control, or measurement of water, or who shall empty, or place, or cause to be emptied, or placed, into any such canal, ditch, flume, or reservoir, any rubbish, filth, or obstruction to the free flow of the water, is guilty of a misdemeanor."

SAN LUIS POWER & WATER COMPANY

Rules and Regulations for Water Users
from the

San Luis Water & Power Company's System
Season of 1913

For an equitable and efficient distribution of water coöperation is necessary, and a strict compliance with the following rules and regulations:

1. Customer must not interfere in any manner with the employees and property of the Company.

2. Ditch riders will have charge of the water and property of the various water districts, and are responsible only to the Water Superintendent.

3. All water will be apportioned by the Superintendent through his ditch riders, to the water users, upon requests from them to be made in the following manner:

A. Delivery and changes in delivery of water must be requested at least 24 hours in advance, and no change will be made during such period.

B. Requests must be made by application to the Superintendent or the ditch rider of the district, or by card left at the headgate or measuring device of the consumer.

C. All requests shall be made not to exceed the rate of 4 acre-feet of water per 24 hours for each 160 acres, or less, of land under the respective laterals of the water user's application for water. Users whose acres are in excess of 160 acres may request amounts in proportion thereto. Exchange between neighbors for the use of "heads" is greatly desired and will be encouraged as much as possible.

D. No request will be granted unless and until at least 6 consumers have made similar requests for water from the same main lateral to be used.

4. Water must not be wasted. Careless and wasteful use of water will not be tolerated, and the water will be shut off from such user until he prepares to make better use of the same to the satisfaction of the Water Superintendent.

5. Complaints of water users shall be taken up first with the ditch rider of the district, and if no relief is afforded, then with the Water Superintendent or his assistant. In case of further complaint, it shall be taken up with the General Manager of the Company by written statement to the same, and in no less than three days after the act complained of has occurred.

6. The limitation in the contract, to 1½ acre-feet of water per acre for the land irrigated during the entire irrigation season will be enforced in the discretion of the officers of the Company.

7. No crossing of a canal or lateral with wagon or other vehicles, which may injure the banks of same, will be allowed, and any such acts will make the party upon whose land the act occurs liable for all damages so done. Obstructions and bridges may be built upon or across the property of the Company, but only upon the permission and under the supervision of the Company.

8. All water measurements will be made in the unit of "acre-feet per day of 24 hours," to all consumers alike. All gages on consumers' measuring devices will be plainly marked in the above unit, so that each consumer can read his rate of delivery and study the economic conditions in the use of his water.

9. Records of delivery will be made daily by the ditch riders and duplicate records made and placed at the measuring device of each consumer. One copy of the same will be placed weekly on file in the office of the Company.

10. Breaks may and will occur. They will always be promptly repaired and regular conditions will be restored as soon as possible. Great assistance will be given if all breaks are reported promptly to the Water Superintendent.

11. In case of shortage of water from any cause, either temporary or for the season, the consumer will be notified as soon as possible, and rotation of water to districts may be made by the Water Superintendent, and then water must be used by the consumer in the rotation periods provided.

12. Water turned into the private ditch of the consumer will be considered as delivered to the water user and for the land covered by the water application. The Company's liability ceases upon such delivery.

13. Party and joint ditches must be properly regulated and to the satisfaction of the Water Superintendent, before water is delivered into the same.

14. Crop data and duty of water for the entire project will be obtained with your coöperation by the Water Superintendent, and summary will be furnished each user at the end of the season.

15. Access to all lands of the water users of the project shall never be denied to the authorized agents of the Company.

16. Service and impartiality is what is wanted, and it can only be obtained by coöperation and strict compliance with the above rules and regulations.

FRESNO CANAL AND IRRIGATION COMPANY

Supplemental Order

IT IS HEREBY ORDERED that the following information, rules and regulations for The Fresno Canal and Irrigation Company and its water users be established by The Fresno Canal and Irrigation Company, effective April 1, 1914:

Information, Rules and Regulations—Fresno Canal and Irrigation Company and its Water Users

Rule 1. *Operation and Maintenance of System.*—The Fresno Canal and Irrigation Company will operate and maintain all diversion works, main canals, branch canals and laterals, where it is the established duty of the Company to do so.

On any portion of the distributing system which the Company is not now obligated to maintain and operate, any user may request the Company to assume control. The Company will then approach all users suggesting a sum for which the Company will place the ditch in proper condition and, further, the rate per acre per annum for which in the future the maintenance and operation will be assumed. Should this be agreed to unanimously, the Company will forthwith assume control. It may be arranged that either the users or the Company shall put the ditch initially in good condition, the actual cost to be paid by the users.

Should the arrangement mentioned in the preceding paragraph fail of agreement by all parties, the user or users desirous of this change may apply to the Railroad Commission, which will decide whether it will be for the furtherance of public convenience to grant the application; and if it be granted, will fix the payment and rates due the Company for such increased service and the time and method of deposit of the payment for such service.

The Company retains the right to supervise the delivery of water to all individuals who make direct payment to it, wherever in the flow of its water supply, and will require that all distributaries not under its direct control shall be maintained in proper condition for the distribution of water to individual consumers.

Rule 2. *Definition of "Pro Rata" Delivery.*—A "pro rata" delivery means a simultaneous flow available at a point nearest on the Company's system for the use of each and every consumer, in an exact proportion of the total amount available, based on the individual's right to receive, as fixed by acreage, contract, payment or otherwise. This method may be applied to all or a part of the system.

Rule 3. *Definition of "Rotation."*—"Rotation" means that method of delivery whereby water is carried through a portion of the distribution system, for a portion of the time, in larger amount than otherwise available, the aim being to deliver to each consumer ultimately as exact a proportion as by "pro rating."

Rule 4. *Protection and Delivery of Full Supply.*—The Company will endeavor at all times to divert all water legally within its right into the canals of the system up to the aggregate amount of demands upon it, and will use every endeavor to protect the water supply available, and transmit same in proportional amount to the points on its system nearest by the established routes to its individual consumers. When sufficient water is available to supply all demands, it will be distributed at all division points and turnouts to branch canals and laterals in a proportional part of the total flow available, allowing for seepage loss, this proportion being based upon the acreage and recognized rights to demand service upon each part of the system. That is, the total amount that is determined can be delivered from the supply available, will be ratably divided.

Rule 5. *Delivery of Intermediate Supply.*—When the supply available at the hands of the Company is insufficient to fully supply demands, but is above 50 per cent. of the amount demanded, water will be pro rated between distributaries of more than 200 cubic feet per second capacity, and may be rotated between smaller distributaries.

Rule 6. *Delivery of Supply Below* 50 *Per Cent.*—When the supply available is not sufficient to satisfy 50 per cent. of the demand, the Company may rotate in all portions of the distribution system. So far as is possible, a forecast will be made of the available water supply, and rotation between main canals shall be so planned as to provide a full head in each canal during the period of flow, which period will be varied in accordance with the amount of the total supply and as many as may be of the branch canals and laterals will be filled simultaneously, and it will be planned to provide a continued flow for sixteen or eighteen days.

Rule 7. *Notice of Water Delivery.*—The Company will provide bulletin boards at convenient points, and will give notice thereon, and by other feasible means, of the time of beginning and ending of rotation periods upon each of the branch ditches and upon all parts of the system where delivery is made by the Company direct to the individuals. The Company will give information of the beginning and duration of each run of water sufficiently in advance for the guidance of consumers. Such publication of rotation periods shall be not less than three days before the beginning of the period, except in case of emergency, when the best endeavor will be made by the Company through all means in its power to spread the necessary information.

Rule 8. *Rotation of Service in Cycles.*—As nearly as is practicable, each individual or aggregation of individuals will be given a ratable service within a single season; provided this has not been done, the rotation shall continue in cycles; that is, those receiving a deficient supply in the preceding season shall be served in precedence of others during the following year.

Rule 9. *Rotation Delivery to Individuals.*—Between the individual users along the main canals of the Company and on minor distributaries where each individual may use the full flow of such distributary, delivery shall be by rotation, commencing generally at the farther end of such laterals, water being delivered to consumers in turn, the length of time being in accordance with the acreage and right. On larger distributaries delivery shall be limited to a rate of 4 cubic feet for 24 hours to each 20-acre lot, and to as many irrigators simultaneously as is possible with the supply available. When rotation has been resorted to in delivery to the main branches the time period shall be reduced proportionally, but the endeavor will be to deliver heads sufficient in amount for the most beneficial use.

Water must be used continuously day and night and should irrigation be completed before the scheduled termination of a period of flow, the superintendent or ditch tender should be notified to have the delivery stopped.

Consumers are responsible for all water delivered to them and must make beneficial use of the entire amount, allowing no avoidable waste.

Rule 10. *Deviations from Schedules.*—Deviation from the established schedule will be allowed only by *previous arrangement*, and when the efficiency of the system is not thereby seriously impaired, so that irrigators desiring a less flow for a length of time may be accommodated, and in case an irrigator is not ready for water when his turn is scheduled, he may exchange with another.

Rule 11. *Credit for Non-use.*—When a water user has not taken advantage of the supply available during any period, nor arranged an exchange with another user, he may be supplied during the next period provided there is more water available than sufficient to supply all demands.

Rule 12. *Control over System.*—(*a*) The structures on the Company's canal system will be under the exclusive control of the Company's employees. The superintendent will give full instructions to ditch tenders in regard to all changes to be made in the flow of water. Any other person tampering with or in any manner changing the arrangement of gates or flashboards in any turnout, check, drop or other structure of the Canal Company, will be dealt with according to law.

(*b*) The superintendent may grant special permission from time to time to irrigators to alter flashboards or gates, which permission should be in writing or by messenger later substantiated by a written communication, and will be for the specified time only. It may, however, be arranged that a number of users on a lateral shall change their gates in compliance with an established rotation schedule.

Rule 13. *Deductions for Over-supply.*—If any consumer shall have been found through his own or any other unauthorized person's acts to have obtained more than his ratable supply of water, the amount above his proper supply shall be deducted from later runs, to compensate the other consumers.

Rule 14. *Unit of Measurement.*—The unit of measurement will be the cubic foot per second.

Rule 15. *Measurement of Water and Records.*—Gaging stations will be established at points in the main and branch canals. At all practicable points in the laterals, weirs or other measuring devices will be placed in sufficient number to arrive at a close approximation of the amounts of water delivered at all points upon the system of the Company. Records shall be kept in the office of the Company showing throughout the season the amount of water that has passed each such point, and will be carried to totals by months, and each interested party will on request be informed at the close of the season of the amount of water which he must reasonably have received in so far as the jurisdiction of the Company extends.

Rule 16. *District Superintendents and Ditch Tenders.*—The official personnel of the Company who will deal with consumers will include two district superintendents, whose duty will be the supervision of the individual ditch tenders and the keeping of records of the amounts of water turned into canals, branches and laterals and chargeable to individual consumers. A sufficient number of ditch tenders will be employed to visit once daily practically every point on the system where water is running. Their duty will be to follow strictly the instructions of the district superintendents in the delivery of water to the various consumers, to make gage and weir readings at all established measuring points, to guard and care for the property of the Company used in the distribution of water, to see that water is not wasted, to report any case of such wasting of water by consumers and trespassers upon any part of the Company's system, tampering with gates and flashboards and complaints made along their respective beats. Complaints may also be made directly to the Company's office, in writing or by phone.

Rule 17. *Relations Between Company and Consumers.*—All officials of the Company are instructed to aid the water users in every manner, and to courteously and respectfully consider all criticisms and suggestions. The

Company will meet with the desires of each consumer in so far as it can do so with justice to all interested parties.

The foregoing Supplemental Opinion and Order are hereby approved and ordered filed as the Supplemental Opinion and Order of the Railroad Commission of the State of California.

Dated at San Francisco, California, this 28th day of March, 1914.

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