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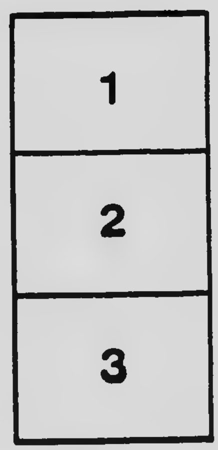
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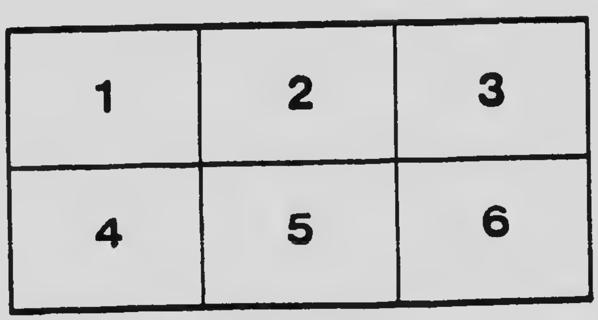
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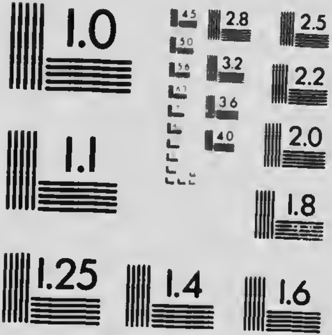

LETTER OF TRANSMITTAL.

Department of Agriculture,

Victoria, B. C., 7th May, 1912.

Hon. Price Ellison,

Minister of Agriculture,

Victoria, B. C.

Sir:—

I have the honour to submit herewith Bulletin No. 45, which is in the nature of a report, prepared by Professor B. A. Etcheverry, Head of the Department of Irrigation, University of California, dealing with the result of investigations conducted by him on Irrigation Systems, and Use of Water, in British Columbia.

I have the honour to be,

Sir,

Your obedient servant,

WM. E. SCOTT,

Deputy Minister of Agriculture.

PRACTICAL INFORMATION

— ON —

IRRIGATION

— FOR —

BRITISH COLUMBIA FRUIT GROWERS

By B. A. ETCHEVERRY

THE GOVERNMENT OF
THE PROVINCE OF BRITISH COLUMBIA

PRINTED BY
AUTHORITY OF THE LEGISLATIVE ASSEMBLY.

VICTORIA, B.C.:
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1912.

Practical Information on Irrigation for British Columbia Fruit Growers.

INTRODUCTION.

In proportion to the extent of agricultural land suitable for irrigation in the arid or semi-arid part of British Columbia, the water supply available is probably more abundant than that of most of the arid regions of the states of the United States, but it is also no doubt true that there are many districts where the supply is either not sufficient or else not available at a reasonable cost to irrigate all agricultural soil which needs irrigation to make it productive. It is therefore important that the available water supply be conserved and used with care and economy in order to cover as much land as possible. This may be done by supplementing the natural flow of the streams by storage reservoirs and by preventing the waste of water.

Measurements made in the United States show that on most irrigation systems consisting mainly of unlined canals excavated in earth, the losses in conveyance from the leaky ditches amounts to about 50 per cent. of the water diverted from the source of supply, and of the remaining 50 per cent. from one third to one half is lost by evaporation, percolation and other wastes due largely to crude methods of irrigation.

Storage reservoirs have been built on many of the streams to increase the water supply. A few irrigation companies are lining their canals with concrete, or using wooden flumes and pipes for their distributaries to stop the conveyance losses of water. This practice will increase the water supply available for new lands, but there will still remain the waste which occurs when water is applied to the land by a careless irrigator or one who does not know the practice and methods of skilful and economical irrigation.

Irrigation in British Columbia with the exception of a few isolated cases, is new and the methods of conveying water to the land and of applying it to the soil are in many cases crude and wasteful. The average irrigator is not interested to the same extent as the irrigation company in saving the water to use it on new land, especially if he pays for the water at a fixed rate per acre and not for the quantity actually used, or if he has an early water right which permits him to use and waste all he desires. But there are other reasons why the irrigator or fruit grower should use water skilfully and economically. First, because if water is valuable and is sold according to the amount used, the elimination or decrease of waste will decrease the water bill. Second, careless and wasteful use of water is liable to cause water-logging of lands not properly drained. Third, it is possible to use an excess of water which will interfere with plant growth and affect the fruit.

For these reasons the writer has attempted to put together information which he hopes will be of value to the new settlers, present fruit growers and to irrigation companies. The information is given under the following topics:

1. Selection of an irrigated farm and laying out orchard.

2. Units of measurement of water and methods of measuring water.
3. Methods of conveyance of water.
4. Duty of water and factors influencing the correct use of water in irrigation.
5. Irrigation and cultivation of orchards.
6. Irrigation of potatoes.
7. Irrigation of alfalfa.
8. The use of small pumping plants for irrigation.

The writer has not attempted to take up questions which are purely agricultural or horticultural and wherever information along those lines is given it is because of their relation to irrigation.

During the summer of 1911 the writer at the request of the British Columbia Government, visited many of the irrigated districts of the province. On two other occasions he has visited the districts in the vicinty of Kamloops and Summerland. This experience has been of great value in selecting for this bulletin information based not only on personal experience and observation, but also on the best practice in the irrigated districts of the United States. Because of the similarity in conditions of the fruit growing regions of British Columbia and those of northwestern states of the United States such as Oregon, Washington, Idaho and Montana, the practice in those states has been given more weight. The writer has not limited himself to his own experience, but has drawn freely from authoritative sources, especially the bulletins of the Irrigation Investigations Office of the U. S. Department of Agriculture and the bulletins of the Agricultural Experiment Stations of the various western states, for which due credit has been given in all cases.

I.—SELECTION OF AN IRRIGATED FARM AND SETTING OUT ORCHARDS.

SELECTION OF AN ORCHARD OR FARM UNDER IRRIGATION.

The intending purchaser should select his land only after he has made a careful investigation of all the requirements necessary for a good farm or orchard. The factors which he should consider are:

1. Climatic conditions.
2. Chemical composition of the soil.
3. Texture of soil and subsoil.
4. Location and site of orchard.
5. Surface conditions.
6. Drainage.

1.—Climatic Conditions.

These include precipitation and its distribution, temperature, wind movement, length of growing season, etc. A study of the rainfall and its distribution will show whether irrigation is necessary or only desirable. The rainfall, no matter how large during the year, is generally deficient during the growing season and there are very few localities which can not be benefitted by irrigation. This is well shown by the extension of irrigation in fruit districts of California, Oregon and Washington where it was formerly believed that irrigation was not necessary.

The conditions desirable for fruit growing are that the growing season be sufficiently long to mature the fruits and that there be no great or sudden fluctuations between high and low temperatures in the winter and spring time. At very high elevations the growing season is too short.

Early frosts in the fall and sudden increases of temperature in the spring, followed by severe late spring frost, may cause considerable damage.

Strong winds are destructive to both trees and fruit and should be provided against by planting wind breaks. The existence of strong winds may be indicated by the trees being permanently bent.

2.—Chemical Composition of the Soil.

The soil must contain all chemical plant food elements and decayed organic matter or humus. As a rule if the soil is deep, these are all present in sufficient quantity with the exception of humus which is often lacking. The lack of organic matter can, however, be corrected by growing suitable crops.

The soil and subsoil should be free from alkali salts. This may be indicated by the character of the native plants. Sagebrush and buffalo grass usually indicate that the soil is easily cultivated, well drained, deep, free from alkali and fertile in chemical plant food, but some times deficient in humus. Greasewood and salt grass indicate the presence of alkali. An analysis of the soil will be of great value. The soil should be rich in potash, phosphoric acid, nitrogen, lime and humus.

3.—Texture of Soil and Subsoil.

The best soil is one which is deep, retentive of moisture and underlaid with an open subsoil. The presence of a hard or impervious stratum closer than 5 feet to the surface is injurious and a greater depth is preferable. The hard stratum prevents deep rooting which is essential for fruit trees. A shallow soil underlaid with open gravel may not have sufficient plant food, will require frequent irrigations, and may cause a large waste of water. Fruit trees will grow in a variety of soil. Apples prefer a deep, retentive loam rich in humus. Cherries will probably do best on a well drained, sandy soil or light clay loam, rich in plant foods, but it should not contain an excess of nitrogen, which has a tendency to produce excessive wood growth. Peach trees will do best on sandy soil. Pears will grow best on clay soils and can be grown on the heavier bottom lands. They all require a deep, rich, well drained soil.

The character of the soil and subsoil is best determined by boring holes with a soil auger to a depth of 10 feet.

The behavior of the soil when irrigated is important. A clay soil or soil which is very close will absorb water very slowly and is more difficult to cultivate and will probably bake after each irrigation. As a rule a sandy loam irrigates well and is easy to cultivate but a very porous soil will allow the water to percolate freely beyond the reach of the plant roots without spreading sideways when applied in furrows.

4.—Location and Site of Orchard.

The orchard must have good air drainage as well as soil drainage. The best air drainage is obtained on rolling lands, on hillsides or on the benches well above the bottoms or lower sides of ravines or depressions where the cold air settles at night. A very [illegible]able location is found at the upper end of small valleys. What is [illegible] is the daily occurence of good air currents.

There seems to be considerable difference of opinion as regards proper exposure. A southern exposure will usually produce earlier fruit because of the earlier growth in the spring, but where there is danger of injury because of late spring frosts a northern exposure will retard the budding and there is less liability of the trees being injured.

5.—Surface Conditions.

The best land for irrigation must have a uniform slope and be free from ravines or depressions which increase the cost of the distribution system and which are liable to be damaged by the accumulation of waste water. Irregular slopes are difficult to irrigate. Land which is smooth is much cheaper to prepare for irrigation. Slopes which are very steep can often be well irrigated by running the furrows across the slopes. Very few soils can be irrigated without excessive washing of the soil on slopes steeper than 10 feet in 100 and usually the fall of furrows should be less than 2 feet in 100. The washing of the soil and in some cases the leaching out of the fertilizing salts from the upper part of the orchard may not be noticeable at first, but the accumulation of this effect may do considerable injury to the land. Steep slopes also have the disadvantage that they make cultivation, spraying and handling the fruit more difficult.

6.—Drainage.

The drainage of the soil is very important. The intending purchaser who wishes to grow an orchard or other deep rooted plants should avoid low lying lands. On a tract which is under a new irrigation system the bottom land may be quite dry and the water table far below the surface. The soil may be quite porous and underlaid with gravel. This may lead to the belief that drainage conditions are very good. But with the extension of irrigation on the higher surrounding land, the drainage conditions are often changed. The higher land is usually porous, absorbs water readily and encourages a waste of water which is not always avoidable. This effect, combined with the percolation losses from leaky ditches will cause a gradual rise of the water table, and unless there is a good natural drain in the trough of the valley, the water table will soon rise until it is near the surface and finally drown out the trees or plants.

Land where the water table has not yet reached the danger height is sometimes spoken of as sub-irrigated land and many advantages are claimed for it, but as a rule this land will soon be injured by a continued rise in the water table and should be avided for deep rooted plants at least.

While the higher lands are usually free from injury by water logging, there are many instances where layers of hardpan may collect the water and interfere with its downward percolation and cause a rise of the water table too near the surface.

The purchaser should investigate these conditions thoroughly and examine the subsoil as well as the top soil by boring deeply with an auger.

PREPARATION OF LAND FOR ORCHARD.

1.—Clearing the Surface.

Land to be irrigated is seldom heavily timbered and is generally free from timber. To prepare land which is timbered the first operation is the felling of the trees which are used for lumber or cut into firewood the value of which may partly pay for the cost of clearing. The removal of the stumps is the next operation. This may be done by various methods, but the process is always quite expensive. It may be done: First, By the hand method with shovels, picks, mattocks and axes. Second, By the use of stump pullers. Third, By the use of powder. Fourth, By the burning method, which consists of boring auger holes at the foot of the stump into which fires are built. Sixth, By the char pit method. This last method which has been developed recently, has given very good results. The cost of removing stumps in the State of Washington by this method was found to vary from 25 cents to $1.00 each for stumps as large as 40 inches in diameter. While the method is most economical for clay soil, it was found that it could be successfully applied to sandy soil. The method has been fully described in General Bulletin 101 of the Agricultural Experiment Station of Washington State College at Pullman, Washington. The cost of clearing will naturally vary with the density of growth and the method used to remove the stumps. It may vary from a few dollars to fifty or one hundred dollars for heavily timbered land.

Where the native vegetation is small brush or grasses, the land should be plowed deeply, then raked to remove the large brush, which is burned. This is followed by harrowing and the grading operation.

Where the vegetation is tall sagebrush, it must be removed before the land can be plowed. This may be done in several ways. Where the brush is not abundant it may be grubbed off by hand. Where the brush is thick and very dry it may be burned off while standing. A method largely used in the Yakima Valley is to break off the brush by drawing a railroad rail or heavy timber over the land, first in one direction and then in the other. The best time to do this is when the ground is frozen. It requires a team on each end of the rail. The brush breaks off at or below the surface and is then raked into windrows or piles and burned.

The cost of clearing off heavy brush in the Yakima Valley varies from about $2.50 to $3.00 per acre when done with a rail and teams and about $3.75 when done by hand. The cost of the first plowing is about $1.50 to $2.00 per acre. The plowing is followed by harrowing and then the surface is ready to be graded and prepared for irrigation. This includes the proper location of the ditches, the grading of the land and in some cases the growing of some crop to improve the condition of the soil.

Before grading the surface the location of head ditches or flumes must be decided on. They must be so placed that when constructed they will give the furrows a desirable grade and must divide the field so that the furrows will not be over 300 feet long for sandy soil and 500 to 600 feet for more impervious soil. Before the construction of these ditches the land must be graded to conform with them.

The grading of the land has been usually neglected in the irrigated sections of British Columbia. This is due largely to the character of the land. Much of it is rolling or on fairly steep hillsides which can be irrigated without grading. But in many cases the land would have been much improved by some grading.

The mistake is often made of planting orchards and other crops before the land has been even properly cleared in order to give the trees an early start and shorten the time before they will bear. In some cases this results in leaving a field or orchard which is difficult to irrigate and which can not be improved by grading because of the trees or other crop which have been planted. The time gained by planting earlier will often be more than balanced by the poor growth due to improper condition of the soil and the uneven application of water. The loss in time necessary to apply the water on poorly prepared land and the waste of water is often greater than the cost of preparing the land.

For furrow irrigation, which is the method most universally adaptable to British Columbia, the only grading necessary is that the land be given a uniform slope and all irregularities removed by scraping off the humps and filling the depressions where otherwise water would collect. Rolling land or land having a steep slope usually requires little grading.

The implements needed for grading are usually some form of scraper and a smoother or leveler. For removing large knolls or for carrying considerable earth the Fresno scraper, which is a wide steel scraper, is extensively used. For loose sandy soil and where the haul is short, the Buck scraper is very effective. It is used extensively in the Yakima Valley and in nearly all irrigated districts. It consists of a board 10 to 14 feet wide, shod along one edge with a steel plate, which can be adjusted to any angle by means of a lever arrangement connected to it and to a foot board or tail board (Fig. 1). To finish the surface smooth a leveler sometimes called float or drag is used after the scraper (Fig. 2).

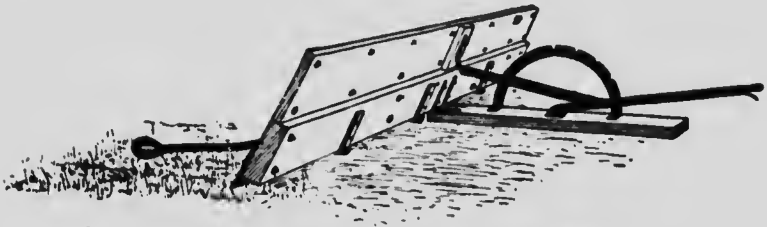


Fig. 1.—Buck scraper for leveling land.
(Farmers' Bulletin 373, U. S. Dept. Agr.)

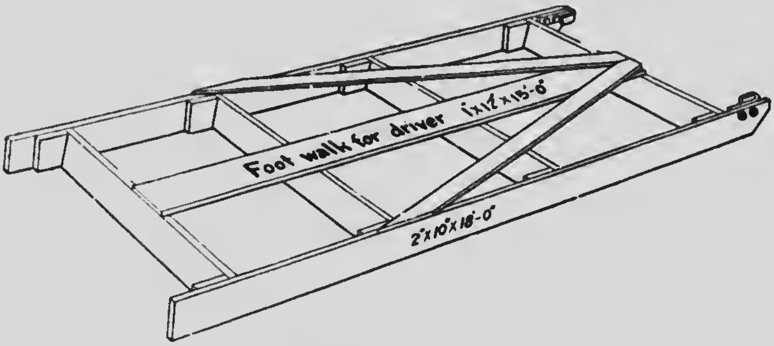


Fig. 2.—Leveler or float.
(Farmers' Bulletin 392, U. S. Dept. Agr.)

2.—Growing Crops to Improve Condition of Soil.

Most soils of the arid type are lacking in organic matter or humus and can be much improved by preliminary cropping to plants which will add humus and bring the soil into good condition. The crops used are clover, alfalfa, peas or cereals. Prof. Fisher, horticulturist for the Montana Agricultural College, states that a method which is practiced with success is to plow the land deep in the fall and grade it. In the spring following oats and red clover are planted. The oats are harvested the following fall and the next year one crop of clover hay can be cut and the second crop plowed under as a green manure. Prof. Judson, horticulturist for the University of Idaho, recommends clover the first season, plowed under in the fall, and potatoes or other hoed crop planted the following spring.

3.—Locating the Tree Rows.

The tree rows should be located to facilitate the application of water. On steep slopes it is desirable to run the furrows on a grade not steeper than 2 feet in 100. It is therefore advantageous to locate the tree rows on a line which will give about this grade. There are two common methods of laying out orchard tracts, one known as the square method and the other as the hexagonal or the equilateral triangle system. The square system is easier to lay out and is best adapted to the use of fillers. The hexagonal system has the advantage that the furrows can be run in three or four different ways and that the trees cover the ground more uniformly. The two methods are illustrated in the accompanying sketches. The square system shows an apple orchard with fillers. These sketches are taken from Farmers' Bulletin 404, (U. S. Dept. Agr.) which gives the following information:

"Under irrigation systems peach trees should be spaced 20 to 22 feet, pear and cherry trees 22 to 28 and 30 feet, apple trees 30 to 36 feet. On the Pacific Coast the tendency toward wide spacing has induced many growers to insert peach fillers between the slower growing apple trees. The arrangement of trees in a young orchard in Douglas County, Washington, is shown in the square system shown above. Here the trees are set in squares 18 feet each way but in every other row peach trees alternate with the standard apple trees. In the remaining rows Winesap apple trees are used for fillers. As the apple trees grow and begin to crowd the fillers, the peach trees are removed. If more space is required the Winesaps can be taken out leaving the apple trees in squares 36 feet both ways."

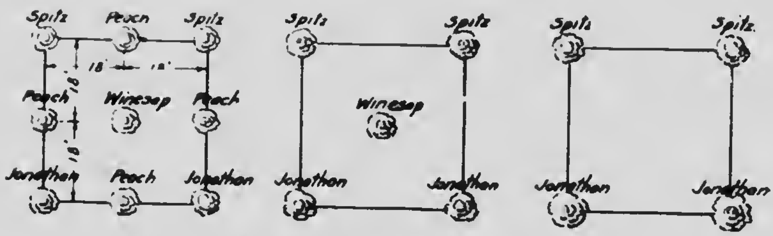


Fig. 3.—Plan of planting apple orchard with fillers.

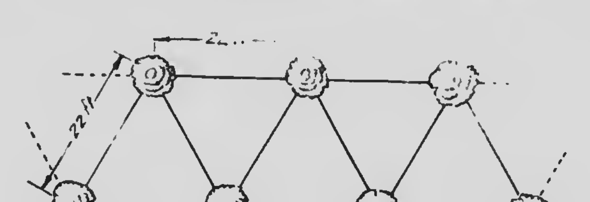


Fig. 4.—Hexagonal or triangular plan of planting orchard.

The methods of staking out the orchards to locate the position of the trees and the setting of the trees as well as other information on apple growing are given in Bulletin No. 43 on Planting the Apple Orchard, published by Agricultural Experiment Station at Moscow, Idaho, also in Bulletin 77 on Fruit Tree Planting in Montana, published by Montana Agricultural College Experiment Station at Bozeman, Montana.

II.—UNITS OF MEASUREMENT OF WATER AND METHODS OF MEASURING WATER.

NECESSITY FOR KNOWLEDGE OF MEASUREMENT OF WATER.

When water is so plentiful that the irrigators can obtain all the water they want and whenever they want it, there is no trouble about its division and no necessity is felt for the measurement of water. But these conditions do not prevail in many districts and where they do exist a knowledge of the measurement of water will help to prevent the large waste due to crude methods of irrigation and to over-irrigation which may damage not only the crops of the careless irrigator but also the land and crops of the landowners below, by the waterlogging of the soil.

Where water is not so abundant the necessity for a knowledge of the measurement of water is felt to a greater extent. An equitable division of the water can only be obtained by correct measurements. The orchardist or irrigator can only know whether he is getting the water he is entitled to or not by measurements of the water delivered. It is only by such means and from a knowledge of the values of the units of flow that the depth of water applied to the land is obtained. This is desirable if the orchardist wishes to irrigate intelligently and determine the effects of different quantities of water on the amount of crops produced.

Other reasons for which there is a necessity for a knowledge of the measurement of water are:

First.—To measure the amount of water carried in a creek or the discharge of a pump.

Second.—To know the required capacity of a pump or of a ditch to give a certain volume of water on a given area of land.

Third.—To determine by measurements at different points on the ditch the seepage losses occurring in that section of ditch.

Fourth.—To be able to compute the storage capacity of a reservoir necessary to give a flow to irrigate a given tract of land.

UNITS OF MEASUREMENT.

The units of measurement can be divided into two classes: first, those used for flowing water; second, those used for water at rest. The units commonly used for flowing water are the cubic foot per second and miners' inch, and for water at rest, the acre foot is used.

1.—The Cubic Foot Per Second or Second Foot.

The cubic foot per second is the standard unit of measurement of flowing water in British Columbia. It may be defined as a cubic foot of water moving at the rate of one lineal foot each second. For instance, a flume 12 inches wide, carrying a depth of water of 12 inches, and placed on such a grade as to give a velocity to the water of 1 lineal foot each second has a carrying capacity of 1 cubic foot per second. In any case the cross sectional area in square feet multiplied by the velocity in feet per second will give the discharge in cubic feet per second.

2.—The British Columbia Miners' Inch.

The legal value of the miners' inch in the Province of British Columbia is the quantity of water that will pass through an orifice two inches high by half an inch wide made in a two inch plank, the water to have a constant head of seven inches above the upper side of the orifice, and every additional inch of water shall mean so much as will pass through the said orifice extended horizontally half an inch.

In cubic measurement one inch of water shall mean a flow of water equal to 1.68 cubic feet per minute. This is equivalent to 35.7 miners' inches for one cubic foot per second.

3.—Acre Foot.

This unit of measurement is the best unit for measurement of large volumes of water at rest and is the legal unit in British Columbia (Water Act 1909). It may be defined as the quantity of water which will cover one acre to the depth of one foot; it is equal to 43,560 cubic feet.

An acre inch is equivalent to 1-12 of an acre foot. It is equal to the quantity of water which will cover one acre one inch deep.

4.—Relation Between Cubic Foot Per Second, Miners' Inch and Acre Foot.

The cubic foot per second and the miners' inch indicate only a rate of flow and to specify any fixed quantity it is necessary to state the time or duration of flow. For instance a flow of 1 cubic foot per second will give in one 24 hour day as many cubic feet as there are seconds in that time or 86,400 cubic feet which is equal to nearly 2 acre feet or 24 acre inches. In other words a flow of 1 cubic foot per second in one hour will give a quantity of water sufficient to cover one acre to a depth of one inch.

The miners' inch as defined by the Water Clauses Consolidation Act, 1897, is equal to about 1-36 of a cubic foot per second, or one miners' inch in thirty-six hours will give as much as one cubic foot per second in a period of one hour, which quantity is about 1 acre inch. As a unit of measurement the miners' inch is condemned by many engineers. While there are some objections there are also many advantages in its use. The objections usually raised are:

First.— That its value in British Columbia and in the different western states of the United States is not uniform

Second.— That the unit is associated with a measuring device and unless the factors controlling the method of measurement are correctly prescribed by law and followed in making the measurement, it is liable to give inaccurate results. The Consolidation Act of 1897 requires that it be measured through a board 2 inches thick. This, as explained farther, is objectionable and greater accuracy would be obtained by using a thin board not over 1 inch thick.

Third.—The term has often been confused with the cross sectional area in square inches of a flume or pipe. For instance if a flume is 10 inches wide and 6 inches deep: it is sometimes wrongly stated by some irrigators that there are 60 miners' inches, the irrigator not thinking that the flow is also dependent on the velocity of the water which varies with the grade of the flume.

The main advantage of this unit of flow is that for small flows the irrigator has a better understanding of its volume when stated in miners' inches. However, as a method of measurement, it has some advantages as explained farther.

To convert measurement from one unit into another the following equivalents are useful.

1 cubic foot per second is equal to 35.7 miners' inches.

1 cubic foot per second is equal to 6.25 Imp. gallons per second, or 7.5 U. S. gallons per second.

1 cubic foot per second will give in one minute, 375 Imp. gallons, or 450 U. S. gallons.

1 cubic foot per second will give in 24 hours, 2 acre feet (approximately), or 1 acre inch in one hour.

1 British Columbia miners' inch will give in one minute, 10.5 Imp. gallons, or 12. U. S. gallons.

1 British Columbia miners' inch running for 36 hours will give 1 acre inch.

METHODS OF MEASUREMENTS.

Measurements of water may be obtained by means of:

1. Volumetric measurements.
2. Weirs.
3. Miners' inch boards or boxes.
4. Special devices such as Grant-Michell meter.
5. Measurements of velocity of water and cross section of canal or flume.

For a measuring device to be entirely satisfactory it should meet the following requirements:

1st. It should not only measure the water at any one time, but it should keep a continuous record of all water delivered.

2nd. In many cases it is desirable that it should maintain a constant flow when once it is set for full capacity or fraction of full capacity.

3rd. It should be able to handle any fraction of its full capacity.

4th. It should not require difficult computations to obtain the results of the measurements.

5th. It should not be easily interfered or tampered with.

6th. Where the available grade is small it should require the least possible loss of head.

7th. The cost of the device should not be excessive.

There is no device which will fulfill all these requirements.

On the irrigated systems of British Columbia the heads of water delivered to the irrigators are usually small, in many cases only a few miners' inches, and there is generally sufficient fall or grade to permit the installation of any type of measuring device. The devices which are most feasible at a moderate cost for delivery of water to the irrigator are the weir box and the miners' inch box.

To measure the flow of streams or canals the weir board may be used when there is sufficient fall to allow its installation; otherwise measurements of the cross section and of the velocity by means of floats or current meters must be made.

1.—Volumetric Measurements.

This method of measurement can only be used for very small volumes of water. It consists of a tank of a given volume in which the irrigating water is delivered, and the time to fill the tank is recorded. Knowing the volume in cubic feet and the time in seconds, the rate of flow in cubic feet per second may be obtained by dividing the first by the other. For instance, if the tank is 2 feet wide, 4 feet long, and 1 feet deep, it holds 8 cubic feet of water and if it takes 40 seconds to fill the box the rate of flow is 8 cubic feet in 40 seconds or 1-5 of a cubic foot per second or about 7 miners' inches.

2.—Weirs.

The weir is the most generally used measuring device found on irrigation systems, for the reason that it is simple to construct and use and will give accurate results when properly installed. The weir is generally limited to moderate quantities of water and requires sufficient fall or grade for its installatio. d for these reasons can not always be used, but in British Columbia the quantities of water to be measured are usually small and in most cases there is ample fall. These conditions are very favorable for the installation of a weir.

The term weir is applied to any dam or barrier across the stream over which the water flows. The weirs used in irrigation consist of a board or barrier into which a notch is formed through which the water flows. The volume of water passing through the notch is obtained by knowing the length of the notch and measuring the depth of water passing over it. The form of notch is generally either trapezoidal or rectangular and in some cases a triangular or V shaped notch is used.

The trapezoidal weir is known as the Cippoletti weir and is more common than the other forms. It consists of a horizontal crest and the two sides, each sloping outward one inch for every four inches rise. The rectangular weir has vertical sides. The first form has the advantage that the flow may be computed by means of a simpler formula. The second form is a little easier to construct and is more accurate because its formula has been derived from a larger number of experiments. In either case the flow can be obtained by referring to the tables given farther.

The weir may consist of a simple board placed across the ditch or of a board set in a short section of flume or box, in which case it is called a weir box. The weir board may be of wood, metal or concrete. When made of wood or concrete it is desirable to use a metal plate to form the edges of the crest and the sides. When no weir box or flume section is used, the weir board is placed directly across the canal, and sufficiently braced with posts. A weir box or flume box is generally used. The box is a short flume section whose length is not less than 8 to 12 feet. The width and depth must be at least sufficient to give the required dimensions to the weir board. The weir board should be placed at a distance from the upstream end equal to two-thirds the length of the box, the lower third forming a floor for the falling water. The depth measurement should be made at least 4 to 6 feet upstream from the crest, from a post or scale fixed on the side of the flume with the zero point level with the weir crest. To obtain accurate results the following rules for the dimensions of the notch should be observed:

1st. The greatest depth of water which should be allowed on the crest of the weir should not be more than one-third the length of the weir and the least depth 1 inch. The depth is usually controlled by the fall available. Where the fall available is small, a large length and small depth are necessary.

2nd. The distance from the crest of the weir to the bottom of the canal or floor of the weir box should be at least three times the depth on the weir.

3rd. The distance from the edges of the weir notch to the sides of the canal or of the weir box should be at least twice the depth on the weir.

4th. The upstream side of both the crest and the edges of the weir notch should be brought to a knife edge or to a sharp corner; the bevelling should be on the downstream side. With a sharp corner and a thickness of crest not greater than one-half the minimum depth of water the discharge will be the same as for a knife edge.

In placing the weir in position the following directions must be followed:

1st. The weir when used on a ditch should be placed in a section of the ditch which is straight for at least 50 feet above the weir and the center line of the ditch should be perpendicular to the weir board and pass through its center. The cross section of the channel should be not smaller than the cross section of the weir box, in order to have slow velocity and fairly calm water above the weir. If the weir box must be placed near a takeout gate the velocity must be made uniform by means of baffles.

2nd. The weir must be set high enough to give to the overflowing sheet a free fall on the downstream side. A common rule is to make the level of the water on the downstream side lower than the crest by not less than one-half the depth of water on the crest. To obtain the free fall it is best to select a section of the ditch which has considerable grade.

3rd. In letting water in a weir box through a pipe it should discharge at the bottom of the box and the depth of the box should be sufficient to produce a calm body of water on the upstream side of the weir. In some cases this requires the use of baffle boards to break up the velocity of the approaching water.

4th. The crest of the weir should be level from end to end.

5th. The measurement of head should show the true elevation of the water surface above the weir crest. Directly at the crest and for a short distance above it the water surface curves down. This requires that the water be measured a certain distance upstream.

Measurement of discharge.

When the weir has been installed the only measurement to take is the depth of water or head over the crest of the weir. To make this measurement it is necessary to provide a reference point level with the weir crest, from which the depth is measured. This point must be at least 2 feet upstream from the weir crest for a small weir, and preferably 4 to 6 feet. For a weir box this reference point may be a nail driven part way in the side of the box at the level of the weir crest, or a bracket or support formed by nailing a strip to the side of the box. For a simple weir board a stake may be driven into the ditch. The depth of water above the reference point can be obtained sufficiently close for ordinary purposes by using a carpenters' rule and reading the depth to nearest one-eighth of an inch.

Knowing the length of the weir crest and having obtained the depth of water, the discharge in cubic feet per second or miners' inches may be obtained by referring to the following tables:

Table of Discharge for a One Foot Cippolletti Weir.

Depth of water on crest.	Discharge.		Depth of water on crest.	Discharge.	
Inches.	Cubic feet per second.	Miners' Inches.	Inches.	Cubic feet per second.	Miners' inches.
1	.08	2.9	4	.65	23.4
1 1/8	.10	3.5	4 1/8	.68	24.2
1 1/4	.11	4.0	4 1/4	.71	25.3
1 3/8	.13	4.6	4 3/8	.74	26.5
1 1/2	.15	5.4	4 1/2	.77	27.6
1 5/8	.17	6.1	4 5/8	.81	28.8
1 3/4	.19	6.8	4 3/4	.84	29.9
1 7/8	.21	7.5	4 7/8	.87	31.1
2	.23	8.2	5	.91	32.3
2 1/8	.25	9.0	5 1/8	.94	33.5
2 1/4	.27	9.6	5 1/4	.97	34.7
2 3/8	.30	10.5	5 3/8	1.01	36.0
2 1/2	.32	11.4	5 1/2	1.04	37.0
2 5/8	.34	12.3	5 5/8	1.08	38.5
2 3/4	.37	13.2	5 3/4	1.12	40.0
2 7/8	.40	14.1	6	1.19	42.5
3	.42	15.0	6 1/4	1.26	45.0
3 1/8	.45	16.0	6 1/2	1.34	48.0
3 1/4	.47	17.0	6 3/4	1.42	51.0
3 3/8	.50	18.0	7	1.50	53.5
3 1/2	.53	19.0	7 1/4	1.58	56.0
3 5/8	.56	20.0	7 1/2	1.66	59.0
3 3/4	.59	21.0	7 3/4	1.75	62.5
3 7/8	.62	22.0	8	1.84	65.0

This table is computed for a one foot Cippolletti or trapezoidal weir, but it may be used for longer weirs by multiplying the quantities given by the length of the weir in feet. For instance a two foot weir will give twice the discharge obtained for a one foot weir. An 18" weir will give 1½ times the values given in the table. For accuracy a one foot weir should not be used for depths greater than about 4 inches. For larger discharges it is preferable to use a longer weir crest.

Table of Discharge for Rectangular Weirs With Full Contractions.

Depth of water on crest. Inches.	Discharge for one foot weir.		Discharge for two foot weir.		Discharge for three foot weir.	
	Cubic feet per second.	Miners' Inches.	Cubic feet per second.	Miners' Inches.	Cubic feet per second.	Miners' Inches.
1	.079	2.8	.159	5.7	.239	8.5
1 1/8	.094	3.3	.189	6.75	.285	10.2
1 1/4	.110	3.9	.222	7.9	.33	12.0
1 3/8	.126	4.5	.255	9.1	.38	13.75
1 1/2	.144	5.1	.29	10.4	.44	15.6
1 5/8	.161	5.8	.32	11.7	.49	17.6
1 3/4	.180	6.4	.36	13.0	.55	19.7
1 7/8	.20	7.1	.40	14.5	.61	21.8
2	.22	7.8	.45	16.0	.67	24.0
2 1/8	.24	8.6	.49	17.5	.74	26.3
2 1/4	.26	9.3	.53	19.0	.80	28.7
2 3/8	.28	10.1	.58	20.5	.87	31.0
2 1/2	.30	10.8	.62	22.1	.94	33.5
2 5/8	.32	11.6	.67	23.8	1.01	36.0
2 3/4	.35	12.5	.72	25.5	1.08	38.5
2 7/8	.37	13.3	.76	27.2	1.16	41.2
3	.40	14.1	.81	29.0	1.23	44
3 1/4	.44	15.8	.94	32.6	1.39	50
3 1/2	.49	17.6	1.02	36.4	1.54	55
3 3/4	.54	19.5	1.13	40.2	1.71	61
4	.60	21.3	1.24	44.1	1.88	67
4 1/4	.65	23.3	1.36	48.4	2.06	73
4 1/2	.71	25.2	1.47	52.6	2.24	80
4 3/4	.76	27.3	1.49	57.0	2.43	87
5	.82	29.4	1.72	61	2.61	93
5 1/4	.86	31	1.81	66	2.81	100
5 1/2	.91	33	1.97	70	3.00	107
5 3/4	1.00	36	2.11	75	3.20	114
6	1.06	38	2.23	80	3.41	122
6 1/4			2.38	85	3.63	130
6 1/2			2.51	90	3.87	138
6 3/4			2.65	95	4.06	145
7			2.80	100	4.29	153
7 1/2			3.00	107	4.47	160
8			3.40	121	5.20	186
8 1/2			3.70	131	5.65	201
9			4.00	142	6.15	220
9 1/2			4.30	154	6.64	237
10			4.64	166	7.15	255
10 1/2			5.00	178	7.71	275
11			5.32	190	8.24	295
11 1/2			5.65	202	8.78	314
12			6.00	215	9.34	333

The above table is for rectangular weirs with crest 1 foot, 2 feet, and 3 feet long. It will be noticed that for this type of weir the discharge is not exactly in proportion to the length of the weir crest, especially for the greater depths of water on the crest.

The form of construction of the weir will depend on the conditions where it is used. It may be used on a ditch or a flume in which case it is placed either as a weir board or a weir box across the canal or flume as shown in the accompanying illustrations (Fig. 5, 6, 7, 8, 9) or it may be used to measure the water taken out of a pipe in which case it is placed around the takeout valve as shown in Fig 11.

Fig. 8.—Rectangular weir box.
(Courtesy of Irrigation Investigations Office, U. S. Dept. of Agr.)

Fig. 9.—Rectangular weir in concrete lined canal.
(Courtesy of Irrigation Investigations Office, U. S. Dept. of Agr.)

Weir board in a ditch.

The method of placing a trapezoidal weir board across a ditch is shown by Fig 5. The measurement of depth of water is taken from the top of a stake driven level with the crest of the weir. Fig. 6 shows a trapezoidal weir board placed in a ditch with an apron and side wings to prevent cutting of the earth sides and bottom of the canal.

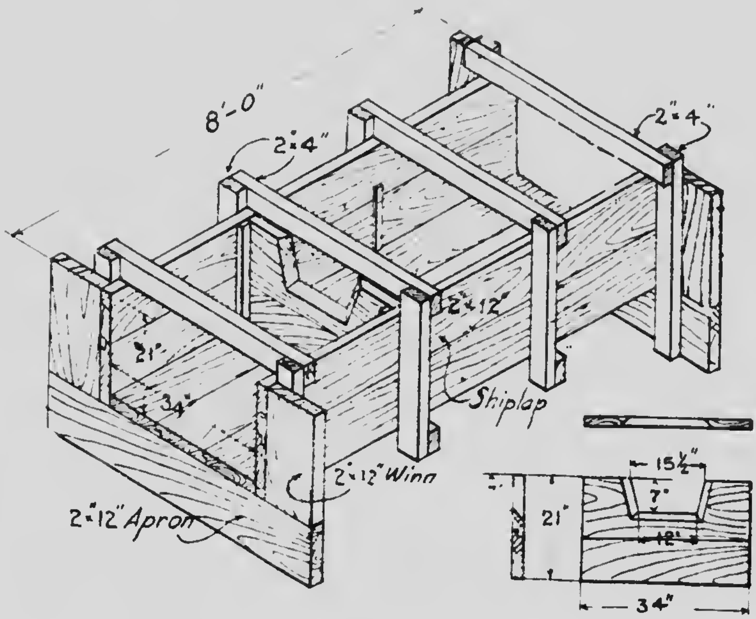


Fig. 7 — TRAPEZOIDAL WEIR BOX FOR 5 TO 40 MINERS INCHES

Weir box.

Fig. 7 is a drawing of a trapezoidal weir box. The weir crest is 12 inches long, the depth of the notch is 7 inches. It is designed for a capacity of 5 to 40 British Columbia miners' inches. It can be used for as little as 3 miners' inches. For 40 miners' inches it requires a depth of water on the crest of 5¾ inches which is a little large for that width of notch, and for very accurate results a larger weir would be preferable.

Wings and cut off aprons are provided on the upstream and downstream end of the box to prevent the water from washing around or under the box. A wooden strip is nailed on one side of the box with its top level with the weir crest, from which the measurements of depth of water will be taken.

Fig. 8 is a photograph of a similar weir box installed to measure the flow from a pumping plant.

The method of installing a rectangular weir in a concrete lined canal is shown by Fig. 9. In this case the weir board is made of metal plates.

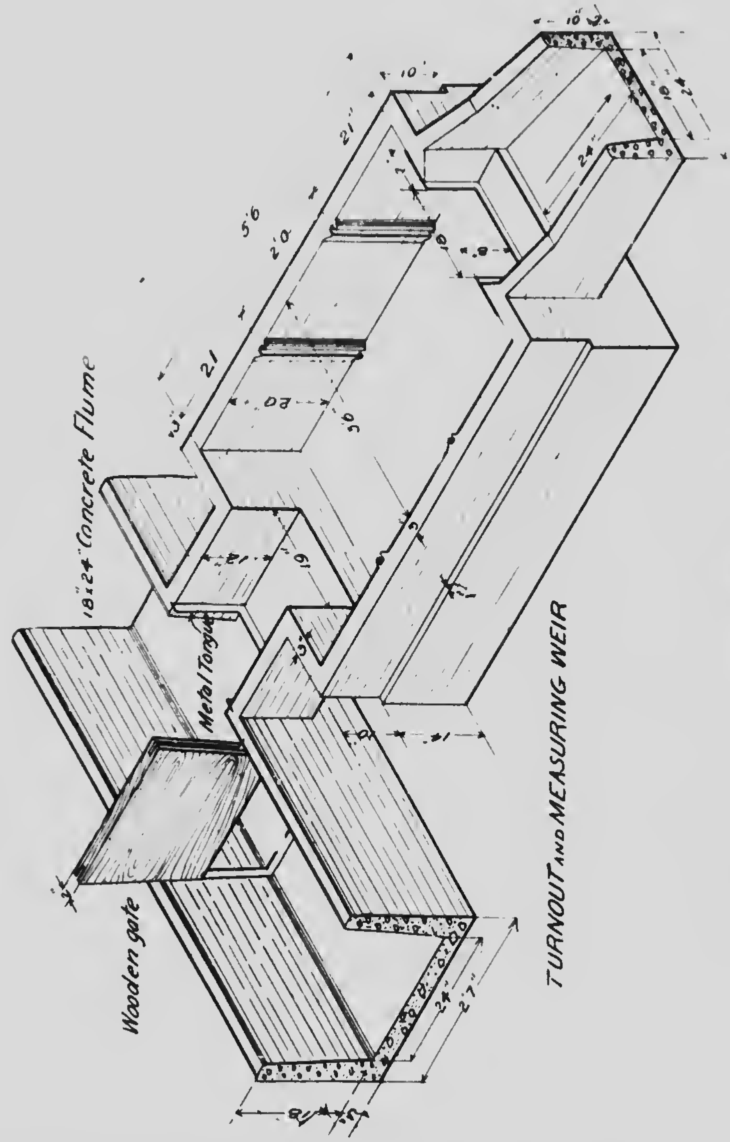


Fig. 10.—Concrete weir box and take out from a concrete flume.

Concrete weir box and takeout from a concrete flume. (Fig. 10).

This box is used on some of the irrigation systems of southern California for takeouts from concrete flumes. The form of construction is equally well adapted to takeouts from wooden flumes or concrete lined canals. The flow is regulated by wooden gates which control the flow in the canal and in the weir box. To form a still body of water in the box grooves are provided for the insertion of baffle boards. The water which passes over the weir discharges into the private flume of the orchardist.

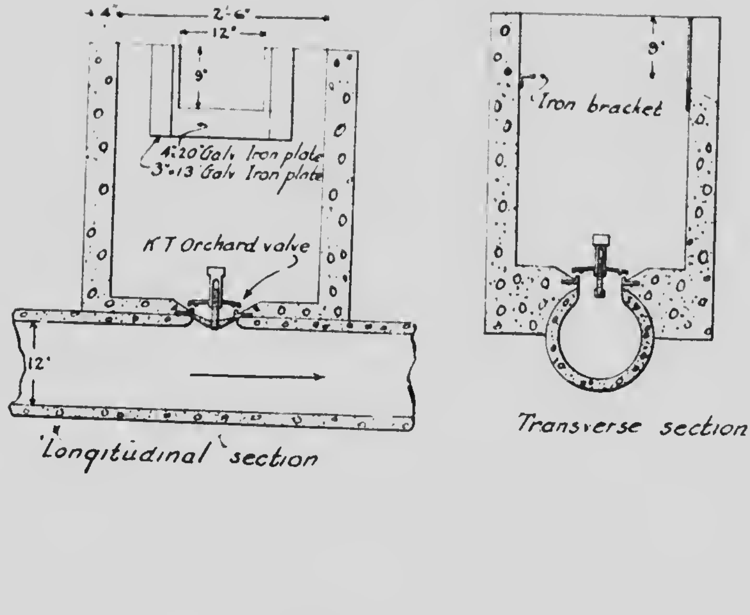


Fig. 11.—Typical weir box for valve take out from pressure pipe line.

Weir box and takeout from pipe line under pressure.

Where the water is carried in a pipe line under pressure the water must be delivered through a valve connected to the pipe. A good type of measuring weir box will consist of a rectangular box placed around the valve, with the measuring board placed at the top of one side of the box. Fig. 11 shows a form of measuring box very similar to those installed on the cement pipe lines of the irrigation system of the Fruitlands Irrigation and Power Company near Kamloops. It consists of a concrete measuring box placed around a takeout valve cemented to the pipe line. The valve is obtained from the Kellar and Thompson Manufacturing Company of Los Angeles. It is cemented over a hole cut in the cement pipe and regulates the flow in the box. The box is rectangular, made of four concrete walls 4 inches thick, reinforced with strands of barb wire 6 inches apart. A notch is formed in one of the side walls and a rectangular weir plate made of galvanized iron strips is cemented in. To measure the depth of water above the crest a metal bracket is cemented in the wall opposite the weir opening and at the same level as the weir crest. The water which passes over the crest discharges into the irrigator's flume or ditch. In case of an earthen ditch it is necessary to prevent erosion or washing away of the soil by the falling water by providing a receiving box or basin or by protecting the soil with paving.

Similar boxes are used in southern California for delivering water from cement pipes and iron pipes, and could well be used in British Columbia for delivery from wooden pipes into the private flumes or ditches.

Figs. 12, 13, 14 show the type of box used by the Gage Canal Company of Riverside, California. The box is not built in place but is cast in wooden forms. It consists of a floor slab and a tapering rectangular box. Fig. 14 shows the box in position connected to a private concrete flume. The inside of the box is 45 inches deep, 16 inches square at the top and 22 inches square at the bottom. The walls and floor slab are 2 inches thick. The opening for the weir is 12 inches high and 14 inches wide and the metal weir plate which is cemented in this opening gives a rectangular notch 10 inches wide and 8 inches deep.

Some irrigation companies in southern California simplify the construction of the weir boxes by using in place of the rectangular box, two or more sections of large size cement pipe placed vertically around the valve. The weir is formed by cementing a weir plate in a notch cut in the upper part of the pipe.

3.—Miners' Inch Board or Box.

The miners' inch as a unit of measurement has the disadvantages previously stated but the method of measurement associated with the miners' inch unit has many advantages.

1st. The irrigator can tell at a glance how much water is being delivered. It requires no computation or reference to tables.

2nd. It is well adapted to measuring small volumes of water and is fairly accurate if properly carried out.

3rd. The flow through a miners' inch board is affected much less by a change in water level than the flow over weir. A 10 per cent. rise of water level will increase the flow over a weir by 15 per cent. while with a miners' inch board the flow is increased only 5 per cent.

Fig. 5.—Trapezoidal weir board placed across a ditch.
(Courtesy of Irrigation Investigations Office, U. S. Dept. of Agr.)

Fig. 6.—Trapezoidal weir board with side wings and apron.
(Courtesy of Irrigation Investigations Office, U. S. Dept. of Agr.)

The disadvantages are:

1st. The device is not adaptable to large volumes of wtaer because the required length of the orifice may be too great.

2nd. Unless the conditions necessary for accurate measurements are carried out, the results obtained may be very inaccurate.

The device consists of a board or thin wall in which is made an orifice, which conforms with the conditions necessary to give the volume as defined by law. The board may be set directly across the ditch or it may be placed in a short section of flume or in a box.

The controlling conditions to give measurements in British Columbia miners' inches are given in the Water Clauses Consolidation Act of 1897. Briefly stated the miners' inch orifice must be 2 inches high and the head on the upper side of the orifice must be 7 inches; this gives 8 inches on the center of the orifice. The Act states that the orifices must be made in a 2 inch board. This thickness is liable to give inaccurate results, unless the four edges of the orifice are bevelled outwards so as to give sharp corners. To obtain accurate results the jet coming through the orifice must touch only the upstream edges and clear the downstream edges so as to discharge freely into the air. With a board 1 inch thick, if the corners are sharp, it is not necessary to bevel the edges for the water jet will clear the outer edges. It is, however, preferable to either bevel the edges or use thin metal plates. The orifice must be made of such length that it will measure the maximum amount of water desired. For instance if this volume of water is 100 miners' inches, the orifice 2 inches high must be 50 inches long. To obtain a smaller volume the orifice must be adjustable by means of a sliding gate.

To measure a large volume of water the length of the orifice will be excessive. To avoid this it may be desirable to use an orifice 4 inches high instead of 2 inches. This will make the necessary length only one-half the length required for the 2 inch height and the accuracy of the device will not be affected to any great extent provided the orifice is made in a thin plate. In either case the head on the center of the orifice must be 8 inches.

To obtain accurate results at least 6 inches must be allowed on the upstream side of the board from the lower edge of the orifice to the bottom of the ditch or floor of the box into which the board is placed, and at least 2 to 4 inches from the ends of the orifice to the sides of the ditch or box. On the downstream side the jet should discharge freely into the air.

The form of construction of the miners' inch measuring device will depend on the purpose for which it is used. It may be used to measure the flow in a ditch or flume in which case it may be given the form shown in Fig. 15 or it may be used to measure the water carried by a pipe under no pressure and is then built as shown in Fig. 16. Where the pipe is under pressure the miners' inch box can be built around the valve in the same manner as the weir box shown in Fig. 11, using a miners' inch orifice plate in the place of the weir plate.

Miners' inch box placed in canal or ditch.

The form of miners' inch box to use for measurement of water carried by a flume or ditch is shown in Fig. 15. This box consists of a short section of flume with the miners' inch board placed at the downstream end. The box may be made as the weir box shown in Fig. 7 and connected with the earth ditch by similar wings and cut off apron. The miners' inch orifice is 2 inches high and its length adjustable by a slide. The center of the orifice is 8 inches from the top of the board, the lower edge of the orifice is 6 inches above the floor. The edges of the orifice are bevelled on the downstream side. The slide consists of a 1 in. x 6 in. piece which passes through a hole of the same size cut through the side of the box. At one end of this piece is screwed a short block which fits into the bevelled orifice and which has one edge bevelled to conform with the other edges of the orifice. To measure the water the slide is pushed in or pulled out until the water stands level with the top of the board; when the slide is pushed in too far the water overflows the top of the board; when the orifice is opened too wide, the water level drops below the top. The number of miners' inches passing through is equal to the length of the orifice multiplied by two. To facilitate the measurements the orifice may be graduated with inch and quarter inch marks, each half inch representing a flow of 1 miners' inch.

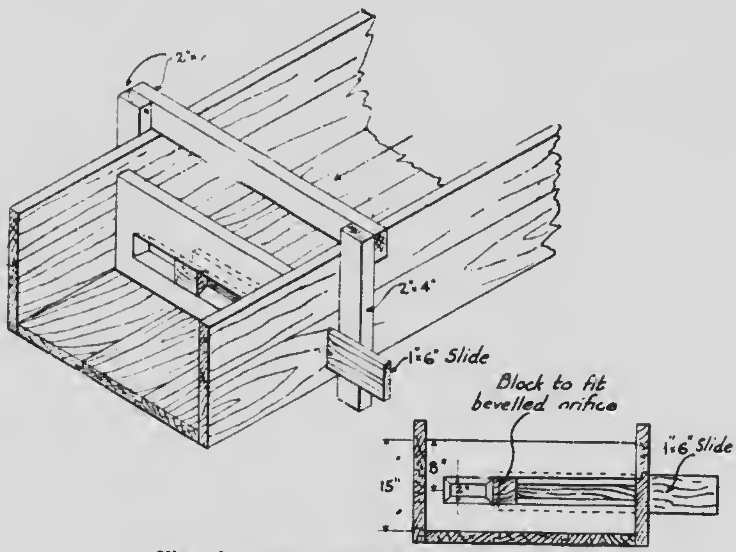


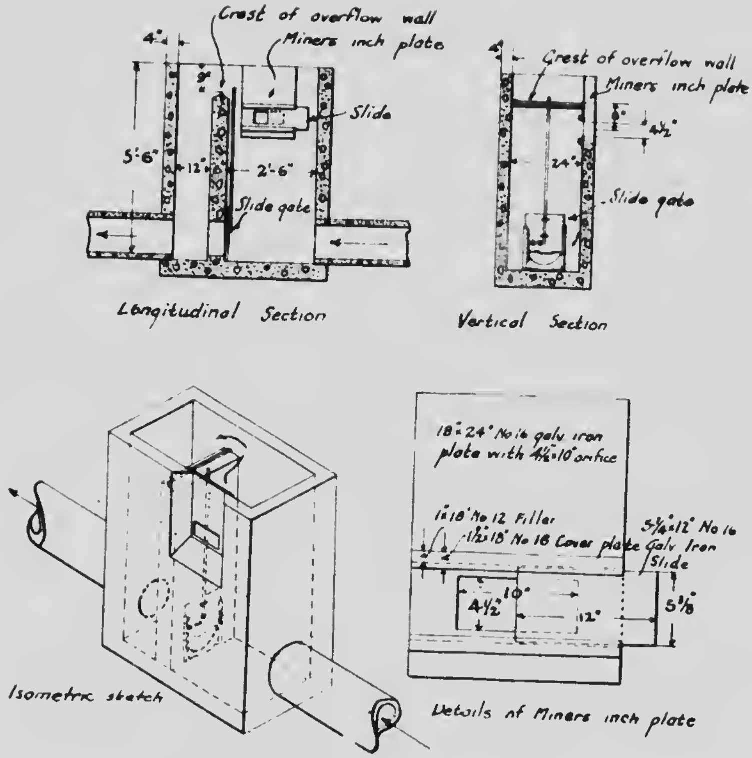
Fig. 15.—Miners' inch measuring box.

Fig. 12.—Weir box take out valve.

Fig. 13.—Weir box in position.

Fig. 14.—Weir box and take out from pressure pipe used by Gage Canal Co., Riverside, Cal

(O. E. S. Bulletin 119, U. S. Dept. Agr.)



TYPICAL MINERS INCH BOX FOR TAKE OUT FROM GRAVITY PIPE LINE UNDER NO PRESSURE

Fig. 16.

Miners' inch box and takeout from pipe line under no pressure.

Where a pipe line is under no pressure the conditions of flow are similar to those in an open ditch. The pipe line is placed on grade and to take out water from it, it is necessary to form a takeout box by means of which the water is checked and forced to rise to the height at which it is delivered to the irrigator. This is somewhat similar to the check gates which are placed across an open canal where it is necessary to raise the water level to make a delivery into the head of the irrigator's flume or ditch. For a pipe line the takeout and measuring device can be formed in one structure as shown in Fig. 16. This form of box is used on the Fruitlands Irrigation system near Kamloops and is similar to the boxes used on many irrigation systems of southern California. The box is rectangular and is divided into two compartments by an overflow wall at the bottom of which there is an opening, controlled by a slidegate. In one of the side walls of the upstream compartment a miners' inch plate is placed with the center of the orifice 8 inches below the crest of the overflow wall. The walls are all reinforced with strands of barb wire. The water enters the upstream compartment and by means of the gate in the overflow wall can be made to rise level with the overflow crest and the quantity delivered is regulated by adjusting the orifice. The pressure on the orifice is regulated and kept more or less constant by the overflow wall. The excess water passes over the overflow wall and also through the regulating gate into the downstream compartment and from there into the pipe. By proper adjustment of the gate the water level may be kept fairly constant. When the gate is entirely closed the excess water will pass over the overflow and increase the pressure on the orifice and the accuracy of the measurement will depend on the quantity of water passing over and the length of the overflow crest. A moderate increase in pressure will not affect the accuracy very greatly, for instance a [illegible] inch increase in pressure will increase the volume delivered by 6 per cent. It would be feasible to use a weir plate in place of the miners' inch plate, but with a weir plate the quantity delivered could not be adjusted and the accuracy would be affected to a much greater extent by an increase in depth of water on the crest.

Fig. 18 shows a similar box used in southern California. It differs from the previous one in that instead of delivering the water through an orifice adjustable in size by a slide, it is delivered through a number of openings varying in size and each closed by a slide gate. In the illustration the three smaller orifices are opened and the fourth one closed. The water passes through the orifices into a basin formed by two half sections of pipe cemented to the box and connected at the bottom to the private pipe of the orchardist.

Miners' inch box and takeout from pressure pipe line.

To deliver water from a pipe under pressure and measure it by miners' inches the same form of construction could be used as for a weir box (Fig. 11), using a miners' inch plate instead of the weir plate. This form of miners' inch box is shown in Fig. 19 which illustrates a box used in southern California. In this case the orifice is 5 inches high and is regula
two slides. The pressure on the center of the orifice is 4 inches, which
a depth of water of only 1½ inches from the upper edge of the orific
the water level. The height of the orifice is too great in proportion to the pressure.

Miners' inch box with overflow wall for canals or flumes.

The use of an overflow to regulate the head on the opening can be applied to miners' inch boxes installed in earth ditches or in flumes very much in the same manner as for pipe lines. Fig. 20 illustrates the construction of the device. It consists of a section of flume divided into two compartments by the parallel overflow crest wall in between. The compartment which forms part of the supply ditch is open at both ends and the flow can be checked or regulated by flashboards. The other compartment forms the box from which the water is taken out through the orifice in the side wall. The flow into the box is regulated by a gate and the excess passes over the crest of the overflow wall back into the canal. The crest of the overflow should be 8 inches above the center of the opening and must be of sufficient length to dispose of the excess without increasing the depth of water to a great extent.

Fig. 18.—Miners' inch and take out box used at Covina, California.

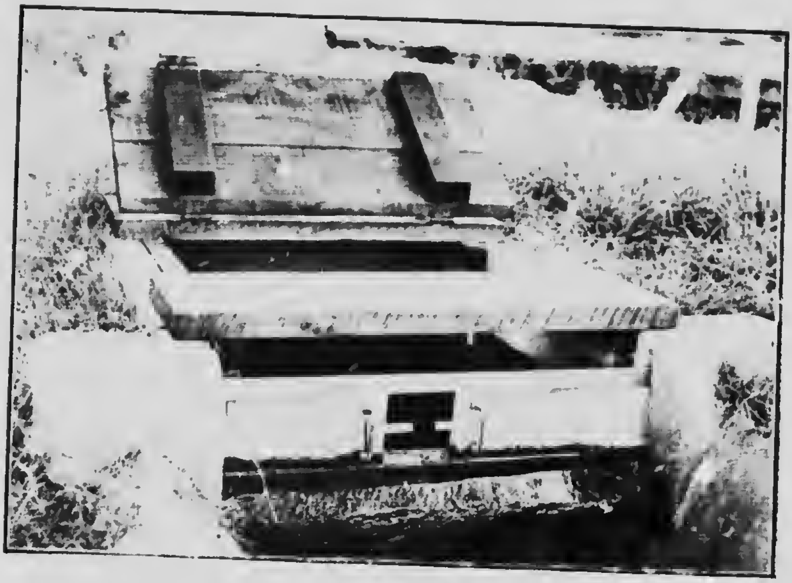


Fig. 19.—Miners' inch box and take out from pressure pipe at Riverside, Cal.
(Courtesy of Irrigation Investigations Office, U. S. Dept. of Agr.)

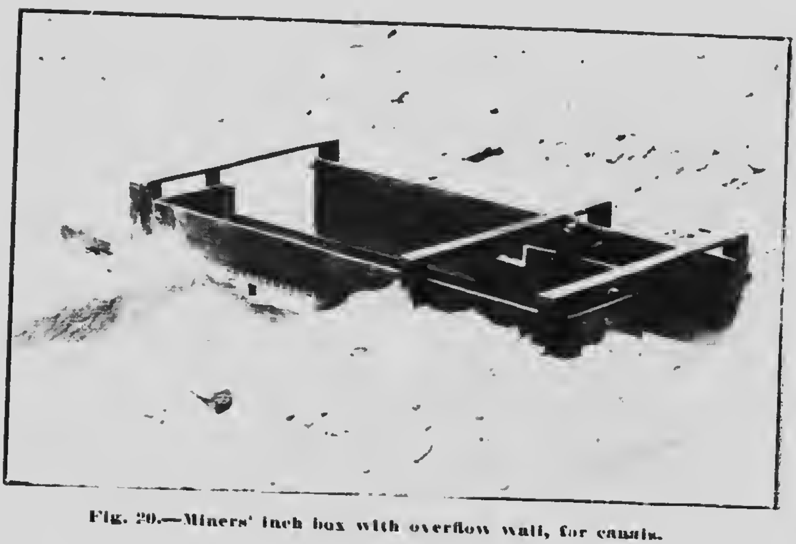


Fig. 20.—Miners' inch box with overflow wall, for canals.

4.—Special Measuring Devices.

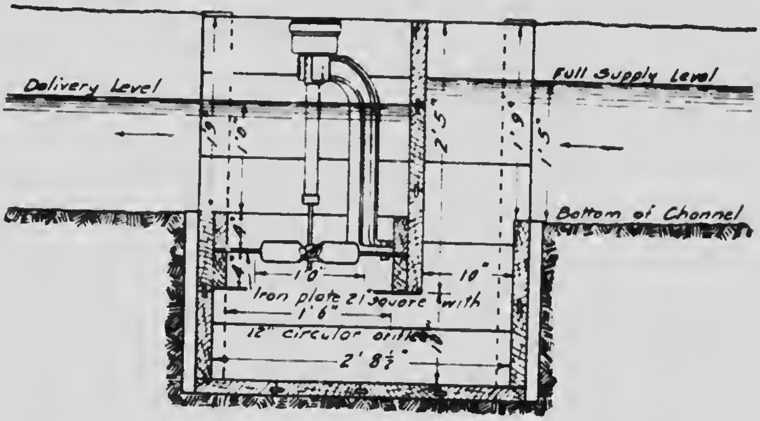


Fig. 21.—Grant-Michell meter; capacity 100 cubic feet per minute.

The Grant Michell meter is known as the Australian meter, having originated in that country. It consists of a four bladed fan fastened to the lower end of a vertical spindle which transmits the revolution of the fan to a gear box at the upper end. This mechanism is suspended from a cast iron bracket over a wrought iron orifice plate placed below the canal bed and built or bolted down into the downstream part of a box divided into two parts by a baffle wall open at the bottom and extending above the water surface. The water passes down through the opening formed by the baffle wall and the box, then flows upward through the orifice and imparts a rotary motion to the fan. The gear box forms the recording device, which consists of a series of dials giving a continuous record in acre inches and fractions, or in cubic feet. The fan, spindle and gear box are removable and portable and can be used for several boxes. The discharge depends on the size of the orifice plate and on the difference in elevation in the water surface upstream and downstream. The size of the meters is generally based on a 3 inch loss of head, but may be designed for less. The orifices range from 9 to 40 inches in diameter and are used for discharge of 1 to 20 cubic feet per second. The serious objection to this meter is the high cost, ranging from $60 for the smaller one to $250 for the larger one. These prices are the catalogue prices of Geo. Kent, Ltd., 199-204 High Holborn Street, London.

5.—Measurement of Discharge by Obtaining Velocity of Flow and Cross Section of Flume or Canal.

This method is best adapted to the measurement of large volumes of water when the installation of a weir is not feasible because of lack of grade or because of the large volume of water. The method depends on the principle that the discharge in cubic feet per second is equal to the area of the cross section of the stream in square feet multiplied by the velocity in feet per second. The following principles will give a better understanding of this method of measurement.

1st. The velocity in a canal varies with the form of the channel, the smoothness of the sides and bottom and the grade.

2nd. The velocity varies in different portions of the channel, being smallest near the bottom and the sides and greatest on the center line of the channel just below the surface.

3rd. In a given channel the velocity increases with an increased volume of water in the channel. For instance a flume 3 feet wide carrying water to a depth of 1 foot with an average velocity of 2 feet per second gives a discharge of 6 cubic feet per second. When it carries a depth of 2 feet the area of cross section is doubled and the velocity will be increased to about 2.55 feet per second giving a discharge of 15.80 cubic feet per second which is more than double the first amount.

To obtain the velocity the following methods are commonly used:

1st. Surface floats of chips or other material.

2nd. Rod floats of bottles, tubes or rods.

3rd. Current meter.

To obtain the velocity with surface floats or rod floats the procedure is the same. It is carried on as follows: Select a straight section of canal at least 50 feet long where the cross section is uniform and the flow not affected by obstructions. Lay off the course by placing two wires across the canal or simply stakes at the desired distance apart which may be 50 or 100 feet. Place the float above the upper wire and time the float for its travel over the course. The distance in feet divided by the time in seconds gives the velocity of the float in feet per second. When a rod float is used it must be weighted at the lower end so that it will float vertically. This may be done by placing weights in the bottle or tube or by wrapping lead or wire at the lower end of the rod or simply tying a stone to the end of a stick. Rods 1½ to 2 inches in diameter should be used. The length of the rod should be such that it will nearly touch the bottom. The velocity obtained with a rod float will represent the average velocity, but the velocity obtained with a surface float is 20 per cent. greater than the average velocity and must therefore be multiplied by 8-10 to give the average velocity.

To obtain the discharge accurately it is necessary to subdivide the cross section into partial areas bounded by imaginary vertical lines extending from the bottom of the canal to the top of the water surface and obtain the velocity for each one (Fig. 22). The widths of these areas are marked by tags placed on a wire or marks on a plank spanning across the canal and the depth of water at each tag is obtained by soundings or measurements with a graduated rod or rule. The width in feet multiplied by the average of the two depths for each section will give the number of square feet in the section. This product multiplied by the velocity in feet per second will give the discharge for each partial area and the sum of discharges of each partial area will give the total discharge.

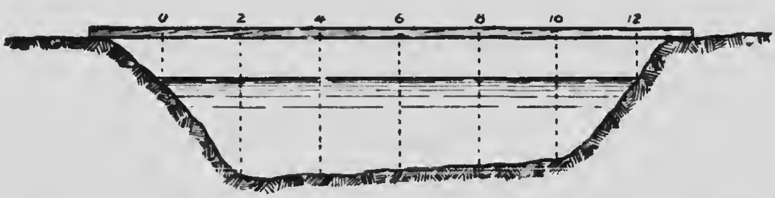


Fig. 22.—Subdivision of canal cross section for measurement of discharge.

The velocity is obtained as explained above by placing the floats so they will travel as nearly as practicable between the tags or marks. It is difficult to get the floats to travel straight down the stream and often the inaccuracy due to this can not be avoided. When rod floats are used, rods of different lengths are usually necessary.

For an ordinary trapezoidal section a less accurate but more expedient procedure is to obtain the total area of the cross section of the channel by multiplying the depth by the average width (which is the sum of the top width and bottom width divided by two) and to multiply the area, thus obtained, by the average velocity. The average velocity is found as explained above, using either surface floats or rod floats.

In case the waterway is a flume the width in feet multiplied by the depth of water in feet will give the cross section.

Current meter.

The current meter generally used to measure the flow in canals consists of a small wheel made up of vanes or cups connected to a rod about which it revolves. The wheel when placed in the flowing water is set in motion by the action of the current and the revolutions are transmitted to a recording or sounding apparatus. By noting the time and the revolutions, the number of revolutions per second are obtained. The velocities corresponding to the number of revolutions are known for each current meter.

A current meter is expensive and is not likely to be possessed by the ordinary irrigator. For that reason a detail description of its use is not given.

Rating station and rating flume.

A rating station is a section of canal the discharge of which is known for different depths of water. To obtain the relation of depth to discharge it is necessary to rate the station. This is done by the measurement of discharge for a wide range of depths, from which a table is prepared giving the discharge at any depth. The rating station should be selected where the waterway has a straight reach of nearly uniform cross section above and below and there should be no obstructions to interfere with the flow, such as gates below it. The selected section should have a channel which is not liable to change by scouring or silting. To insure a permanent section a rating flume, which is a short section of flume, is often used. The depth of water is indicated by a graduated rod placed on one side of the canal or by graduations marked on the side of the flume.

Automatic registers.

The volume of water delivered over a weir or the discharge of a ditch flume or creek obtained by measurements at a rating station or rating flume will vary with the fluctuations in the water level. Where it is desired to have a continuous record of the quantity of water, automatic registers have been used. These registers are of different types. They can, however, be classified in two classes. They all consist of a clock, a float and a cylinder or drum to which is fastened a sheet of paper on which the depth of water at different times is recorded by a pencil or pen.

With one class of register the cylinder is placed vertically and is rotated by a clock which gives it one revolution a week. The pencil is connected to the float which is placed in a well or box built on the side of the weir box or rating flume and connected with the water through an orifice. The fluctuations in water level cause a rise and fall of the float and a corresponding movement of the pencil which is recorded on the sheet placed on the drum. Fig. 23 shows a simple form of register of this class used in southern California, the cost of which is about $40.

The other class of register differs from the first class in that the cylinder is placed horizontally and is rotated by the float instead of by the clock and the pencil is carried parallel with the cylinder by connections with the clock. In each case the record obtained is the result of two motions which give an irregular line showing the fluctuations and giving the depth of water at any time. The various types of registers are illustrated and described in Bulletin 86, part 1, of the Office of Experiment Stations of the U. S. Department of Agriculture, Washington, D. C.

The cost of registers ranges from about $40 upwards and for that reason they are seldom used for the measurement of water delivered to irrigators. They are, however, of much value in the operation of a system when installed at the head of laterals.

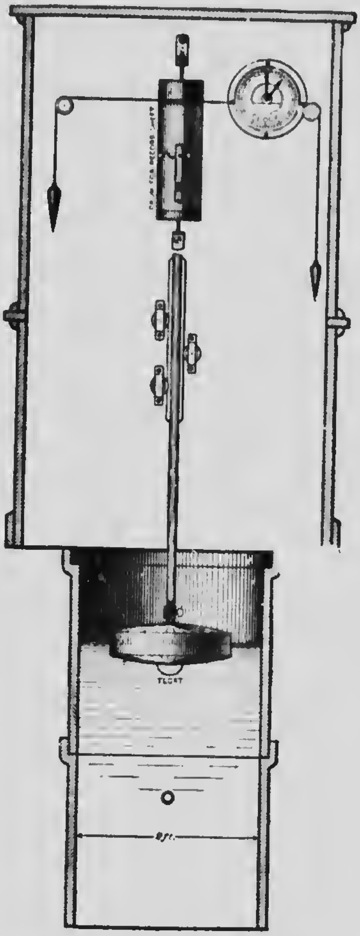


Fig. 23.—Automatic register used at Riverside, California.
(O. E. S. Bulletin 86, Part I., U. S. Dept. Agr.)

III.—CONVEYANCE OF WATER FOR THE IRRIGATION SYSTEMS OF BRITISH COLUMBIA.

TYPES OF IRRIGATION SYSTEMS.

The topography of the land of the irrigated districts of British Columbia is often very rough and the land irrigated is generally rolling as compared to irrigated land in most of the arid region of the United States. Because of the character of the topography the construction of an irrigation system is expensive and difficult. Ordinarily the main canal which heads at the diversion dam, is excavated on the steep hillsides and continued around the hills, skirting the land to be irrigated. The main laterals or main branches head at the main canal and, where possible, run down the ridges which separate the smaller valleys which make up the entire body of land covered by the system. These laterals either supply directly the farms or are the source of supply for smaller laterals. A large part of the main canal is often excavated in porous material and fissured rock and frequently it must cross canyons or depressions. Open canals have been used where possible; flumes placed on benches cut in the side hill have been used where the side hill was too steep, where the material was too porous, or where the excavation of an open canal was impossible or too expensive, and flumes on trestles or wooden pipes have been used to cross depressions.

Because of the low winter temperature which will cause freezing of water in open canals, at least two irrigation companies have used in the place of open canals for the main as well as for the distributaries, a system of wooden pipes buried in the ground below the reach of frost in order that the irrigation system could be used for domestic supply as well.

The distribution system consists of all laterals and branches necessary to deliver water to each farm. The topography of the land is such that the laterals must often be placed on grades that are too steep for earth ditches and on irregular slopes where the depressions must be crossed by flumes or pipes. Because of this and also because of the small volumes of water usually carried by the laterals, wooden flumes and wooden pipes have been extensively used. Where wooden flumes are used they are placed as much as possible on mud sills resting on the ground and the depressions are crossed on trestles. Where pipes are used they are usually under more or less pressure but occasionally they may be placed practically on grade with very little or no pressure on them, in which case they act more as a covered flume.

The systems of British Columbia can be classified into the following types based on the form of construction used.

1st. Those which consist of an open main canal and of open laterals, (either open ditches or flumes), and to which class belong the irrigation systems at Keremeos, Penticton, and Walhachin, and parts of the systems of White Valley Irrigation Company, Summerland, Naramata.

2nd. Those which consist of an open main canal and of pipe line distributaries such as the Kelowna Irrigation Company and the Fruitlands Irrigation system near Kamloops, the latter consisting of a concrete lined canal and cement pipe.

3rd. Those which consist entirely of pipe lines, both for mains and laterals such as the Kaleden system and part of the Summerland system.

As regards the cost of installation the first type has the advantage that the cost per acre of the distribution system is less than that of a wooden pipe system. For ordinary conditions it is roughly estimated that a wooden flume system will cost one-half as much as a wooden pipe system. For very rough land requiring a great deal of fluming on high trestles, the comparison in cost would not be so favorable to wooden flume. As far as durability is concerned, the life of a well constructed wooden flume should be between 8 and 12 years. The life of a wooden pipe which is full only part of the time is problematical; it depends somewhat on the kind of wood and on the soil in which it is placed. In Idaho 4 in. x 4 in. wooden posts used for lot corners, made of the best fir and painted, have been almost completely destroyed in one year. There are a number of instances where wooden pipes have gone to pieces in four or five years or even less. However, if the pipe is made of good selected material, free from sap wood, the life should be from ten to fifteen years for a wooden pipe empty part of the year. The life of wooden pipe which is kept constantly full and buried to such depth as to prevent freezing, would be considerably greater, probably 20 to 30 years provided the soil in which it is buried does not contain injurious salts. Were it not necessary to prevent the water in the pipe from freezing, it is my opinion that the life of a wooden pipe kept constantly full and under sufficient head for the wood to be saturated, would be increased if it was laid above ground not in contact with the soil.

As far as the cost of maintenance is concerned, a wooden flume system requires frequent repairs, tarring, and calking, the cost of which would be greater than the maintenance of a pipe system.

It is impossible to represent numerically the above statements with any degree of accuracy because of the varying conditions. Roughly they may be represented as follows:

Annual cost of wooden flumes and wooden pipes given in per cent. of first cost:

For wooden flumes, life 8 to 12 years—

Annual maintenance and repairs distributed over entire life	5	per cent.
Sinking fund for renewals	9	" "
Interest on capital invested	6	" "
Total	20	" "

For wooden pipes empty part of the time, life 10 to 15 years

Maintenance and repairs	2	" "
Sinking fund for renewals	7	" "
Interest on capital invested	6	" "
Total	15	" "

For wooden pipes always full, life 20 to 30 years—

Maintenance and repairs	1	" "
Sinking fund for renewal	4	" "
Interest on capital invested	6	" "
Total	11	" "

These figures show that the annual cost which must be provided for to maintain and renew a system and pay interest on capital invested is 20 per cent. for a wooden flume system, 15 per cent. for a pipe system part of the time, and 11 per cent. for a pipe system always full. These costs are in the ratio of 1.8, 1.3 and 1. Therefore a flume system is more economical than a wooden pipe system, which can be kept full of water only part of the time, when the cost of the wooden pipe system would be in excess of 1.3 times the cost of the flume system. Also the flume system is more economical when the cost of a wooden pipe system which can be kept full of water all the time is 1.8 times the cost of the flume system. As stated above, a wooden pipe system under average conditions will cost about twice as much as a wooden flume system; therefore, if the above cost alone is considered a wooden flume system is more economical. But there are other relative advantages and disadvantages which should be considered.

The third type of system—that is, the wooden pipe system which can be kept full all the year around without freezing—has the advantage that it can be used for domestic supply. The other two types require a separate domestic system if domestic water is desired. But it is not always possible to combine the two, for often the source of supply from which the irrigation water is obtained may be frozen in the winter or it may be so polluted that it is not safe drinking water and if it must be filtered or treated to purify it, it would be very poor economy to have to purify the irrigation water as well as the domestic water which are carried in the same pipe. If these conditions exist a separate domestic system is preferable.

PERMANENT CONSTRUCTION.

The short life of wooden flume and wooden pipes and the increasing value of water have led to more permanent and better class of construction throughout the arid region. Wooden flumes on trestles are being replaced by steel flumes; wooden flumes resting on the ground or bench flumes which were necessary to carry the water on steep hillsides or through porous ground, are being replaced by concrete flumes and concrete lined channels. Concrete linings are being constructed wherever the seepage losses must be prevented because of the value of water loss or because of the damage caused to adjacent land by the seepage water. Concrete pipes, both plain and reinforced, which a few years ago were only used in southern California, are now being used to some extent in many of the irrigated districts of Washington, Oregon, Idaho, and other western states and their use is growing. The use of plain concrete pipe is, however, limited to small heads and concrete pipe reinforced with steel can only be used for moderate heads. So far reinforced concrete pipe has been used only where pressure heads are under 100 feet, and some manufacturers of reinforced concrete pipe will guarantee them for heads as large as 150 feet. But it can not be expected that cement pipe will replace wooden pipe where pressures are large and as much of the land covered by irrigation systems in British Columbia is irregular and the surface has a steep slope which often produces high pressures, the use of reinforced concrete pipe can not be adopted in general. For such locations wooden pipes, especially if they can be kept full and protected from freezing, are the best solution. On steep slopes which are fairly uniform with no deep depressions, it is possible to so regulate the pressure that cement pipes can be used.

During the past two years some of the irrigation companies of British Columbia have realized the economy of improved method of construction and some of the work which has been done and is being done is equal to any in the country. Excellent examples of permanent construction are found on the systems of the Kelowna Irrigation Company and the South Kelowna Company, near Kelowna, and the Fruitlands Irrigation and Power Company, near Kamloops. Some of the systems installed and others which are in the process of construction will cost upwards of $50 an acre and probably as high as $100 an acre. Those systems which are installed and which consist largely of wooden flumes or wooden pipes, will before very long require renewal to a large extent, and where these systems have passed in to the hands of municipalities this cost of renewal will have to be met directly by the farmers or fruit growers of the municipality. The information given in the following pages will, it is hoped, be of assistance in the reconstruction of old systems and in the installation of new systems. The subject has been subdivided and is taken up in the following order:

1st. Seepage losses in canals.
2nd. Canal linings to prevent seepage losses.
3rd. Steel flumes.
4th. Plain concrete pipes.
5th. Reinforced concrete pipes.

CONVEYANCE LOSSES OF WATER IN CANALS.

All irrigators are well acquainted with the fact that the losses in conveying water in earth canals are in many cases very large and with newly excavated canals are often so great that it is difficult to deliver water at the lower end. On irrigation systems with unlined canals these losses usually range from 25 to 60 per cent. of the water diverted and taken in the canal system, and there are many instances where the losses are much greater. In two miles of canal of the Canyon Creek Irrigation Company, near Kelowna, the losses amounted to 60 per cent. of the water entering the canal. This is not an exceptional case for on some California canals losses of 64 per cent. per mile have been observed. It is safe to state that on an irrigation system consisting of earth ditches, only 50 per cent. of the water diverted is delivered to the fields.

The water lost by seepage disappears through some underground drainage channel or raises the water table of the lands adjacent to and below the canal. This causes the waterlogging of the land or accumulation of alkali salts on the surface. This effect, combined with wasteful irrigation, has been the cause of over ten per cent. of the irrigated lands of the West becoming unfit for crop production. On one project in eastern Washington after only the first irrigation season considerable land was waterlogged and in some portions the water table had risen sufficiently to cover the land several feet deep. These damages alone, in many cases, justify the expense of lining the canals. But even if injury by waterlogging is not considered, there are many localities where the water is sufficiently valuable to make the lining of canals to stop the loss of water a paying proposition. The amount of money which one is justified in spending will be in proportion to the extent of the losses.

1.—Extent of Seepage Losses in Canals.

The extent of seepage losses depends on many factors such as porosity of the soil, the form of cross section, the size of the canal, the number of seasons the canal has been operated, the amount of silt in the water, the velocity of flow, the depth to the water table, etc.

The most valuable general observations as regards the amount of these losses are those of the Irrigation Investigations Office of the United States Department of Agriculture. From series of measurements on seventy-three ditches in the western states, they have found that the average loss per mile of ditch is 5.77 per cent. of the entire flow; the measurements range from a maximum of 64 per cent. per mile to a slight gain in a few cases. Large canals in general lose less in proportion than small ones. The measurements show that the loss per mile averages about 1 per cent. for canals carrying 100 cubic feet per second or more, about 2½ per cent. for canals carrying 50 to 100 cubic feet per second, 4½ per cent. for canals carrying 25 to 50 cubic feet per second, and 11¼ per cent. for canals carrying less than 25 cubic feet per second.

For some purposes it is preferable to know the extent of seepage expressed in cubic feet of water per day per square foot of wetted area of the canal. This is equivalent to stating the depth of water in feet lost each day. A number of measurements have been made in various parts of the country and some of these have been assembled by F. W. Hanna, Project Engineer of Boise U. S. Reclamation Service Project, in Idaho, who states that from careful consideration of the data assembled, it would appear that a seepage loss of 0.5, 1 and 1.5 cubic feet per square foot wetted surface per day might be assumed for canal losses respectively for rather impervious, mediumly pervious and rather pervious soils. Based on the above figures and assuming a common form of cross section, he obtains the following results as the seepage loss per mile expressed as per cent. of flow.

Capacity of canal	Loss in per cent. of flow per mile.		
Cubic feet per sec	For rather impervious soil.	Mediumly pervious soil	Rather pervious soil.
10 or less	4	8	12
11 to 25	2.5	4.5	7
26 to 50	1.5	3	4.5
51 to 75	1	2.	3.
76 to 100	.75	1.5	2.5

The above table gives results which agree with those obtained by the Irrigation Investigations Office as closely as can be expected because of the numerous factors involved.

2.—Evaporation Loss From Water Surface of Canals.

The losses above stated include seepage and evaporation, but contrary to the general belief, the losses of evaporation from flowing water in a canal are insignificant when compared with those of seepage. It has been shown that the losses of seepage and evaporation per day might be assumed at 0.5, 1 and 1.5 cubic feet of water per square foot of wetted surface, respectively for rather impervious, mediumly pervious and rather pervious soil. These are equivalent to losses of water 6, 12 and 18 inches deep. As compared to these figures, the evaporation from water surface for the irrigation season will generally be about ¼ of an inch per day, which is from 25 to 75 times less than the above seepage losses. Seepage and evaporation measurements made at Twin Falls, Idaho, and reported by Elias Nelson (Bulletin 58, University of Idaho) show that the evaporation ranged from less than 1 per cent. to less than 2 per cent. of the total loss in the canals. On one of the largest systems in the San Joaquin Valley, California, the total length of canals is 165 miles and the total seepage loss was 28 per cent. and 30 times greater than the evaporation loss. These and other numerous experiments show that the evaporation losses in the conveyance of water are so small as compared with the seepage losses that they are of no importance.

PREVENTION OF SEEPAGE LOSSES IN CANALS.

To prevent the loss of water in conveyance lining the canals with different materials has been tried. Those used or experimented with are concrete, wood, asphalt, oils, and clay puddle. A good lining should fulfill the following requirements: it should be water tight, prevent the growth of weeds, stop burrowing animals, be strong and durable, and preferably not affected by the tramping of cattle. From investigations made by the writer in 1906 and from more recent experience as regards the efficiency of the different types of linings, the following results can be anticipated:

1st. A good oil lining constructed with heavy asphalt road oil applied on the ditch sides and bed at the rate of about 3 gallons per square yard, will stop 50 to 60 per cent. of the seepage.

2nd. A well constructed clay puddle lining is as efficient as a good oil lining.

3rd. A thin cement mortar lining about 1 inch thick, made of one part cement to four of sand, will prevent 75 per cent. of the seepage.

4th. A first-class concrete lining, 3 inches thick, made of one part of cement to two of sand and four of gravel, will stop 95 per cent. of the seepage.

5th. A wooden lining when new is as efficient as a concrete lining, but after two or three years, repairs and maintenance will become an important item and by the end of eight or ten years, it will necessitate complete renewal.

The cost of an oil lining where oil can be bought at California prices (about 2 cents a gallon) is about ½ cent per square foot. Cement mortar lining 1 inch thick costs about 3 to 4 cents per square foot. Cement concrete 2 inches thick costs about 6 cents and 3 inches thick about 8 cents a square foot. These prices do not include the trimming and preparation of the ditch before the lining is put on, which would add from ¾ to 1½ cents per square foot. The cost of a clay lining depends greatly on the nearness of the canal to suitable clay. If clay is close at hand, it can be hauled and spread on the canal, then either tramped in by cattle or worked in by dragging over it, at a cost of less than 1 cent per square foot, but there are localities where the writer has seen enough money spent on clay linings to pay for a good concrete lining. Wooden lining has been used in very few cases and the cost of such a lining built of 2 inch lumber nailed on sills and side yokes will not be less than that of a 2 inch concrete lining and not nearly as durable.

The disadvantages of the cheaper linings are the following: An oil lining stops only a part of the seepage losses, and while it will resist erosion well, it probably will not prevent the growth of weeds for more than one season unless a high velocity is used, and it will not stop the activities of burrowing animals. Another serious objection is that suitable oil would be hard to obtain in British Columbia at a reasonable cost. Oil linings have not been sufficiently tested to determine their durability.

Clay puddle will not prevent the burrowing of animals, and weeds grow rapidly, especially since the velocity of the water must be small in order to prevent the eroding or washing of the lining.

A concrete lining has none of the above disadvantages and it meets the requirements of a good lining better than any other material. The only objection is its higher first cost. This, however, can be partly balanced, especially on side hill work, where a new canal is to be constructed, by using a higher velocity and a smaller cross section, thus decreasing the cost of excavation. Where an old canal must have its capacity enlarged, this may be done either by lining the canal which will give a higher velocity because of the smoothness of the channel, or by increasing the cross section by excavation. The cost of extra excavation, especially on side hills through hard material, may be greater than the cost of lining.

Concrete lining will usually prove to be the most economical type of lining to use in British Columbia. However, where good clay is available and where it is not financially feasible to use concrete, clay puddle may be used to advantage in improving leaky earth canals when the velocity of flow is under 3 feet per second.

1.—Concrete linings.

The earliest use of concrete linings was in southern California about 1880 when the increasing value of water made it necessary to do away with losses. Since that practically all of their canals, which are comparatively small, carrying less than 100 cubic feet per second, have been lined with concrete and in some cases replaced with concrete pipes. Until recently very little concrete lining had been done outside of that region, but during the last few years concrete lined canals have been constructed on many of the projects of the United States Reclamation Service and on numerous private projects. There are now several examples in California, Oregon, Nevada, Washington, Idaho and other states and during the past two years some excellent work has been done in British Columbia. The Fruitlands Irrigation and Power Company near Kamloops has lined about 6 miles of its main canal which averages 3½ feet in depth, 4 feet wide at the bottom and 7½ feet wide at the top, with an average thickness of concrete of 3 inches and when the system is completed there will be about 15 miles of concrete lined canal. (Figs. 24, 25). The Kelowna Irrigation Company, near Kelowna, has lined the upper 5 miles of its main canal, 2½ feet deep, 3 feet wide at the bottom, and 5½ feet wide at the top, with 3 inches of concrete (Fig. 26). The remaining 7 miles of the canal, which is 1.5 feet deep, 2 feet wide at the bottom and 4½ feet wide at the top, is lined with 2 inches of concrete.

Form of cross section, and thickness of lining.

Unlined canals in earth are usually constructed broad and shallow with the side slopes varying according to the character of the soil. This may be as steep as ½ horizontal to 1 vertical for hardpan or very firm soil, or as flat as 2 to 3 horizontal to 1 vertical for loose sandy soil. For a lined canal it is more economical to use a comparatively narrow deep section and fairly steep side slopes. This reduces the excavation and the amount of concrete. The side slopes must not be much steeper than the slope on which the ground will stand or the earth pressure may be sufficient to push the sides in and break the lining. The side slope and the thickness of the lining are dependent upon each other and they vary with the depth of the canal, the character of the soil and the method of construction. Generally the flatter the side slopes, the thinner can the lining be made. In southern California fairly satisfactory results have been obtained on many systems with linings 1 inch or less in thickness. But because of extremes in temperature and the low winter temperature, it is probable that such thin linings would not be very satisfactory in British Columbia. There are no good examples of very thin linings built where the winter temperature is low. The writer has seen four miles of canal in eastern Washington lined with ½ to 1½ inches of concrete. The lining was rather badly cracked, but this was largely due to poor workmanship. It made it possible, however, to carry water over this length of canal which was impossible before its construction.

For the ordinary conditions in British Columbia the following thickness of concrete lining and side slopes should be used. For a canal 2 to 4 feet deep excavated in an ordinary firm soil which will stand naturally on a slope not flatter than 1 or 1½ horizontal to 1 vertical, use a concrete lining not less than 3 inches thick built on a slope of ½ horizontal to 1 vertical, or a lining not less than 2 inches thick built on a slope of 1 horizontal to 1 vertical. For loose soil which will stand naturally on a slope of 2 or 3 horizontal to 1 vertical use a 3 inch lining placed on a slope of 1 vertical to 1 horizontal. For canals 12 to 18 inches deep use a minimum thickness of 2 inches.

When side slopes of ½ horizontal to 1 vertical are used, the form of cross section requiring the least concrete will have a bottom width equal to 94-100 of the square root of the area in square feet and a depth equal to 76-100 of the square root of the area. When the side slopes are 1 horizontal to 1 vertical, the bottom width and depth will be 61-100 and 74-100 respectively of the square root of area.

Shrinkage and expansion.

No matter what the thickness is, unless the concrete is reinforced with steel, or expansion joints provided, cracks are to be expected because of the contraction or shrinkage in the winter. These cracks will usually be fine cracks occurring at more or less regular intervals and the leakage through them will be small and often silt up. For better appearance and to distribute the cracks at uiform intervals, the lining shoud be laid in sections or strips 6 to 8 feet long.

Effect of frost.

Frost should have no effect on the lining if the soil is well drained. But when the soil contains water, freezing will produce heaving of the soil which will not be resisted even by thicker linings than those recommended. Usually a canal which must be lined is located where the water drains too readily from the soil, but if the canal is located where water is liable to collect behind the lining, a drain should be provided. The drain should be a 3 or 4 inch tile placed below the floor of the canal lining in a trench 12 inches deep, located along the center line of the canal and the tile covered preferably with loose rock, gravel, sand, or other porous material. To discharge the water collected cross drains should be placed every 400 or 500 feet or wherever there is a drainage channel. The tile may be omitted and the trench filled entirely with rock or gravel but this is not as efficient.

Method of construction of concrete linings.

The details of construction in lining canals usually vary with the ideas and judgment of the men in charge of construction. There are two general methods of construction.

The first method of construction requires forms behind which the concrete is placed. The second method requires no forms, the concrete being spread on the bottom and sides of the canal much in the same manner as for sidewalk work. The first method is used when the side slopes are steeper than 1 horizontal to 1 vertical. The second method is used for side slopes of 1 to 1 or flatter.

Construction of concrete lining by means of forms.

This method has been used by the Fruitlands Irrigation and Power Company, near Kamloops, by the Kelowna Irrigation Company and the South Kelowna Irrigation Company. It has also been used extensively on a num-

Fig. 21.—Concrete lined canal of Fruitlands Irrigation and Power Company, Kamloops, B. C.

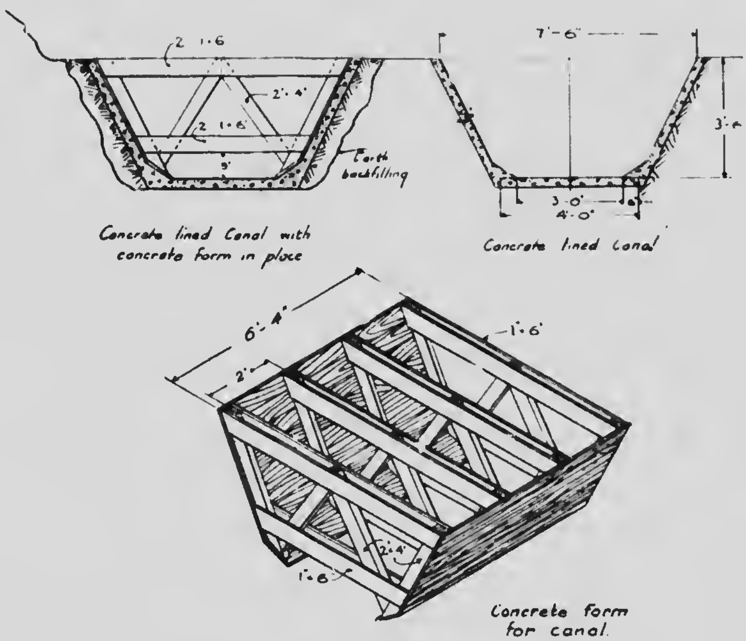
Fig. 25.—Concrete lined canal of Fruitlands Irrigation and Power Company, Kamloops, B. C.

Fig. 26.—Concrete lined canal of Kelowna Irrigation Co., Kelowna, B. C.

her of canals in southern California. It is well adapted to canals less than 8 or 10 feet wide at the top. The method is as follows:

For a new canal the excavation is made about 6 inches larger on each side than the finished earth section when ready to receive the lining. For an old earth canal all vegetable matter is removed and if necessary more material taken out in the same manner as for a new canal. In each case the bottom is brought carefully to grade. To shape the canal ready for the lining, the means used on the canals of Fruitlands Irrigation system near Kamloops were wooden forms 6 feet long. These forms are placed in position in the excaavted section as shown in Fig. 27, earth is thrown in between the form and the earth bank and well puddled with plenty of water which was pumped for this purpose. This was found much better and more economical in labor than tamping the earth. Even when using a very wet mud, the ground drains sufficiently to allow the removal of the forms next morning. This leaves a very smooth ditch with moist banks ready to receive the concrete lining (Fig 28). The wooden form is a trapezoidal trough with no bottom; the sides are tongue and groove or shiplap boards nailed to frames made of 2 in. x 4 in. scantlings cross braced for rigidity.

To place the concrete forms similar to the earth forms are used (Fig. 29). This concrete form is smaller than the earth form by the thickness of the lining and is built so as to give a greater thickness of concrete at the



METHOD OF CONCRETE LINING CANALS WITH FORMS
AS USED BY FRUITLANDS IRRIGATION AND
POWER CO., LTD

Fig. 29.

corners where the floor and sides come together. The concrete work follows shortly after the earth forms are taken off when the banks are still moist. The concrete forms are placed in position in the finished earth ditch, but instead of placing them continuously as the earth forms, only every alternate form is put in place (Fig. 30); then the concrete, which is mixed wet, is placed between the form and the earth and well stirred or cut with thin bars. To protect the earth slope when pouring the concrete mixture, it is well to cover the earth slope with thin galvanized iron sheets, which are pulled up as the concrete is poured in. The sides and bottom are put in at the same time. This gives a good connection at the corners which is very desirable. To do this it is necessary to block the forms above the ground by 3 inches (the thickness of the lining). To hold the concrete at the ends of the sides and also to hold the form the right distance away from the earth side, 2 inch by 3 inch pieces are placed edgewise between the earth slope and the wooden forms. When the sections have hardened the forms are removed and moved ahead to the adjacent section. In order that the ends of the form will rest on the two adjacent completed sections the forms should be a little longer than 6 feet (the length of a section), preferably 6 feet 6 inches. After the removal of the forms the concrete must be prevented from drying out too quickly, this may be done by protecting it with burlap kept wet by sprinkling or by letting water in the completed section as soon as possible. It is preferable to keep the concrete moist for several days after the removal of the forms.

The proper handling of the forms especially on rough side hill work will materially affect the cost. When the lining is started from the upper end of a canal and the work progresses downstream, probably the most economical manner is to place the forms in position for a length of canal which can be lined in one day and begin the concrete work at the downstream end and extend it upstream. The concrete at the downstream end hardens first and this allows the removal of the downstream forms which are carried downstream in the ditch and placed in position at a distance from their previous position equal to the length of canal lined in one setting of the forms. This procedure allows continuous work and does away with the necessity for carrying the forms around the side hill.

Joints.

The lining is done in strips in order that all contraction cracks will occur at the joints which are places of weakness. To separate the sections more distinctly the edges of the sections may be painted with oil or a strip of tarred paper may be used. By using short sections the contraction cracks are very small and the seepage through them is negligible. It is probable that the cracks in most cases will silt up.

Expansion joints.

Ordinarily expansion joints are not necessary but there are some classes of soil in which any seepage through cracks will cause the settlement of the soil and destroy the lining, in which case it may be desirable to do away with all open joints to prevent seepage by using some form of expansion joint. This, however, is quite uncommon but occasionally occurs where the soil has probably been formed from the coarser material carried by the flood waters of a heavy cloudburst and deposited in small fan shaped valleys or benches. The lack of rainfall and of the occurrence of further cloudburst, has left the soil in an unsettled condition and any seepage water passing through the concrete lining may carry off the finer soil particles into the subsoil below and cause a settlement.

Fig. 27.—Method of using forms for backfilling to prepare canal for concrete lining, Fruitlands Irrigation System, Kamloops, B. C.

Fig. 28.—Earth canal ready for concrete lining, Fruitlands Irrigation System, Kamloops, B. C.

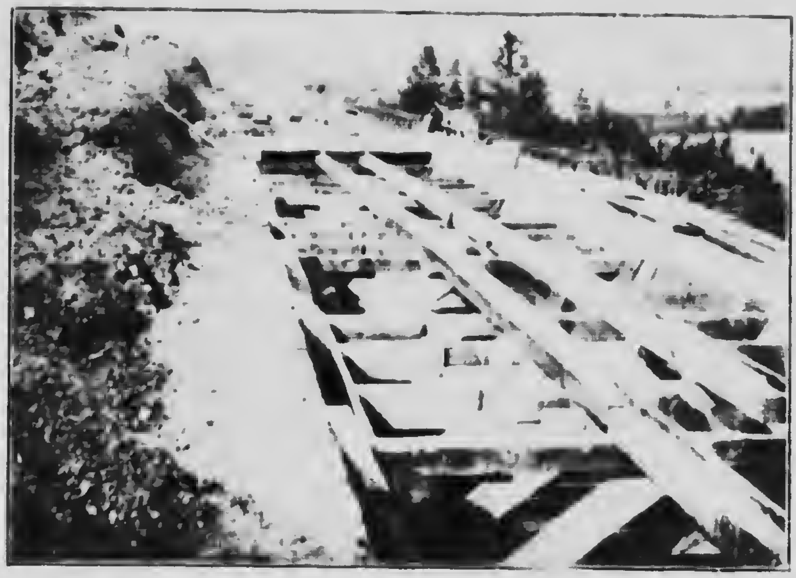


Fig. 30.—Forms in position for concrete lining. [illegible] lands Irrigation System, Kamloops, B. C.

Fig. 31.—Construction of concrete lining, Kelowna Irrigation Company, Kelowna, B. C.

For these conditions it may be advisable to use expansion joints spaced about 12 feet apart and omit all other joints. However, the writer believes that the soil can be thoroughly settled by running water in the excavated canal prior to the construction of the lining. The expansion joint, if desired, could be made by imbedding in the edges of the adjacent section a metal tongue about 4 inches wide. This tongue may be of galvanized iron well painted with oil to prevent adhesion of the concrete.

Method used near Kelowna by Kelowna Irrigation Company.

The method was very similar to the one described above. The main difference was that no separate earth forms were used. The concrete forms were placed in position in the excavated ditch and galvanized iron metal plates were put outside of the concrete form and held away from it by pieces of timber of the thickness of the lining (Fig. 31). The earth back-filling was placed against these plates and the concrete was poured in between the plates and the concrete forms. The plates and pieces of timber were pulled out as fast as the concrete was poured in.

The above methods of lining by means of forms are limited to side slopes steeper than 1 to 1, because when using a wet mixture even with side slopes between ½ to 1 and 1 to 1, the forms will tend to raise. Bolting the forms together will help to keep them in position.

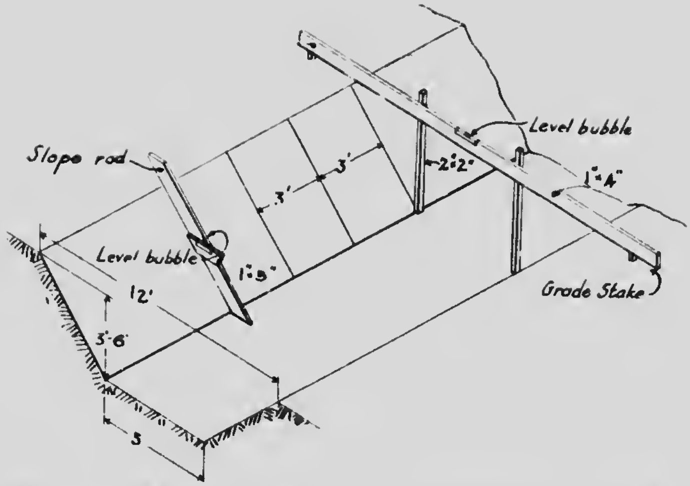
Construction of concrete lining without forms.

This method of construction has not been used in British Columbia but it is used extensively on irrigation canals in California and other states where concrete lining was necessary. It is the method to use for side slopes of 1 to 1 or flatter and is well adapted to large canals. While the first method is usually preferable for new canals on side hills, because steeper side slopes can be used, the second method may be preferable in the valley or in level land and especially in loose sandy soil which will stand naturally on slopes of 2 horizontal to 1 vertical or more.

The method used in preparing the excavated earth canal for the lining and in applying the concrete lining varies. One of the best methods which has been used by the Gage Canal Company of Riverside, California, is as follows:

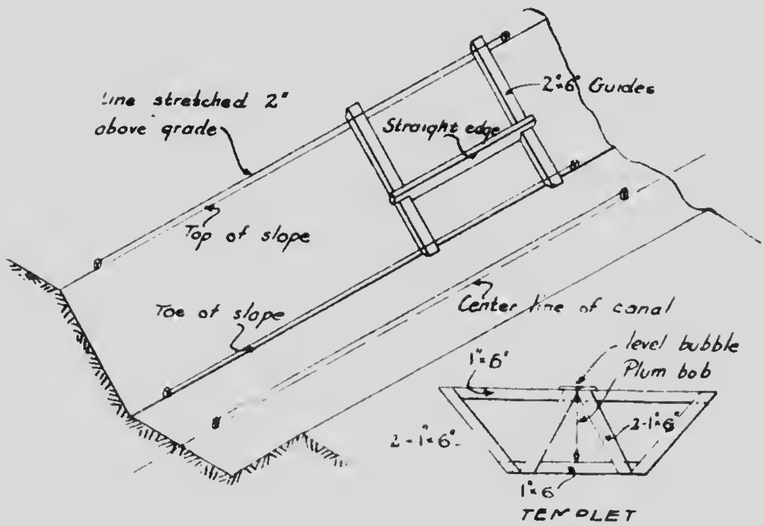
Preparation of earth canal (Fig. 32). Place the grade stakes 20 feet apart along one side of the ditch at a distance of 1 foot from the top of the sloping side. Hold a level rod or cross section rod across the ditch with one end resting on the grade stake, set the corresponding grade stake on the other side and put the bottom stakes in position by measuring down from this rod. By means of these stakes the bottom is cut to grade. To trim the side slopes, iron strips 1 inch wide, ¼ inch thick and of suitable length are driven edgewise in the sloping sides 3 feet apart, and extending up and down the slopes. The lower ends of these bars are placed in line by means of a line stretched between the bottom grade stakes and the proper slope is given to the bars by using a specially constructed slope level, which consists of a wooden rod on which a level bubble is placed, the bubble coming to the center when the rod is on the desired slope. The iron bars when in position, are guides for a sharp iron straight edge with which all irregularities are shaved off and hollow places filled in and well tamped.

A modification of this method would be to locate the top and bottom grade stakes by means of a templet of the same form as the finished ditch, the templet being equipped with a plumb bob or spirit level will indicate when it is in position (Fig. 33). Then stretch longitudinal lines between the stakes and grade approximately to these lines and finish the dressing



METHOD OF TRIMMING CANAL USED ON GAGE CANAL, CALIFORNIA

Fig. 32.



ALTERNATIVE METHOD OF TRIMMING CANAL

Fig. 33.

Fig. 34.—Concrete lined canal, Gage Canal Company, Riverside, Cal.

by placing flatwise 2 inch by 4 inch timbers across the slopes at the distance desired and with a straight edge tamp and level the earth between.

It is important to remove all deposits of vegetable character and the sides and bottom must be well settled to prevent the cracking of the lining. It is well to run water in the ditch before the ditch is prepared and lined.

The placing of the concrete should follow the trimming as soon as possible and if the channel is dry it should be thoroughly moistened by sprinkling. The concrete lining is built in alternate strips or panels. To place the concrete wooden guide pieces of the thickness of the lining are laid across the side slopes at the required distance apart which may be 3 feet or more. The concrete is spread between these studdings and raked to about a uniform thickness, tamped and made smooth and level by means of a straight edge resting on the guide timbers. The floor is finished in the same manner. Fig. 34 shows the completed canal.

Cost of concrete linings.

The cost of concrete lining varies a great deal with the accessibility of the canal, the material through which the canal is cut, the planning of the work, the efficiency of the construction force, the price of labor and material.

The cost of lining with forms is given by the following examples.

The Anaheim Union Water Company of southern California, which has many miles of concrete lined canal, obtained the following unit cost for 1,000 feet of a canal 9 feet wide at the top, 6 feet wide at the bottom and 3 feet deep, lined with average thickness of concrete of about 3 to 3½ inches, with the corner at the bottom made thicker.

Material.	Cost per 1000 feet.
170 barrels of cement at $2.70	$ 460.00
170 cubic yards of gravel at 65c	110.00
Labor of backfilling using earth foro	254.00
Labor of placing with concrete f rm	212.00
	$1,036.00

Cost per lineal foot, including backfilling, $1.036.
Cost per square foot, including backfilling, $0.0818.

For 4,070 feet of a small canal 2½ feet wide at the top, 1 foot wide at the bottom and 1½ feet deep, lined with 2 inches thickness of concrete, the cost was:

Mateclal.	Total cost for 4070 feet.
180 barrels of cement at $2.40	$432.00
180 cubic yards of gravel at $1.25	225.00
Total labor for backfillang, mixing and placing concrete	270.06
	$927.06

Cost per lineal foot, including backfilling, $0.228.
Cost per square foot, including backfilling, $0.0526.

The wages paid were:

$1.75 per day for men using earth form and backfilling.

$2.00 per day for men mixing and placing concrete.

$3.00 per day for foreman.

These costs include only the cost of materials in the concrete and the labor, but do not include cost of engineering, depreciation and interest on cost of forms and plant. These items would be small for the work was done under the supervision of the superintendent of the company who is paid largely for other duties, and the cost of forms and plant was small. The wages and cost of cement are low and the canal was easily accessible, making the cost of lining lower than could be obtained in British Columbia.

On the system of the Fruitlands Irrigation and Power Company, near Kamloops, the cost of lining 12,000 feet of canal 4 feet wide at the bottom, 3½ feet deep, and 7½ feet wide at the top with 3 inches of concrete averaged as follows:

Hauling forms, placing forms, backfilling with earth forms..	$ .18	per lineal foot
Cost of cement	.50	" " "
Cost of sand and gravel	.16	" " "
Cost of placing concrete forms, mixing and placing concrete	.30	" " "
Gasoline for concrete mixers	.01	" " "
	$1.25	

Cost per lineal foot, including backfilling, $1.25.
Cost per square foot, including backfilling, $0.105.

The concrete used was a mixture of 1 part of cement to 3 of sand and 4 of gravel. The cement cost $3.40 delivered on the job. The above cost was obtained where the canal was easily accessible along the foothills and the forms and concrete mixer could be easily moved along the banks of the canal. The cost of engineering, administration, interest and depreciation on cost of plant are not included in the cost.

On several thousand feet of canal where the canal was excavated on a steep rocky side hill, it was very difficult to deliver the concrete and the total cost of the above items was $1.72 per lineal foot or 14½ cents per square foot.

On the system of the Kelowna Irrigation Company, which has about 12 miles of lined canal, no separate form was used for backfilling the earth; instead metal plates were held away from the concrete forms by studding of the thickness of the concrete inserted between concrete forms and the plate as described above. The cost of lining 24,000 feet of main canal, 3 feet wide at the bottom, 2½ feet deep, and 5½ feet wide at the top gave the following average cost:

Making rock drain below floor, hauling forms, placing forms and backfilling	$ .21	per lineal foot
Cost of cement and hydrated lime	.47	" " "
Cost of sand and crushed rock	.16	" " "
Mixing and placing concrete	.49	" " "
Miscellaneous	.03	" " "
Cost per lineal foot	$1.36	
Cost per square foot	.158	

The concrete was a mixture of 1 part of cement to 3 of sand and 5 of crushed rock. Cement cost $3.20 to $4.10 delivered. The wages were $2.75 per day of 10 hours for common labor and $3.50 to $5.00 for skilled labor. The cost of engineering, which included location of the canal and the cost of depreciation and superintendence, brought the total cost to 17.73 cents per square foot. As the cost of lining only is considered here the cost of location should not be added. The higher cost per square foot obtained in this case was due to the higher cost of cement, the necessity for building roads to deliver material and move forms and mixer along the canal and to the placing of a rock drain under the floor of the canal. It was also necessary to rush the work and this probably increased the cost.

The South Kelowna system has started during this summer to excavate and line the upper part of their main canal which is in very difficult ground on very rocky and steep hillside, in some places the excavation alone costing over $3 a lineal foot. The canal was very inaccessible, requiring the construction of expensive roads to deliver the material and move the mixers. The forms were carried considerable distance around the bluff. This and other difficulties as well as the high cost of cement, brought the cost very high. Cement cost about $5.25 a barrel delivered at the mixer, and was mixed with 4 parts of sand and 5 parts of crushed rock. The canal was 3 feet wide at the bottom, 3 feet 3 inches deep and 6 feet 3 inches wide at the top. The lining 3 inches thick cost about $2.15 a lineal foot or about 21 cents per square foot.

Cost of lining without forms.

The main canal on the Gage Canal system near Riverside, California, has a bottom width which varies from 5 to 10 ft. and a depth from 3½ to 4 feet and side slopes of 1 to 1. The contract cost for trimming the canal and placing the lining of cement mortar ¾ to 1 inch thick was from 3¾ to 4 cents per square foot. This work, however, was done many years ago when labor was cheaper.

The Burbank Power and Water Company of Washington has recently lined 4,100 feet of the main canal which has a bottom width of 6 feet 6 inches, a depth of 2½ feet and a top width of 14 feet. The lining is 2½ inches thick for the bottom and 3 inches thick for the sides. At the top of the sides the lining extends horizontally for 6 inches to form a coping. The concrete was mixed in the proportion of 1 part of cement to 2 of sand and 4 of gravel. The lining was finished by painting with a thin mixture of 1 part of cement to 1 of sand. The contract price was $12.50 a cubic yard or about 11½ cents a square foot.

The U. S. Reclamation Service has lined 6 miles of the Main South Side Canal on the Boise Project in Idaho, with a concrete lining 4 inches thick. The canal is 40 feet wide at the bottom, 8 feet deep and 64 feet wide at the top. The concrete mixture was 1 part of cement to 3 of sand and 6 of gravel. A finishing coat of cement mortar was floated over the concrete to give it a smooth surface. The work was done at a cost of a little less than 10 cents a square foot excluding the cost of preparing the foundation.

These and many other examples show that for either method of construction and with average conditions and average prices, a concrete lining 3 inches thick should cost from 10 to 15 cents, including cost of backfilling or trimming the ditch to prepare it for the concrete lining and the cost of engineering, depreciation and interest on the equipment necessary for the work. A concrete lining 2 inches thick should cost from 7 to 12 cents. The lower cost in each case should be obtained with very favorable conditions.

Economy of concrete linings.

While concrete linings have many advantages, it is not an economical proposition to line canals indiscriminately without considerng all the factors upon which a decision should be based. The problem resolves itself to a comparison between the cost and the benefits derived. The factors which must be considered are (1) cost of construction, (2) cost of maintenance and operation, (3) damages due to waterlogging and alkali, and (4) value of water loss.

When a new canal is to be constructed the choice between an unlined canal and a concrete lined canal will depend largely on the first cost of construction. When there is sufficient fall available, a concrete lined canal can be given a steeper grade than an unlined canal which could not resist the erosion due to high velocity. The steep grade and also the smoother cross section will give a high velocity which will make the necessary size of the canal much smaller. The concrete lined ditch can also be given steeper side slopes which will decrease the excavation. For these reasons, the amount of excavation, especially on side hill work, will be much smaller for the concrete lined canal than for the unlined canal. This will reduce the cost of excavation sufficiently to balance for at least part of the cost of lining, and in some cases where the excavation is in hard material, the concrete lined canal may cost less than an unlined canal. Where there is not sufficient fall available to give the lined canal a steep grade, the comparison will not be quite as favorable but even then a lined canal because of its smooth bed and sides will have a greater velocity than an unlined canal on the same grade, and therefore a smaller cross section, and on side hill work in hard material the saving in cost of excavation will be considerable. Other benefits which must be considered are the decreased cost of maintenance and operation and the greater safety. There are no weeds to contend with, no breaks to mend and consequently the cost of patrolling is eliminated. To this must be added the value of the water saved and the prevention of waterlogging of the land below a leaky ditch. These benefits can not be closely estimated when a new canal is to be constructed but should be considered before deciding the feasibility of a concrete lining.

With existing canals the problem is to prevent the seepage losses or to increase carrying capacity by either enlarging the canal or by lining it with concrete. The extent of the seepage losses can be obtained by measurements, the damages done to adjacent land below and the maintenance of the canal are fairly well known and will furnish sufficient data to estimate what can reasonably be spent in concrete lining. When the capacity of the canal must be increased, the choice is between making a larger unlined canal or to use a lined canal of smaller cross section which will have a higher velocity because of the smoothness of the sides and bed. There are many cases where the value of the water loss alone will justify the improvement of the canals by lining. This is obtained when the value of the water loss will be equal to or larger than the depreciation and interest on the capital invested. As an illustration, if a canal carrying 50 cubic feet per second throughout the irrigation of 4 months or 120 days, loses 3 per cent. per mile, which is not excessive, this loss is equal to a continuous flow of 1.5 cubic feet per second or 3 acre feet, which gives a total of 360 acre feet whose value at $1.50 an acre foot is $540. For this case we would be justified in spending per mile a capital, the interest of which plus depreciation is equal to $540. If we assume interest and depreciation at 8 per cent the capital is about $6,700. In most cases this would be more than enough to build a concrete lined canal of that carrying capacity, depending on the velocity which can be used.

STEEL FLUMES.

During the past two seasons several miles of steel flumes have been used on the irrigation systems of the Kelowna Irrigation Company and of the Fruitlands Irrigation and Power Company, near Kamloops. The flumes are semi-circular and are made of metal sheets curved in a semi-circular form with a bead or corrugated groove rolled in each edge of the sheet. The

Fig. 35.—Steel flume in process of construction, Fruitlands Irrigation and Power Co., Kamloops, B. C.

sheets are put together by means of an interlocking joint formed by overlapping the edges which fit over each other. The joint is made tight by means of a curved rod which fits on the outside of the corrugated groove and a curved bevelled bar or small channel on the inside. The steel rods carry the weight of the flume. The ends are threaded for nuts and pass through the carrier or tie beams which are supported on stringers usually about 16 feet long. The stringers rest on trestle bents to which they are connected by bolts. By screwing the nuts the outside rod is drawn firmly against the flume and the channel or bar presses on the inside making a water tight joint. The method of construction and the completed flume are shown by Figs.

There are two makes of flume on the market, one known as the Maginnis galvanized steel flume, sold by the Maginnis Flume Co., Ideal Building, Denver, Colorado; the other known as the Hess flume, sold by the Hess Flume Company, First National Bank Building, Denver, Colorado. The first type of flume has been used in British Columbia. The second type has been developed only recently. The construction is very similar, differing only in the method of forming the interlocking joint. The Maginnis flume has a small channel which fits on the inside of the flume at each joint, while the Hess flume has a bevelled bar which fits in the groove. The Hess flume is made in sizes ranging from a diameter of $15\frac{1}{4}$ inches to 12 feet 9 inches, the Maginnis flume in sizes ranging from 15 inches to 10 feet 2 inches. The capacities given in the catalogues are for the flumes running full with no free board or clearance between the water level and the edges of the sheets. The purchaser should consider this and obtain a flume of ample capacity. The Hess flume has a greater capacity than the same size Maginnis flume because of the form of interlocking joint. The inside channel of the Maginnis flume projects above the inside surface of the metal sheets, while the outside surface of the bevelled bar of the Hess flume is flush with the inside surface of the sheets.

The metal used is either galvanized iron or steel sheets or some metal such as Ingot Iron or Toncan metal. These last two metals are a grade of iron in which all impurities found in ordinary steel or iron have been eliminated as far as possible. The resulting metal has the property of resisting rust or corrosion much better than the common or galvanized iron and steel. The cost of the better grade of metal is not much higher and it should be used in all cases.

As regards economy, the first cost of a metal flume will be higher than that of a wooden flume, but its greater durability as well as its water tightness will make its ultimate cost lower.

PLAIN CONCRETE PIPE NOT REINFORCED.

During the past thirty years cement pipes from 6 to 36 inches in diameter have been used very extensively in southern California where the scarcity and value of water have necessitated its most economical use and have justified the expense of putting in the best form of construction. On many systems the open ditches, especially the laterals, have been entirely replaced by cement pipes. Several hundred miles of cement pipes are now in use and it will not be many years before open ditches will have disappeared with the exception of some of the larger main canals. The advantages which have led to their adoption are:

1st. They eliminate the losses of conveyance.

2nd. They do not occupy any land which can not be cultivated.

3rd. They do not interfere with traffic and cultivation.

4th. They do not collect the seeds of weeds and distribute them on the irrigated land.

5th. They minimize the cost of maintenance.

Where cement pipes have been found deficient it has almost always been due to defects in the process of manufacturing. The use of cement pipes during the last few years has been extended to other states and there are now many miles of pipe on some of the irrigation systems of eastern Oregon, eastern Washington, and Idaho. During the past two years several miles of pipes have been manufactured by the Fruitlands Irrigation and Power Company, near Kamloops, for use on the distribution lines of the system.

The cement pipe so extensively used in southern California is made in sections two feet long. One end of the pipe tapers in and the other end tapers out so that when two pipes are joined together they form a bevelled lap joint. This form of joint is preferred to bell joint used for sewer pipes because the outside of the pipe is straight and the pipe is easier to lay; it also requires less material to manufacture. The pipe is made by means of metal moulds in which a moist mixture of cement and sand or cement and gravel is very carefully tamped. The mixture is comparatively dry in order that the moulds may be removed to be used again immediately after the tamping is finished. This is necessary to obtain a large output with one set of moulds and as much as 100 feet a day of 30 inch pipe and 300 to 400 feet of 6 to 8 inch pipe are made by experienced pipe men with one set. After the pipe is made it is carefully cured by being kept moist for at least one week and allowed to harden. At the end of a month it is ready to be laid and joined in the trench with cement mortar.

The sizes commonly used are 6, 8 and 10 inches inside diameter for private distributing lines and 10 to 30 or even 36 and 48 inches for the main lines of the irrigation system. The sizes to use in any case depend on the desired carrying capacity and the grade or fall obtainable.

The cement pipe, as manufactured by this dry process, has not the same strength nor is it as impermeable as a pipe made with a wet concrete and can only be used to cross shallow depressions or where the pressure is very moderate. The pressure head which it will safely stand depends on the efficiency of the manufacturer, the mixture used and the diameter of the pipe. The writer recommends the following maximum values as safe for pipes manufactured with care:

Diameter of pipe in inches.	Maximum Pressure Head in Feet. 1 to 2 mixture.	1 to 3 mixture.	1 to 4 mixture.
12	20	15	12
14	20	15	12
16	18	14	10
18	18	14	10
20	16	12	8
24	16	10	6
30	12	8	6

By using unusual care, experienced pipe men can make pipe which will stand safely 30 per cent. greater heads than those given in the above table.

The use of hand tamped non-reinforced pipe is therefore limited to low pressures and great care must be used in planning and constructing pipe lines in order that the safe pressures recommended above be not exceeded and all sudden stresses or pulsations which are likely to occur where air is allowed to accumulate in the pipe line must be prevented by providing ample air vents or air inlets at all summits in the pipe line. These air inlets can be formed by cutting a hole in the pipe and cementing to it a vertical stand pipe made of several sections of cement pipes, the lower end of which is cut to saddle around the hole and the upper end extending above the height to which water will rise.

1.—Manufacturing Hand Tamped Cement Pipes.

Mixtures used.

The best proportion to use depends on the material available. With good clean pit gravel containing about 50 to 60 per cent sand, less cement can be used than with sand alone. The mixtures commonly used are 1 part of cement to 4 parts of pit gravel and sand for pipes up to 18 inches in diameter, and 1 part of cement to 3 parts of gravel and sand for larger pipes. If crushed rock or screened gravel is used, a good mixture is 1 part of cement to 2 of sand and 3 or 4 of gravel or rock. No gravel or rock larger than one-half the thickness of the pipe should be used. To make the pipe more water tight 5 per cent. of the weight of cement in hydrated lime is added. The sand and gravel must be free from dirt or organic matter.

Mixing materials.

The mixing is very important. It is usually done by hand and in small batches, but for a large plant concrete mixers are advisable. The materials are mixed by means of a hoe or with a shovel; they should be mixed three times dry and three times wet. While it is desirable to use as much water as possible, only sufficient water is added to the mixture to give the consistency of damp earth which will retain its shape when squeezed in the hand. When too much [illegible] the mix will stick to the mould and the pipe will collapse [illegible] is removed. In order to make the ends smoother, some [illegible] for the ends a finer and richer mixture made of 1 part [illegible] 3 of screened sand.

Process of moulding. [illegible]

The moulds consist of a [illegible] which are bevelled to form the base of the pipe, an inside [illegible] jacket, a funnelled sheet iron hopper, a rimmer or cast [illegible] around the inside core and bevelled on the inside edge, a [illegible] and a feeding scoop. The pipe is usually made on a solid platform or levelled area. To set the mould in position the inside core is placed inside of the base ring and clamped tight to it by turning a lever, the outside jacket is placed around the base ring and contracted by turning a lever. The hopper fits on the top of the outside jacket. The mortar is fed in the moulds and spread in thin layers of one to two inches thick. Each layer must be carefully and uniformly tamped all around the inside core in order that the core be not shifted and the pipe made unequal in thickness. When the last layer has been tamped a little extra material is placed all around the top and the hopper is removed; the rimmer is then placed around the inside core, is jammed down and revolved, at the same time pressing down on the pipe. The inside core is now contracted and removed; the rimmer is taken off. If the pipe has been made on a platform it is now carried by means of lifting hooks with the jacket still clamped on the base ring and placed on level ground. The jacket is now released and removed and the pipe left on the base ring until it has hardened. For large size pipe to avoid lifting and carrying the pipe, the base rings are placed on the levelled ground instead of on the platform.

Where the pipes have to be used for pressures slightly greater than those given and especially for pipes above 18 inches in diameter, it is advantageous to place in the moulds during the tamping process hoops of ordinary wire about six inches apart. This permits using a slightly wetter mixture and adds strength to the pipe without increasing the cost materially.

Considerable practice is necessary before satisfactory pipe can be made and many pipes will be broken before sufficient experience has been acquired.

Curing the pipe.

When the process of moulding is completed the manufacturing is not finished and the pipe may be ruined if not properly cured. The dry mixture does not contain sufficient water for the cement to crystallize properly and additional water must be supplied by sprinkling during the curing period. The first sprinkling is done with a fine spray as soon as the pipe has set sufficiently to stand it without washing. After this the pipe must be kept continually moist by frequent sprinkling or by covering with wet burlap or sacks for a period of at least one week and not be allowed to dry or become white.

Coating the pipe.

To make the pipe less pervious it is usually coated on the inside with a thin paste of neat cement. Some prefer to use a cement lime mixture made of 2-3 cement and 1-3 lime. The coating of the smaller sizes of pipes, 6 to 12 inches in diameter, is often obtained by dipping the pipe in the liquid. For the larger sizes of pipes the coating is applied with a fiber brush. It is preferable to do this as soon as the pipe will stand the handling, usually when it is 24 hours old, at which time the base rings can be removed. To lift the larger size pipes a lifting jacket which fits around the pipe and tightens when the pipe is lifted, is often used.

Cost of moulds.

There are various makes of moulds, some of which are very cheap. A good mould must be substantially made to withstand the tamping and must be easily and quickly set in position and removed. The largest manufacturer of the moulds used in southern California and supplied to the U. S. Reclamation Service for use on some of its projects is the Kellar and Thomason Company of Los Angeles, California. Their list price in California of a set of moulds for 6 inch pipe with 100 base rings is about $50; for 12 inch pipe with 100 base rings, $82.50; for 18 inch pipe with 50 base rings, $91.25; for 24 inch pipe with 25 base rings, $107.50; and other sizes in proportion.

Dimensions of cement pipes and rate of manufacturing.

The table given below gives the thickness of the pipe, the number of feet made per barrel of cement, the number of men in one crew of pipe makers, and the number of feet of pipe made per day. The number of men stated is the number required for a large production. The number of feet per day is not the maximum which may be obtained but is an average rate for good experienced men. The 1 to 3 mixture requires about 2¼ barrels of cement per cubic yard of concrete. For the 1 to 4 mixture 1¾ barrels of cement per cubic yard are required.

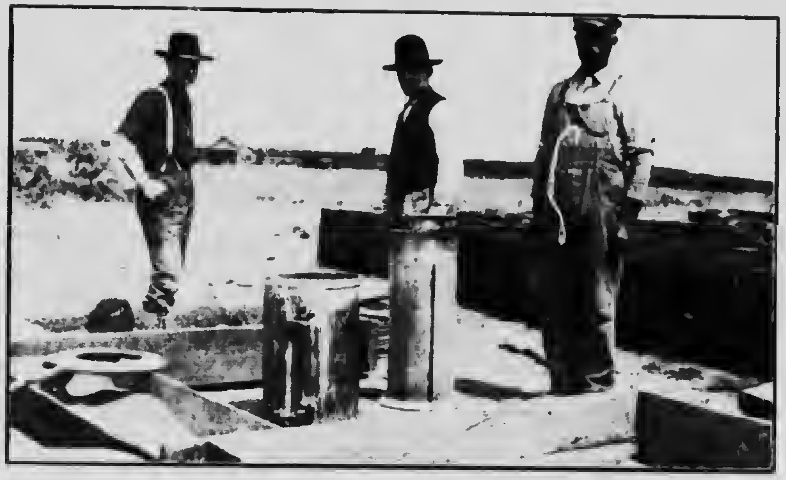


Fig. 36.—Moulds for casting hand-tamped pipe, showing inside core in position.

Fig. 37.—Process of tamping.

Fig. 38.—Removal of inside core.

Cement Pipe Data.

Inside diameter of pipe in inches	Thickness of pipe in inches	Number of feet of pipe made with 1 barrel of cement: 1:4 mixture	1:3 mixture	Men composing one crew	Number of feet made per day
6	1 1-16	95	75	1 mixer, 1 or	400-500
8	$1\frac{1}{4}$	63	50	2 moulders,	350-400
10	$1\frac{3}{8}$	47	37	1 finisher and	300-400
12	$1\frac{1}{2}$	36	28	helper.	250-350
14	$1\frac{5}{8}$	28	22	1 or 2 mixers	225-325
16	$1\frac{3}{4}$	23	18	2 moulders	200-275
18	$1\frac{7}{8}$	19	15	1 finisher	150-225
20	$1\frac{7}{8}$	17	14	and	125-175
22	2	15	$11\frac{1}{4}$	helper.	100-150
24	$2\frac{1}{4}$	$12\frac{1}{4}$	$10\frac{1}{2}$	3 or 4 mixers	100-150
26	$2\frac{1}{4}$	$11\frac{1}{2}$	9	2 moulder	90-120
30	$2\frac{1}{2}$	9	7	1 finisher and	90-110
36	3	$6\frac{1}{4}$	5	helper.	80

Cost of making pipe.

The table of cost given below is obtained from the above data and for the following prices of labor and material:

Portland cement, $3.50 delivered on the ground.

Gravel, $1.00 a cubic yard.

Labor: Tampers $3.00 a day; mixers and sprinklers, $2.50 a day.

The figures given include all materials and labor and an allowance of about 10 per cent. for interest and depreciation on plant, administration and supervision, and should not be exceeded with efficient workers.

Cost of Making Cement Pipes (in cents), per Lineal Foot.

Diameter of pipe in inches.	Cost for 1:2 mixture.	Cost for 1.3 mixture.	Cost for 1.4 mixture.
6	13 cents	10 cents	7 cents
8	15	12	9
10	20	15	11
12	25	20	15
14	30	25	20
16	36	30	25
18	42	35	30
20	50	43	35
24	68	60	50
26	87	75	63
30	95	85	70
36	130	115	95

2.—Construction and Laying of Pipe Line.

Excavation of trench.

The pipe should be laid sufficiently deep below the surface to have an earth covering of at least 12 inches and preferably 18 inches or even more. The bottom of the trench should be graded on an even grade to avoid short siphons which may produce air chambers in the pipe. The width of the trench should be larger than the outside diameter of the pipe by about 12 inches to allow the pipe layers sufficient space to work in. The trench width and depth with the cost of excavation are given in the table below, based on an 18 inch depth of earth covering. The cost of excavation and backfilling is assumed at 20 cents a cubic yard.

Cost of Excavation for Cement Pipe Lines (in cents), per Lineal Foot.

Size of pipe.	Depth of trench.	Width of trench.	Excavation in cubic yds. per lineal foot.	Cost of excavation in cents.
6 inches	26 inches	20 inches	.13	2.6
8	28	22	.16	3.2
10	31	25	.20	4.0
12	33	27	.23	4.6
14	35	29	.27	5.4
16	38	32	.32	6.4
18	40	34	.35	7.0
20	42	36	.38	7.
24	47	41	.50	10.0
26	49	43	.55	11.0
30	51	48	.66	13.2
36	60	54	.83	16.6

Laying the pipe. (Fig. 39).

The pipes are placed in the trench standing on end with the bell end or grooved end up. To lower the large pipes more easily they may be slid on a chute or skid made of timber. The pipe sections are joined with a mixture of 1 part of cement to 2 of fine sand. The taper end of the pipe which has already been laid, and the bell end of the pipe to which it is to be joined, are brushed clean and well wetted with a fiber brush. About an inch thick of the soil under the bottom of the joint to be made is removed and a trowel full of mortar is spread in its place to form a bed of mortar. The bell end of the pipe which is standing on end is filled with cement mortar and is jammed against the taper end of the previously laid pipe. The mortar which is squeezed out on the inside of the joint is wiped with a wet brush to form a smooth joint. To complete the joint a band of mortar from 2 to 3 inches wide and ¼ to ½ inch thick is formed on the outside of the pipe.

It is always preferable to lay the pipe uphill to avoid the shrinkage at the joints due to the pipe pulling away. It is well to protect the bands from the action of the sun for about 30 minutes before backfilling by using wet burlap or placing a board over them. To raise a pipe and hold it on grade do not use clods but shovel in dirt and compact it by tamping. The bands should be wetted before backfilling; this must be done carefully by shoveling the earth, free from rocks, around the pipe and tamping it until the pipe is well covered. With loose sandy soil which packs easily, very little tamping is necessary. The pipe should not be used for at least 2 to 3 days, especially if under pressure, to give sufficient time for the bands to harden.

In the accompanying table is given information regarding the laying and hauling of cement pipe, based on the wages and cost of material given above. Ten per cent. has been allowed for supervision, organization, breaking of pipe and miscellaneous.

Fig. 39.—Method of laying and joining cement pipe.

Cost of Laying and Hauling Cement Pipe (in cents) per Lineal Foot.

Diameter in inches	Weight of pipe in pounds per foot.	Number of feet laid per bbl. of cement.	Number of men in laying crew.	Number of feet laid per day	Cost of laying exclusive of trenching and hauling, in cents per foot.	Cost per foot of hauling 2 miles.
6	20	500	3	600	2.25	.9
8	32	400	3	600	2.50	1.1
10	42	350	3	500	3.00	1.9
12	56	300	3	450	3.50	2.5
14	69	225	3	400	4.00	3.1
16	85	200	3	300	5.00	3.8
18	100	175	4	300	6.25	4.5
20	110	150	4	300	6.60	5.0
24	160	100	6	300	10.0	7.2
26	175	85	6	250	12.0	7.9
30	220	75	6	200	14.0	9.9
36	320	60	7	200	17.0	14.4

The cost data given in the preceding table are assembled and given below.

Cost of Making, Laying, Trenching and Hauling Cement Pipe (in cents), per Lineal Foot.

Diameter of pipe in inches	Cost of making		Cost of laying.	Cost of trenching	Cost of hauling 2 miles.	Total Cost	
	1:3 pipe	1:4 pipe				1:3 pipe	1:4 pipe
6	10	7	2.25	2.6	.9	15.75	12.75
8	12	9	2.50	3.2	1.4	19.10	16.10
10	15	11	3.00	4.0	1.9	23.90	19.90
12	20	15	3.50	4.6	2.5	30.60	25.60
14	25	20	4.00	5.4	3.1	37.50	32.50
16	30	25	5.00	6.1	3.8	45.20	40.20
18	35	30	6.25	7.0	1.5	15.20	10.20
20	43	35	6.60	7.6	5.0	52.75	17.75
24	66	50	10.0	10.0	7.2	62.20	54.20
26	75	63	12.0	11.0	7.9	87.20	77.20
30	85	70	14.0	13.2	9.9	105.90	93.90
36	115	95	17.0	16.6	14.4	122.10	107.10
						163.0	143.00

These cost values agree quite closely with those given below which are those obtained for about 5 miles of pipe on the irrigation system of the Fruitlands Irrigation and Power Company, near Kamloops. The concrete mixture used was composed of 1 part of cement to 2½ of sand and 1½ of stone, which corresponds to a 1 to 3 mixture of cement and pit gravel. Cement cost $3 a barrel, sand 75 cents a cubic yard, crushed rock $2.50 a cubic yard, common labor $2.50 per day, skilled labor $3 to $3.50 per day, and teams $6 per day. The cost given includes all materials, labor, supervision, and depreciation on plant.

Cost of Making and Laying Concrete Pipe on Irrigation System of Fruitlands Irrigation & Power Co., Near Kamloops.

Diameter of pipe.	Cost of making.	Cost of laying.	Total cost.
8 inches	11.1 cents	....	.... .
10 "	15.7 "	... .	....
12 "	20. "	11. cents	31. cents
16 "	29.5 "	15.5	45 "
20 "	39.5 "	20.3 "	59.8 "
24 "	54.7 "	23.3 "	78 "

3.—Other Methods of Making Cement Pipe.

The lack of uniformity in the pipe made with a dry mixture tamped by hand as described above and the porosity of the pipe, have led to other processes of making pipe some of which are still in the experimental stage. Two methods have been used, machine tamping and the wet process.

Machine tamped pipe.

Machine tamped pipe is made by a number of plants in the West including one at Peachland. The pipe is made with a comparatively dry mixture much in the same manner as hand made pipe, but the mixture is thoroughly tamped by a mechanical tamper of small cross section which tamps rapidly and gives a high degree of compression. The inside core also rotates during the tamping processes and this gives the inside of the pipe a very smooth surface. The pipe obtained by this process is a very dense pipe. It should be very uniform and superior to the hand made pipe, especially when a pipe is desired for pressure heads greater than the hand made pipe will stand.

The pipe is made with a bell end similar to sewer pipe. This requires more material than the shiplap end obtained with the hand made pipe which increases the cost.

Pipe made by wet process.

To make pipe by the wet process, a wet mixture of cement mortar or cement concrete is poured in the mould and after the mixture has hardened, the moulds are removed. As this takes several hours, only a few pipes can be made per day. For a large output several moulds would be needed and the cost of the plant would be high. However, the moulds need not be as strong as those used for hand tamping and could be obtained at a much smaller cost. The increased cost of plant would be overbalanced, if a large quantity of pipe was made, by the saving in labor and also by the saving in cost of material because a pipe equal in strength and impermeability could be obtained with less cement.

To reduce the number of moulds it has been attempted to accelerate the hardening of the mixture by heating it with steam. This process, however, is still in an experimental stage. The U. S. Department of Agriculture, through its Irrigation Investigations Office, is investigating the wet method of making pipe. The U. S. Reclamation Service has also devised methods of making a wet mixture cement pipe at a reasonable cost for the Tieton Irrigation project in Eastern Washington, and for other projects. Their results have not yet been published.

REINFORCED CONCRETE PIPE.

There is a great field for a concrete pipe which will stand moderate pressure and can be manufactured at a cost which will compare well with that of wooden pipe. The hand tamped plain concrete pipe has sufficient strength only for low pressures, and machine tamped pipe or pipe made by the wet process has not been sufficiently tested to know what heads it will stand, though they are probably safe for at least twice the pressure resisted safely by hand made pipe. Reinforced concrete pipe has been used successfully for pressures above 100 feet and is guaranteed by some pipe manufacturers for pressures as large as 150 feet. Reinforced concrete pipe consists of a skeleton of iron or steel imbedded in the concrete shell of the pipe. The reinforcement is made of rods or bars of metals, or some form of expanded metal or wire mesh. For small pipes the circumferential reinforcement is often made as a spiral of wire. For larger pipes the re-

Fig. 10.—Moulds for casting 48-inch reinforced concrete pipe, Umatilla Project, Oregon.

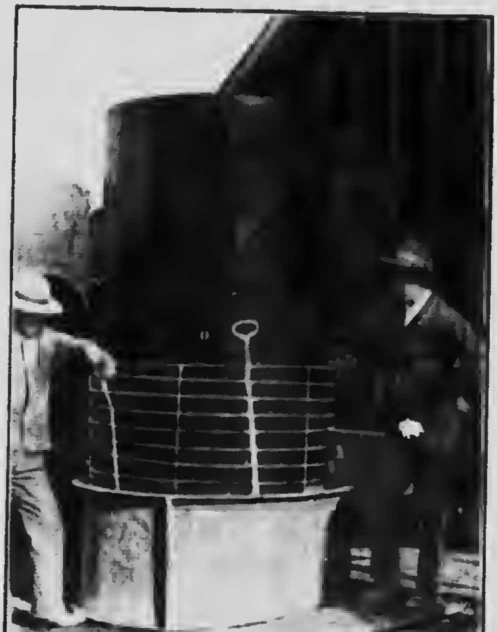
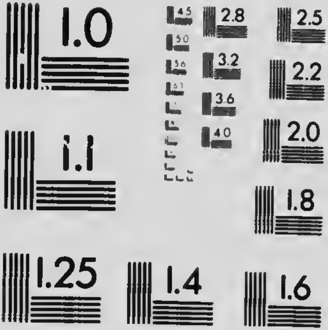


Fig. 11.—Process of casting pipe, Umatilla Project, Oregon.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



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inforcement is bent into hoops by means of rolls and the ends are welded, or overlapped and tied together with wire, or bent to form hooks and a longitudinal rod passed through the eye of the hooks.

The pipes may be made in short sections cast in moulds as the non-reinforced pipe described above, or they may be built continuously in the trench. The latter method has the advantage that it does away with the joints which are usually the point of weakness, but it requires a thicker pipe and is only used for the larger sizes of pipes. For pipes up to 4 or even 5 feet in diameter the first method is generally used and the pipes are cast in sections 3 to 8 feet long. The thickness of the shell seldom exceeds 2¾ to 3¼ inches. When the reinforcement consists of a spiral, the wire is wound by machinery and kept to the proper spacing by means of longitudinal rods tied to the spiral wire. When hoops are used, they are also tied to the longitudinal reinforcement.

Two companies in the United States make a specialty of the construction of reinforced concrete pipes. One is known as the Meriwether pipe made by the Lock Joint Pipe Co., of New York, with branches at Winnipeg and at Seattle, Washington. The other is made by the Reinforced Concrete Pipe Co., of Los Angeles, California. These manufacturers make pipe up to 72 inches in diameter, from 2½ to 7 inches thick, in sections 3 feet long. On the Umatilla project, in Oregon, several miles of reinforced concrete pipe 30, 46 and 47 inches in diameter have been constructed. The sections were made 4 feet long for the 30 inch pipe and 8 feet long for the larger size. The Roswell park project in Idaho has four miles of reinforced pipe, some of it resisting heads of 70 feet.

1.—Method of Casting Reinforced Concrete Pipe. (Umatilla Project, Oregon.)

The pipes are usually cast in moulds which consist of an inside collapsible core, an outside sectional jacket and a base ring. The process of casting used on the Umatilla project is a good illustration of this form of construction. For the large size pipe cast in sections 8 feet long, the inside core is made of two main pieces of curved steel plate ⅛ inch thick, held together by a vertical hinge, and a third narrow closing piece or wedge which fits between the other two pieces when the core is set up and is removed when the core is collapsed. The outside jacket is made of twelve curved parts, each 2 feet high and 1-3 of a circumference in length, which when joined in sets of three form a section of the jacket 2 feet high. These parts are made of ⅛ inch steel plate and to the edges of each part are riveted angles by means of which the parts can be bolted together. The base ring which forms the bell end of the pipe is made of cast iron. (Figs. 40, 41).

To set up the moulds the inside collapsible core is placed in position fitting inside the base ring, and the lowest section of the outside jacket is formed by bolting the three parts around the base ring. The reinforcing skeleton is placed around the inside core, then the concrete, which is a wet mixture of 1 part of cement to 1.8 parts of sand and 3 parts of gravel, is poured between the forms and worked down by means of thin tamping bars. (Fig. 37). The outside jacket is built up in sections, each being filled nearly to the top before the next one is bolted on. To fill the last section a funnel shaped collar is placed around the inside core and bolted to the top of the section. When filled the collar is removed and the upper end of the pipe is finished by hand. The forms are removed 24 hours after the pipe has been moulded and the pipe is left standing on the base ring for eight days.

For the 30 inch reinforced pipe the forms used are 4 feet long and made of lumber lined with sheet steel (Figs. 42, 43). The interior core consists of two main parts and a wedge or closing piece. The outside form is made of four parts bolted together.

The reinforcement is made of wire wound into spirals 4 feet long by means of a reel on which are hinged spacing bars with notches which give the wire the proper spacing. (Fig. 44) After the wire is wound, longitudinal rods 4 feet long are placed on he outside of the spiral and connected to it by bending the ends over the wires of the spiral at the two ends and by tying them together with wires. The spiral can then be removed from the reel by turning down the hinged spacing bars, and is made more rigid by cross lacing with wire.

2.—Method of Joining.

The pipes, after they have hardened sufficiently, are placed in the trench where they are joined. The best time to lay the pipe is in cold weather, for a rise in temperature will produce expansion and make the joints tighter, while if they are laid in the summer time, any contraction due to lowering of the temperature will tend to produce shrinkage cracks. The joints may be made in three ways: (1) bell and spigot, (2) collar joint, and (3) lock joint.

Bell and spigot joint.

The bell and spigot joint has been used on smaller pipes where the pressure is not great. On the Umatilla project some of the 30 inch pipe has been laid under a pressure head of 23 feet with this type of joint. The pipes are similar to the non-reinforced pipe previously described and have a taper end and a bell end, the joints being made in the same manner as the joints for non-reinforced pipe.

Collar joint.

This joint is used for larger pipes and greater pressures. The joint is made with a reinforced collar from 4 to 8 inches wide, whose inside diameter is slightly larger than the outside of the pipe. The collar, which has been slipped over the pipe last laid, is placed over the joint and the space between the interior of the collar and the outside of the pipe is filled with a rich cement grout poured through two holes in the collar and prevented from running out by means of a mortar paste spread around the edges of the collar.

Lock joint.

The lock joint is intended to make the longitudinal reinforcement continuous. It is used by the Reinforced Concrete Pipe Company and the Lock Joint Pipe Company.

3.—Method of Making and Laying Reinforced Concrete Pipe on Roswell Project, Idaho.

On this project the reinforced pipe was made with the dry mixture hand tamped pipe around which was wound the reinforcing steel wire which was covered with a rich cement mortar. The method of winding the wire, applying the plaster and laying the pipe is described as follows by Zenas N. Vaughan, the engineer in charge:

"Two movable bulkheads, with crank-handles attached, are so arranged that the pipe length can be firmly clamped between them. At a distance back of this device a steel shaft, into which is cut a screw groove, works

Fig. 42.—Inside core and spiral reinforcement in position for casting 30-inch reinforced concrete pipe, Umatilla Project, Oregon.

Fig. 43.—Placing concrete in moulds, Umatilla Project, Oregon.

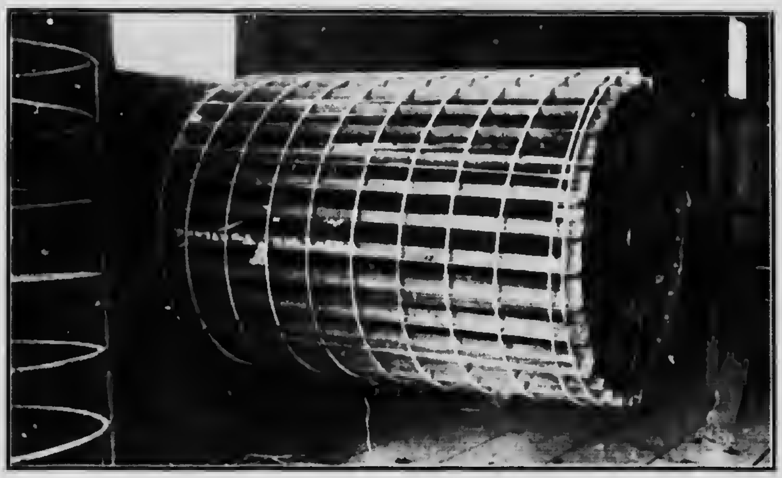


Fig. 44.—Reel for making spiral reinforcement, Umatilla Project, Oregon.

freely horizontally. Back of this, and horizontal to it, a wooden shaft is placed for regulating the tension of the wire, and still back of this is a vertical spindle, from which wire unwinds automatically. The wire used for reinforcing is a No. 12 gauge, galvanized wire, having a tensile strength between 500 and 600 pounds. A coil of this is placed vertically upon the spindle, the wire is passed around the tension shaft, thence into the screw groove, and is finally firmly attached to one end of the pipe length by soldering. The pipe is then revolved by two men at the crank handles, by which process the wire is wound upon the pipe under a high tension, the spacing of the laps of the wire being made even by the screw groove. Variation in spacing for different heads is accomplished by using pulleys of different diameters, to govern the rate of revolution of the grooved shaft as compared with that of the pipe length. The reinforcing is stressed the same as that in the main pipe.

When the reinforcing reaches the end of the pipe length, the last two or three laps being made parallel, it is again soldered, and the wire is severed. A steel trowel curved to conform to the shape of the pipe, and suspended abo e it, is then dropped into place, and then cement mortar 1½-1, is run upon the pipe as it revolves, the trowel smoothing this down to a uniform thickness. The bulkheads are then unclamped by a lever at one side, the pipe is removed, and is carried away to be properly cured.

"In the trench the bell and spigot ends of the pipe are fitted together, as in the case of sewer pipe. Around the joint is placed a flexible form, made of very heavy canvas, attached to blocks of wood, sawed out in such a way that a space of about one inch measured transversely to the pipe, and six inches longitudinally is left vacant for the reception of the mortar. Along each edge of the form is run a 12-gauge wire, terminating at one end in an iron ring, at the other in a tongue pin, curved in shape, so that when clamped through the ring, it draws the wire to a high tension, firmly binding the form to the pipe. The form is then filled with cement mortar, and immediately afterwards the interior of the joint is carefully pointed to insure water tightness, independently of the collar, as far as practicable. As soon as the collar forms can be remov ', the trench is backfilled, to protect the collars while curing."—Journal of Idaho Society of Engineers, pp 40-41, Vol. No. 1.

In southern California reinforced pipe built in the same manner has been used. It is wound with No. 12 galvanized wire spaced about 1½ inches apart and coated over to protect the wire from corrosion. The cost of reinforcing the hand tamped pipe is 10 cents per foot for 10 inch pipe, 15 cents for 12 inch pipe, 25 cents for 20 inch pipe, and 35 cents for 26 inch pipe.

4.—Cost of Making Reinforced Concrete Pipe.

On the Umatilla project in Oregon, a number of reinforced concrete pipe lines 46 and 30 inches in diameter and aggregating several miles in length, have been installed and are entirely successful. These pipes were three inches thick, made as described above. The cost of each is given below. The concrete was composed of 1 part of cement to 2.3 parts of sand and 3 parts of gravel, screened through 1 inch mesh and rejected on ¼ inch screen. Cement cost $2.25 a barrel, sand $1.00 a cubic yard, gravel $2.65 a cubic yard. The steel spiral in place cost 5½ cents per pound.

Inside diameter of pipe in inches	Length	Maximum head.	Cost of pipe.	Total cost laid including hauling trench excavation.	Cost of placing and making joints including material
16........	9831	110	2.97	1.13	.59
16........	5312	36	2.24	3.86	.18
46........	1284	15	2.21	3.26	
30........	5330	45	1.26	2.25	
30........	3556	26	1.26	2.16	
30........	3615	25	1.26	2.04	.22
30........	1622	18	1.26	1.96	

The Reinforced Concrete Pipe Company of Los Angeles quotes the following approximate prices which include the material, the making and laying but not the excavation of trench and backfilling:

Diameter in inches.	Cost in dollars for 25 ft. head.	50 ft. head	100 ft. head.
24	1.75	2.00	[illegible]
30	2.25	2.50	3.00
36	2.65	3.10	3.60
42	3.20	3.65	4.25
48	3.85	4.10	5.10

The prices in southern California for reinforced pipe made with hand tamped pipe wound with wire and plastered with mortar are quoted as follows. These prices are for the pipe laid:

6 inch pipe	$ .20	per lineal foot
8 " "	.30	" " "
10 " "	.40	" " "
12 " "	.60	" " "
14 " "	.75	" " "
20 " "	1.20	" " "
26 " "	2.00	" " "

The prices in British Columbia due to higher cost of cement would probably be about 10 per cent. higher.

5.—Advantages and Economy of Reinforced Concrete Pipe.

The great advantage of reinforced pipe is its durability. The first cost as compared to wooden pipe is usually a little greater, but its longer life will make its ultimate cost much lower, especially when the pipe can not be kept constantly full.

It has been shown that for a wooden pipe whose life is 10 to 15 years the total annual cost to pay interest on first cost, renewal and depreciation, is 15 per cent. of the first cost, and for a wooden pipe whose life is 20 to 30 years, about 11 per cent. For a concrete pipe, depreciation and renewal are practically eliminated; therefore interest only, at about 6 per cent., need be considered. Based on these figures a concrete pipe would be as economical in cost as a wooden pipe even when the concrete pipe cost about twice as much as the wooden one. The prices of wire wound wood pipe good for 50 to feet head are about as follows for the Okanagan district:

6 inch pipe	$ .28	per lineal foot
8 " "	.38	" " "
10 " "	.52	" " "
12 " "	.57	" " "
14 " "	.61	" " "
16 " "	.80	" " "
18 " "	.95	" " "
20 " "	1.25	" " "
22 " "	1.45	" " "
24 " "	1.60	" " "

The prices for wooden stave pipe for 50 foot head, built in place, are about as follows:

Diameter.	Per lineal foot.
26 inches	$1.8
28 "	2.06
30 "	2.20
42 "	2.80
48 "	3.40
54 "	3.90

Comparing the above prices with those for reinforced concrete pipe it is seen that there is no great difference in first cost, but if ultimate cost is considered, the economy is in favor of reinforced concrete pipe.

However, the use of reinforced concrete pipe is limited to moderate head under 100 or 150 feet, and they require careful workmanship and an expensive manufacturing plant. Wooden stave pipes have the advantage that they can be used for higher heads and that they are easily and quickly put together.

With concrete pipes it is very necessary to prevent the accumulation of air in the pipe to avoid water hammer. This requires that air valves of ample capacity be placed wherever air will collect in the pipe.

IV.--DUTY OF WATER AND FACTORS INFLUENCING THE CORRECT USE OF WATER IN IRRIGATION.

DUTY OF WATER.

A knowledge of the quantity of water used in irrigation and of the factors influencing the correct use of water in irrigation is necessary if the best use of the available water supply of British Columbia is to be obtained. The term duty of water is used to express the relation between the area of land served and the quantity of water used. It may be further qualified by using the expressions gross duty, duty measured at heads of laterals, and net duty.

The **gross duty** of water represents the relation between the quantity of water diverted from the source of supply and the total area of land irrigated. It is obtained from measurements of the flow taken at the head of the main canal of the irrigation system and includes besides the quantity applied to the land, all losses and waste in conveyance.

The **duty of water measured at the head of the lateral** is higher than the gross duty because the losses obtained from the head of the main canal to the head of the lateral are not included.

The **net duty** of water represents the water delivered to the field as obtained by measurements taken at the margin of the field. It includes besides the quantities used by the plants, the los[illegible] by evaporation, percolation and waste occurring on the field, which can be control[illegible] to a large extent by a skillful irrigator.

The duty of water is spoken of as high when t[illegible] a[illegible] by a certain volume of water is comparatively large, and [illegible] low [illegible] the a[illegible]a is comparatively small. The gross duty is lower than [illegible] net [illegible] the difference depending on the efficiency of the main canal and [illegible]aries. If all losses of conveyance were eliminated, the gross duty a[illegible] [illegible]ty would be equal. A knowledge of the gross duty is necessary [illegible] plan the irrigation system in order to make allowances [illegible] loss. It is also of value in determining the efficiency of a [illegible]

The **net duty** must be distinguished from the **correct a[illegible] water required for maximum production**, for it merely represen[illegible] of water which is used according to the available water and the [illegible]nt and skill of the irrigator. In most cases where water is abunda[illegible] quantity used is in excess of what is actually needed, while where w[illegible] very scarce, it may be less than the correct amount. The **correct a[illegible] of water to use** is that quantity which is necessary to produce max[illegible]eld when all the losses of water by percolation, evaporation and waste which can be controlled by ordinary careful methods of irrigation and cultivation, have been eliminated.

The duty of water can be stated in three ways:

1st. In number of acres irrigated by a flow of water of one cubic foot per second for a certain length of time during the irrigation period.

2nd. In number of acres irrigated by one miners' inch for a certain length of time during the irrigation period.

3rd. In number of acre feet per acre which is equivalent to stating the depth of water applied to the land.

The first and second expressions must always include the time in order to specify a given volume of water. For instance a duty of 1 cubic foot per second for 100 acres during the entire irrigation season of 5 months or 150 days would mean 300 acre feet on 100 acres or a depth of 3 feet on the land. If the length of time or period of delivery is only one-half of the irrigation season, the water delivered will give a depth of 18 inches on the land. In the same way a duty of 1 miners' inch to 2 acres during half the time of an irrigation season of five months will give a depth of water on the land of about 5 inches per month or a total depth of 25 inches per season.

The third method of expressing duty avoids any misunderstanding. For instance 2 acre feet per acre means a depth of 2 feet of water on the land. The duty when expressed by either of the first two methods can easily be converted into acre feet or acre inches per acre by the relation previously given which is: One cubic foot per second in 24 hours will give 2 acre feet, or 1 acre inch per hour, and one British Columbia miners' inch in 36 hours will give 1 acre inch. Based on this relation, the following equivalents are obtained.

Depth of Water Applied to the Land in One Month of Continuous Flow.

Rate of flow.	Depth applied.
1 miners' inch to 1 acre, or 1 cubic foot per second to 36 acres.....20	inches
1 miners' inch to 2 acres, or 1 cubic foot per second to 72 acres.....10	"
1 miners' inch to 3 acres, or 1 cubic foot per second to 107 acres..... 6 2-3	"
1 miners' inch to 4 acres, or 1 cubic foot per second to 143 acres..... 5	"
1 miners' inch to 5 acres, or 1 cubic foot per second to 180 acres..... 4	"

1.—Principal Factors Affecting the Net Duty of Water in Irrigation.

The factors which have more or less effect on the duty of water are:

1st. The kind of crops. It is known that some crops require more water than others; for instance, alfalfa requires more water than orchards, and young orchards require less water than full bearing orchards.

2nd. The preparation of land, method of application of water and skill of the irrigator. Poor preparation of the land will cause water to accumulate in the swales and uniform distribution of water is difficult. With furrow irrigation unless great care is taken in the division of water between furrows, there will be a larger amount in some furrows than in others. When the furrows are too long a large excess of water sinks into the soil at the upper ends of the furrows and goes down beyond the plant roots. At the lower ends of the furrows there is often a waste which may cause injury to the neighbors' land or to the road below. If deep furrows are used there is less water and wet soil exposed to the air and less evaporation than with shallow furrows.

3rd. The time and frequency of cultivation. Thorough cultivation as soon as possible after irrigation decreases evaporation losses.

4th. Number of seasons irrigation is practiced. In all irrigated districts it has been the experience that irrigation causes a rise of the water table. If this rise is too great it may submerge the roots and waterlog the soil, but if the water table rises only to a depth where the soil water can be drawn by capillarity to the roots, this will lessen materially the necessary amount of irrigation water.

5th. Climate. Rainfall, temperature, humidity of the air, wind movement, all have an effect. The rainfall and its distribution are important. Abundant rainfall or snow in the winter will be partly stored in the soil and is available to deep rooted plants during the growing season, thus decreasing the necessary irrigation. On the other hand, light showers during the summer may do more harm than good by destroying the soil mulch and increasing soil evaporation. An increase in temperature and in wind movement will increase the soil evaporation.

6th. Character of soil and subsoil drainage. A sandy soil underlaid with a porous subsoil which drains readily will take care of large volumes of water without waterlogging and encourage waste.

7th. The value of water, method of payment for water, judgment of irrigator. A high cost of water leads to higher duty. If water is sold at so much per acre of land independent of the amount of water used, it is human nature for the average irrigator to use all he can. On the other hand, where the water charge is based on the quantity actually used, this leads to careful use and high duty. This factor combined with the judgment or lack of judgment may have more effect on value of the duty of water than all the other factors together.

Because of all the factors on which the duty of water depends, it is to be expected that there is a great difference in the value of the duty of water obtained in different localities or even in the same localities for farms, or orchards under the same conditions but owned by different parties. There are no measurements of the duty of water in British Columbia, but values of the duty of water in the arid states of the United States are very numerous. These measurements have been largely made by the Irrigation Investigations Office of the U. S. Department of Agriculture, usually in cooperation with the state governments. In a review of ten years of irrigation investigations, carried on by the U. S. Department of Agriculture since 1898, Mr. R. P. Teele gives a large number of duty of water mersurements which are very instructive. These measurements show that the gross duty ranges from a maximum average of 13.18 acre feet per acre for 7,000 acres of the Modesto system in California, to a minimum of 2.0 acre feet per acre for 5,160 acres irrigated by several small systems in the Santa Ana Valley, of California. The gross duty for 50,000 acres in the Yakima Valley irrigated by several canal systems is 5.70 acre feet per acre. For 20,000 acres of the Bitter Root Valley the average is 4.69 acre feet per acre.

The duty of water is generally lower for a new system, because seepage losses are greater for new canals, new lands require more water, water is more plentiful as only a part of the land is irrigated, and the irrigator is less skillful. As the system gets older, less water is used and the gross duty increases. This is well shown in the following table.

Gross Duty of Water Under Sunnyside Canal, Washington.

Year.	Area irrigated (acres).	Quantity of water per acre. (acre feet).
1898	6,883	11.1
1899	8,197	10.6
1900	10,947	10.2
1901	14,961	9.6
1902	18,870	9.1
1904	32,000	6.0
1909	17,000	4.57

This table shows that after 11 years only two-fifths as much water was used as in the first year, or the same amount of water will irrigate $2\frac{1}{2}$ times as much land.

The **duty of water measured at the heads of laterals.** On new canals the average of measurements made on several canal systems shows that about 50 per cent. of the water diverted is delivered to the laterals. On older canals the percentage is much higher. For the Sunnyside Canal in eastern Washington it was 79 per cent. in 1909.

The **net duty of water** is the duty as measured at the margin of the fields. This duty is much higher than the gross duty as shown by the table below.

Quantities of Water Delivered to Several Farms Compared With Water Received at head of Main Canal, or Net Duty vs. Gross Duty.

State.	Canal.	Gross duty, or water diverted by canal. Acre ft. per acre.	Net duty, or water delivered to farms. Acre ft. per acre.	Per cent.	Remarks.
California	Gage	2.16	1.98	92	Concrete lined canals and pipe systems.
Idaho	Ridenbaugh laterals	4.79	2.50	52	
Washington	Sunnyside	9.60	3.96	41	For year 1901.
"	"	4.57	2.79	68	For year 1909.

These measurements show that for the Gage canal system, which consists of a main canal, concrete lined with cement mortar about 1 inch thick, and pipe distributaries, 92 per cent. of the water diverted reaches the land. The measurements for the Sunnyside canal show the increase in efficiency of a system as it gets older. The above results indicate that in a new canal system of unlined earth canals the water delivered to the farms is probably not more than 40 per cent. of the water diverted. For old canals in good condition the efficiency will be increased to 65 or 70 per cent.

2.—Duty of Water for Orchards.

There is relatively little data on the duty of water for deciduous orchards. The data which is of most interest to British Columbia fruit growers is that obtained for the orchards of Washington, Idaho and Montana. Mr. S. O. Jayne, Irrigation Manager in the State of Washington for the U. S. Department of Agriculture, gives the following information:

"The water on a 20 acre apple orchard at Wenatchee was measured during the season of 1908, showing that a depth of 23.04 inches was applied between May 13th and September 23rd. On the same orchard in 1910 27 inches of water were used, the first irrigation was May 30th and the last September 12th. The trees were seven years old in 1908 and bore a very heavy crop that year, another in 1909 and another last year. The orchard is one of the best cared for as well as one of the best producers of the Wenatchee district. The irrigation was done with more than ordinary care and intelligence. But the soil texture is rather coarse and the water holding capacity low, thus favorable to large percolation losses in the subsoil. Undoubtedly a considerable saving in water would have been possible had the furrows used been only 330 feet long instead of twice that length."

"Another Wenatchee orchard of 50 acres, including apples, peaches and other fruits, used 16 inches in 1908 and 17.5 inches in 1910. The soil here was somewhat heavier than in the former case, but the furrows used were twice as long and besides the run off was considerable. Part of the orchard, however, was not in bearing and none of it so uniformly good as the other example cited. The annual precipitation at Wenatchee is about 6 to 8 inches and comes late in the fall, winter and early spring."

"The records of one of the Spokane valley companies show that on that system a depth of 11.7 inches was applied in 1905, 19.2 inches in 1906, 22.8 inches in 1907 and 17 inches in 1910. The annual precipitation at Spokane is about 18 inches of which less than a fourth occurs during the irrigation season."

In the Bitter Root Valley of Montana, measurements were made on a 40 acre tract of orchard trees. The top soil was a vegetable loam underlaid by a gravel and small cobbles subsoil. In 1900 the 5 year old orchard was irrigated in April, June, July and August. The total depth applied in the four irrigations was about 18 inches and the rainfall during the irrigation season was $1\frac{1}{2}$ inches. In 1901 the 6 year old orchard received four irrigations and the total depth applied was 18.7 inches; the rainfall during the season was 5.9 inches. In 1902 the orchard received 21 inches of irrigation water and the rainfall for the season was 8 inches.

These measurements and others made by the U. S. Department of Agriculture are assembled in the following table.

Net Duty of Water for Orchards.

Locality.	Acreage.	Year.	Duty of water, in acre feet per acre	Remarks.
Wenatchee, Wash............	20	1908	1.92	Coarse soil.
" "	20	1910	2.25	" "
" "	50	1908	1.33	Medium soil.
" "	50	1910	1.45	" "
Spokane Valley System, Wash	..	1905	1.23	
" " " "	..	1906	1.60	
" " " "	..	1907	1.90	
" " " " .	..	1910	1.42	
Boise Valley, Idaho..........	1 farm	....	1.18	
Bitter Root Valley, Mont.....	40	1900	1.50	Vegetable loam
" " " "	40	1901	1.56	underlaid with
" " " "	40	1902	1.77	subsoil of gravel
				and small cobbles.
Average.............			1.62	

This table shows that from 1.23 to 2.25 acre feet per acre were used on these orchards, with an average of 1.62 acre feet per acre or a depth of about $19\frac{1}{2}$ inches. This is equivalent to a net duty of 1 cubic foot per second for 148 acres during an irrigation season of 4 months. Expressed in British Columbia miners' inches, it would be 1 miners' inch to a little over 4 acres.

Professor Fortier, Chief of Irrigation Investigations for the U. S. Department of Agriculture, makes the following statement in Farmers' Bulletin 404, Irrigation of Orchards:

"In general the most water is applied in districts that require the least. Wherever water is cheap and abundant the tendency seems to be to use large quantities, regardless of the requirements of fruit trees. In Wyoming the duty of water is seldom less than at the rate of a cubic foot per second for 70 acres. In parts of southern California the same quantity of water not infrequently serves 400 acres, yet the amount required by the fruit trees of the latter locality is far in excess of the former. In recent years the tendency all over the West is toward a more economical use of water and even in localities where water for irrigation is still reasonably low in price, it is rare that more than $2\frac{1}{2}$ acre feet per acre is applied in a season. This is the duty provided for in the contracts of the Bitter Root Valley Irrigation Company of Montana, which has 40,000 acres of fruit lands under ditch. Since, however, the water user is not entitled to receive more than one-half of an acre foot per acre in any one calendar month, it is only when the growing season is long and dry that he requires the full amount."

"In the vicinity of Boulder, Colorado, the continuous flow of a cubic foot per second for 105 days serves about 112 acres of all kinds of crops. This amount of water if none were lost would cover each acre to a depth of 1.9 feet."

3.—Duty of Water for Alfalfa.

A number of measurements have been made to determine the quantity of water applied on alfalfa fields. In Washington measurements on the Sunnyside project of the Yakima valley gave a net duty in 1909 of 2.79 acre feet per acre. This represents the average for 47,000 acres included in the system, of which about 30,000 acres were in timothy, clover and alfalfa, 10,000 acres in orchard, and the remainder in potatoes. Professor Waller of Pullman, Washington, obtained from measurements made in 1905 on five farms in Washington, aggregating 189 acres, an average net duty of 2.35 acre feet per acre or a total depth of 28.2 inches, the values for the different farms ranging from 21 inches as a minimum to 39.0 inches as a maximum. The average yield was 7.85 tons per acre; the field receiving 39 inches of water gave a yield of 8 tons per acre, and that receiving 21 inches $7\frac{3}{4}$ tons per acre.

In Idaho, measurements made by D. H. Bark in 1910 on five farms in the Big and Little Wood valleys gave the following results:

Net Duty of Water for Alfalfa on Big and Little Wood River Valleys, Idaho.

Locality.	Area (acres).	Kind of soil.	Total depth applied (ft.)	Estimated yield.
Ketchum.......	158.4	Sandy loam, gravelly subsoil.	21.13	3 to $3\frac{1}{2}$
Hailey..........	15.2	Gravelly loam, gravelly and sandy subsoil..............	16.00	3 to 4
Gooding........	51.0	Uniform lava ash soil........	4.80	4
Gooding........	31.8	" " " "........	4.06	4
Gooding........	69.6	" " " "........	4.00	4

The large depths of water applied on the farms of Ketchum and Hailey are due to the amount of water decreed by court being far in excess of the needs of the land; this leads to wasteful and careless use. These amounts are double or triple the amount used upon similar and more porous soils in the upper Snake River valley. The soil absorbed a large quantity of water but retained only a small part of it, the remainder being lost by percolation.

4.—Duty of Water for Potatoes.

Measurements were made in 1905 on four tracts of potatoes in Washington aggregating 27 acres. A mean depth of 17.6 inches of water was used and the yield was 8.5 tons per acre. Other scattered measurements made in various states gived uties ranging from 1.00 acre foot per acre in the San Joaquin valley of California, to 7.8 acre feet in Nevada.

The duty of water measurements give above show the usual conditions obtained on an ordinary irrigation system. The large losses in conveyance which occur from the head of the main canal to the point of delivery on the farm, are shown by the large difference between the gross duty and net duty. The values of net duty of water show the variations in the quantities of water applied not only on different crops but also for the same crop under similar conditions. These variations are due not only to local conditions but largely to the skill used by the irrigator in preventing losses of water and to the value of the water. The decrease of the losses or increase in duty as the water becomes more valuable and the irrigators more skillful, is well shown by the measurements obtained on the Sunnyside project in eastern Washington.

FACTORS INFLUENCING THE CORRECT USE OF WATER IN IRRIGATION.

The net duty of water represents the best use of water only when sufficient water is applied to give the best crop production and when the losses of percolation and evaporation are eliminated as much as practicable by skillful application of water and proper cultivation. An intelligent use of water in irrigation requires a careful consideration of the following principles:

1st. Disposal of water applied to the soil.
2nd. Relation of soil water to soil texture.
3rd. Evaporation of soil water and methods of checking it.
4th. Percolation of water applied to the soil and percolation losses.

1.—Disposal of Water Applied to the Soil.

The water applied to the soil is disposed of in four ways:

1st. Plant transpiration. A useful part is used to produc plant growth. It passes from the soil into the root hairs, from the root hairs into the stem and is carried to the leaves from where it evaporates. This process is called plant transpiration.

2nd. Soil moisture evaporation. A part is lost by evaporation from the soil. This loss will depend on the texture of the soil, the percentage of moisture in the soil, the method of irrigation, the time and frequency of cultivation, the temperature, the humidity in the air, the amount of wind movement.

3rd. Soil percolation. A part is lost by percolation into the soil beyond the reach of plant roots. This loss depends on the character and quality of soil and subsoil, the depth to the water level, the topography of the land, the skill of the irrigator, the efficiency of the distributing system, the length of the furrows.

4th. Surface waste. A part is lost by the waste of water at the ends of fields or furrows. This water passes to the lower neighbor or on the roads where it may do considerable damage. This loss can be prevented by using care.

2.—Relation of Soil Moisture to Soil Texture.

Water may exist in the soil in three conditions: (1) hygroscopic water, (2) capillary water, and (3) gravity water.

Hygroscopic water is that which occurs in all soils not dried by artificial heating. It is the moisture which a soil dried by artificial heat will absorb from moist air. It exists as a very thin film surrounding each particle but is distinguished from capillary water in that it does not move by capillary action or otherwise and can not be absorbed by the plant roots in sufficient quantities to be of any practical value to sustain normal plant growth.

Capillary water is that which exists as a thickened film around each soil particle and partially fills the pore spaces. It is held in the soil against gravity and is not drawn out by drainage. It moves in the soil in any direction, and rises in the soil between the soil particles because of the same action which draws the oil up a lamp wick. Capillary water is of greatest importance to plant growth. It covers the plant roots and is the water on which the growth of plants depends.

Capillary water moves from a wet soil to a drier soil and this is what causes the water to spread laterally and to be drawn from the wetter subsoil to the surface where it is evaporated if the evaporation is not checked by a mulch. The water will rise to a greater height in a soil whose texture is fine than in a soil whose texture is coarse, but the rapidity of rise is greater for a soil of coarse texture than for one of fine texture. For instance, Professor Hilgard found that in a sandy soil the maximum height to which water rose was 17 inches in 6 days, while the maximum height for a clay soil was 46 inches in 195 days. In the sandy soil it took 1 hour to rise 8 inches while in the clay soil it took 12 hours to rise the same height.

Gravity water is that water which moves downwards through the soil pores because of gravity. When the soil is saturated the pores are entirely filled with water and that water which fills the space between the pores not occupied by capillary water, is gravity water. Gravity water is not retained by the soil if there is natural or artificial drainage. It passes downwards and supplies capillary water to the soil below and the excess reaches the water table or a drainage channel. When there is an excess of gravity water, it passes down to a depth which is too far below the ends of the plant to be drawn up by capillarity and is wasted.

A soil which is saturated contains gravity, capillary and hygroscopic water. A soil which is drained contains capillary and hygroscopic moisture only. A soil which is air dried in the sun contains hygroscopic moisture only and a soil which is dried by artificial heat contains no moisture.

Percentage of free moisture in soil for plant growth.

The pores for most cultivated soils will average from 25 to 50 per cent. by volume of the entire volume, being smallest for sandy soils and greatest for clay soils. For plants to grow it is necessary that they have air as well as water and for best growing condition it has been found that the capillary water in the soil should range from 40 to 60 per cent. of the pore space. This leaves about an equal space for air. In other words, for maximum growing condition a very sandy soil containing 25 per cent. pore space should have 10 to 15 per cent. by volume of free moisture, while a heavy clay soil containing 40 to 60 per cent. pore space should have 20 to 30 per cent. by volume of free moisture. Expressed in per cent. by weight, for a very sandy soil air dried weighing 110 pounds per cubic foot, the free moisture content should be from 5.7 to 8.5 per cent.; for a stiff clay soil weighing 75 pounds the moisture content should be 16.6 to 25 per cent. and for an average sandy orchard loam, 10 to 15 per cent. Professor Loughridge found that on a sandy soil where the moisture content in the fourth foot of the soil was 15 per cent. by weight, there was an excess of moisture which crowded out the air and caused the trees to suffer. In this case the correct moisture content should have been about half of the pore space or about 10 per cent. by weight.

The minimum amount of free soil moisture in four feet of soil necessary to keep trees in good growing condition has been found to be from 2.5 to 3 per cent. for apples and prunes, 3 to 4 per cent. for pears, and 1 per cent or even less for apricots and peaches. The irrigator may use these above relations to determine by experiment if his soil has sufficient moisture. The procedure would be to take samples from the soil around the roots and determine the percentage of moisture. This is done as follows: By means of a soil auger take soil samples of each foot of soil beginning with the top soil where the roots begin, which may be 6 inches or more from the surface, down to the depth to which they extend, which may be four or five feet or more. The samples should be immediately placed in a jar to prevent evaporation. A very suitable jar is a glass fruit jar which can be closed air tight. The percentage of moisture is determined by weighing out 100 ounces of the sample before losing any moisture; then spread the sample thinly over a tin plate and expose it to the sun for the greater part of a day or until thoroughly air dried. If the weight is now 90 ounces there was 1 ounce of free water for every 10 ounces of moist soil, which is sufficient for good growing condition. If the weight air-dried had been 97 per cent. it would show that there was only 3 per cent. free moisture and that irrigation was necessary.

Professor Loughridge found from determination of soil moisture in southern California citrus orchards (Bulletin 203, Office of Experiment Stations, U. S. Department of Agriculture) that the percentage of soil moisture for a sandy loam averaged about 4.68 per cent. for the upper 4 feet and 5.76 per cent. for the upper 13 feet before irrigation and immediately after irrigation the percentage in the upper four feet averaged about 9.64 per cent. Six weeks after irrigation the amount of moisture was a little greater than previous to the application of water. About one-fifth of the water applied was retained, the other four-fifths had been taken up by soil evaporation and plant transpiration. For a clay loam soil the percentage of moisture averaged for 5 feet depth of soil, 6.81 before irrigation, 11.27 immediately after irrigation, and one month after irrigation the moisture percentage almost returned to its normal amount before irrigation. On a heavy loam the percentage of free moisture was 5.47 before irrigation and 10.86 immediately after irrigation.

3.—Evaporation of Soil Water and Methods of Checking It.

The effects of the various factors influencing soil water evaporation have been investigated through very interesting experiments made in the arid region by the Irrigation Investigations Office of the U. S. Department of Agriculture, the Agricultural College of Utah, and others. The results were obtained by means of tanks or pots filled with soil and placed as nearly as possible under actual field conditions for irrigation and cultivation. The water applied was measured in each case and loss from evaporation was obtained by weighing the tanks at desired intervals. The results obtained have appeared in the following bulletins: U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 177; Utah Agricultural College, Bulletins 80, 86, 104, 105. While these investigations have been carried on for some time, the results so far published are not sufficient to justify definite conclusions, but the work is being continued and with the additional information very valuable and practical results will be obtained.

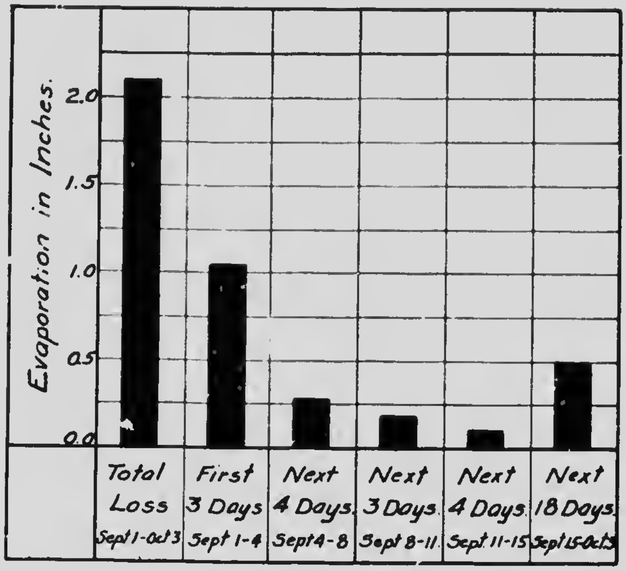


Fig. 15.—Evaporation during a period of 33 days from soil irrigated 6 inches deep, Davis, Cal.

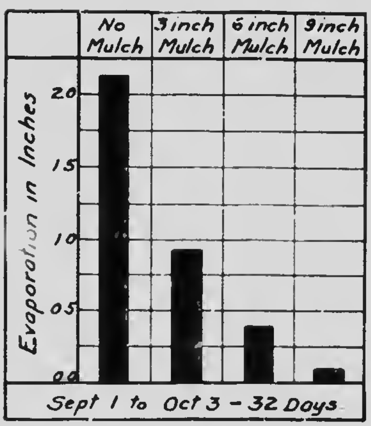


Fig. 16.—Effect of mulches on evaporation from soil, Davis, Cal.

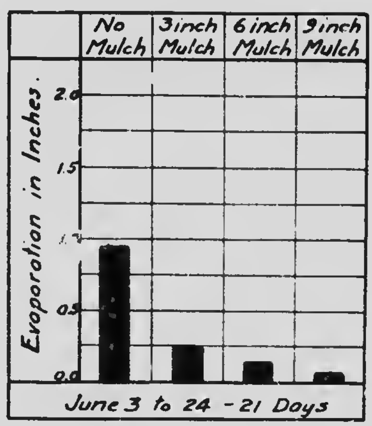


Fig. 17.—Effect of mulches on evaporation from soil, Wenatchee, Wash.

The results already obtained by experiment are of great value in indicating how some of the factors on which the use of water depend can be controlled by the irrigator. These results may be summarized as follows:

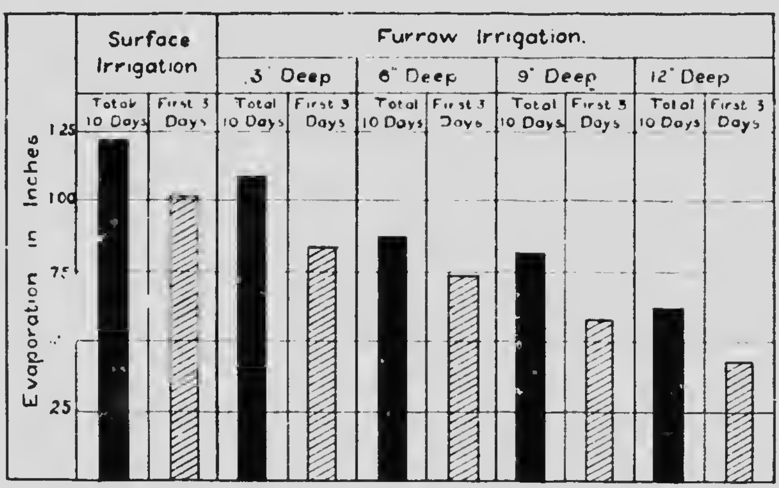
Extent of evaporation from bare soils not cultivated.

On four California orchard soils an average of $12\frac{1}{4}$ inches of irrigation water was applied and the evaporation loss per season (Feb. 23rd to August 31st) was 94 per cent. This shows the large percentage of loss in soil moisture which may obtain during a long season. The rate of evaporation depends much on the moisture in the soil. The results obtained on a sandy orchard loam in southern California are as follows:

For a sandy loam saturated . . . . . . Weekly evaporation was 1.75 in. water
For a sandy loam with 17.5% free water. . . . weekly evaporation was 1.33 in. water
For a sandy loam with 11.9% free water. . . . weekly evaporation was 1.13 in. water
For a sandy loam with 8.9% free water. . . . weekly evaporation was .88 in. water
For a sandy loam with 1.8% free water. . . . weekly evaporation was .25 in. water

The large rate of evaporation from soils which are very wet indicates the necessity for wetting as little of the surface as possible when irrigating. With orchards this may be obtained by using deep furrows.

The rate of evaporation for a period of 33 days following an irrigation 6 inches in depth is illustrated in the diagram given below for a California brown loam soil not cultivated after irrigation (Fig. 45). This diagram shows the excessive rate of evaporation immediately after irrigation when the surface soil is very wet. The loss during the first three days was 17 per cent. of the water used and is about equal to one-half of the total loss during the 32 days which is 35 per cent. These results indicate the importance of preventing the evaporation loss as early as possible after irrigation.



Effect of Depth of Furrows on Evaporation from Soil.

Fig. 48.

Effect of soil mulches on soil evaporation.

The effect of dry soil mulches of different thickness applied on the soil surface after irrigation are shown in the diagrams given below. The first one (Fig 46) is for the California soil whose daily rate of evaporation is given above. The second one (Fig. 47) is for a Wenatchee orchard sandy loam soil typical of the orchard lands of the north central portion of the State of Washington. These diagrams show the effectiveness of different depths of mulches. A 9 inch mulch practically stopped all evaporation.

These experiments represent theoretical conditions which can not be obtained in the field. It is, however, possible to approach these conditions by producing a mulch by cultivation. Conditions more nearly like field conditions were followed in another experiment made in California on a sandy loam soil. In this experiment 8 inches of water was applied to the soil surface in a furrow 4 inches deep. The water was applied during the first two days and at the end of the third day some of the tanks were cultivated 6 inches deep, the others receiving no cultivation. The evaporation loss during the first three days was 10.5 per cent. or .84 inch, during the next three days it was 1.2 per cent. from the cultivated tanks and 3.6 per cent. from uncultivated tanks, showing that the loss from cultivated soil was one-third that from uncultivated soil.

Effect of depth of furrows on soil evaporation.

The experiments made on California orchard soil imitated as much as possible actual field practice. A depth of 5½ inches of water was applied to different pots, on the surface and in furrows 3, 6, and 9 inches deep. The irrigation lasted two days and the soil was cultivated at the end of the third day. The evaporation losses for the first three days and for the next seven days following cultivation were as shown in the accompanying diagram. The loss for furrows 12 inches deep was ½ of the loss obtained with surface irrigation.

4.—Percolation of Water Applied to the Soil.

To obtain maximum benefits from irrigation water the water applied should be uniformly distributed throughout the soil down to the lower end of the roots and any water which passes beyond the capillary reach of the lower ends of roots is wasted. It flows underground either into some drainage channel or may cause considerable damage by the waterlogging and the rise of alkali in the lands below. In actual practice it is impossible to obtain perfect distribution of water and have no waste, but by careful irrigation it is possible to minimize the loss by percolation.

Effect of texture of soil and subsoil on percolation.

When water is applied in irrigation, the soil directly in contact with the water is saturated, a portion of this water moves downwards and wets the soil beneath furnishing capillary water or free moisture to the roots below. If sufficient water has been added, the excess water passes into some drainage channels or down to the level of standing water. This excess water is wasted. This loss by percolation is usually greater in open soils well drained through which gravity water percolates readily and it is very easy for a careless and wasteful irrigator to use a great deal more water than necessary. Some of the waste can not be eliminated because when a soil is irrigated by furrows the upper end of the furrows where the water is turned in receives an excess of water. In some southern California orchards with careful irrigation, it has been found that the water at the upper end of the furrows percolated to depths as great as 30 feet. Where irrigation is practiced less carefully the waste is no doubt still greater. Mr. D. H. Bark, in charge of Irrigation Investigations in Idaho, states that sometimes on porous soils where the water is run long distances, as high as 95 per cent. of the water percolates so deep on the upper one-third of the field that it passes beyond the zone of the roots and is lost. The waste can be minimized by using short furrows.

Sandy soil underlaid with gravel is the most difficult to handle to prevent percolation losses but they may be made small by using frequent irrigation applied in light quantities instead of heavy irrigations, a part of which is wasted, and by laying out the distribution system so that the water does not have to travel long distances in the furrows or over the field.

Percolation of water applied in furrows.

It is important that the irrigator should know how the water applied to orchards in furrows distributes itself within the soil, in order that he may know how far apart the furrows should be, how long they should be and the length of time water should be run in the furrows. The correct practice will vary with the different types of soils and each irrigator should become acquainted with his soil by observing the motion of the water in the soil by means of borings made with a soil auger and trenches dug across the furrows.

Very interesting experiments were made in southern California citrus orchards by Professor Loughridge for the Irrigation Investigations Office of the U. S. Department of Agriculture (Bulletin 203, Office of Experiment Stations). Cross trenches were dug across several furrows to a depth of 5 or 6 feet, the furrows were extended over the trench by short wooden troughs. At regular periods during irrigation a thin slice of soil was cut from the face of the trench exposing a fresh surface of the wet area. The outlines were measured and recorded during and after the period of irrigation. The accompanying diagrams give the percentage of free moisture in the soil and show by irregular curves the depth of percolation at different times.

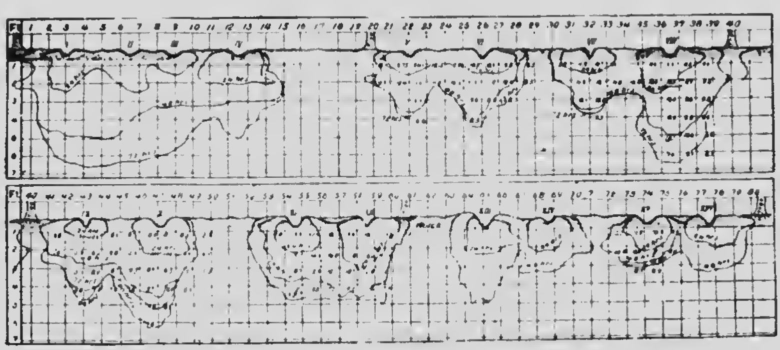


Fig. 19.—Outlines of percolation under sixteen furrows in sandy loam.
(O. E. S. Bulletin 103, U. S. Department of Agriculture.)

The first diagram (Fig. 49) is for a sandy loam soil, 7 to 9 feet deep underlaid with a sandy soil. The observations were made in a trench excavated across sixteen furrows. The furrows were 660 feet long and the trench was half way down the furrows; it required about five hours for the water to travel half the length of the furrows and about 12 hours more to reach the end. This diagram shows results which are very surprising to the irrigator. It is commonly believed that the water spreads laterally so as to give a fairly uniform distribution throughout the soil, but the diagram shows that the water spreads only a small distance laterally, usually less than 3 feet from the furrows, which is not sufficient to wet the soil uniformly. In the first foot 77 per cent. of the soil was wetted, in the second foot 78.75 per cent., in the third foot [illegible]1.13 per cent., in the fourth foot 40 per cent., in the fifth 27.50 per cent., and in the sixth 5 per cent. This shows the necessity for placing the furrows close to the trees and for having sufficient number of furrows to bring them close together.

The next diagram (Fig. 50) is for a gritty clay loam with a subsoil which is very compact, but which quickly absorbs water and becomes soft. The trench was made across five furrows half way down the furrows. At the end of 54 hours the water was cut off. The distribution of water in this soil was much more uniform than in the previous case. This is due to the soil being more compact which produces a slower downward percolation and a greater sideways motion because of the greater effect of capillarity.

The third and fourth diagrams (Figs. 51, 52) show the limit of percolation in a sandy soil from single furrows 10 inches deep and 5 inches deep for a period of seven hours. With the deep furrow there is a greater depth of percolation and the water spreads farther sideways. The deep furrow also has the advantage that less of the surface mulch is wetted than with shallow furrows.

The fifth and sixth diagrams (Figs. 53, 54) show the outlines of percolation in heavy loam for four deep and four shallow furrows under the same conditions of soil and water. The deep furrow gives a more uniform distribution of water, a greater depth of percolation, a greater sideways absorption, and a smaller percentage of moisture rises by capillarity to the surface to be lost by evaporation.

The seventh diagram (Fig. 55) shows the probable distribution of moisture in a sandy loam lengthwise with the furrows, from the head to the foot of the furrows as determined by a few borings. The furrows are 660 feet long and the water was run in them for a period of three days. Sufficient borings were not taken to determine the curve accurately. Other experiments showed that the curve may ascend quite abruptly toward the surface as indicated by the dotted line. This diagram shows clearly that the water is not evenly distributed; the depth of percolation near the head ditch is much greater than the average depth of percolation along the furrow; a large part of the water passes beyond the reach of plant roots and is wasted. With heavy soils the difference in percolation would not be so great. This experiment shows the necessity for short furrows, especially in sandy soils.

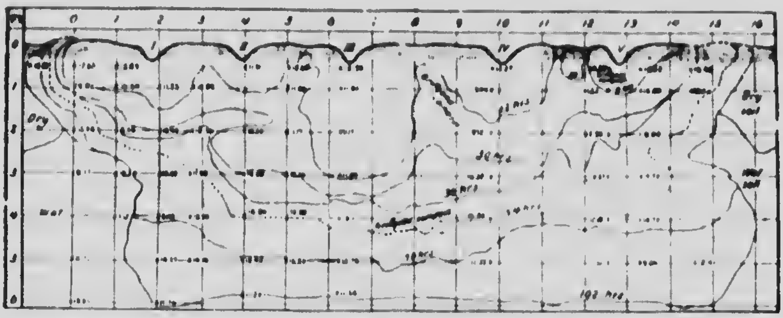


Fig. 50.—Outlines of percolation under five furrows in gritty clay loam.
(O. E. S. Bulletin 203, U. S. Department of Agriculture.)

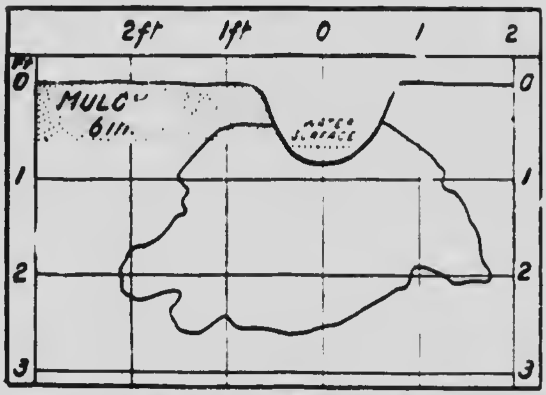


Fig. 51.—Outline of percolation in sandy soil from furrow 10 inches deep in seven hours.
(O. E. S. Bulletin 203, U. S. Dept. Agr.)

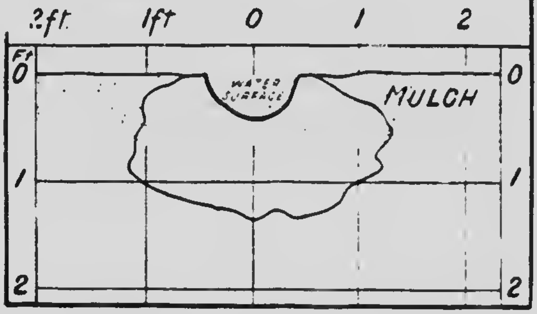


Fig. 52.—Outline of percolation in sandy soil from furrow 5 inches deep in seven hours.
(O. E. S. Bulletin 203, U. S. Dept. Agr.)

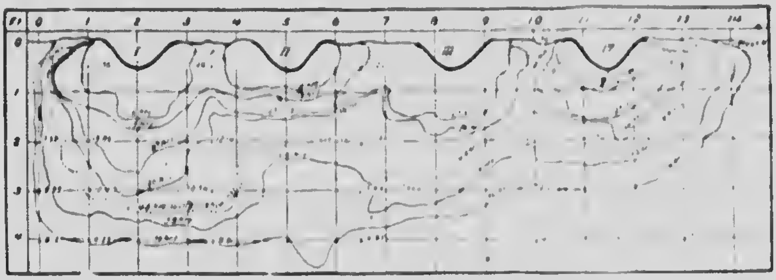


Fig. 53.—Outlines of percolation under four deep furrows in heavy loam.
(O. E. S. Bulletin 203, U. S. Dept. Agr.)

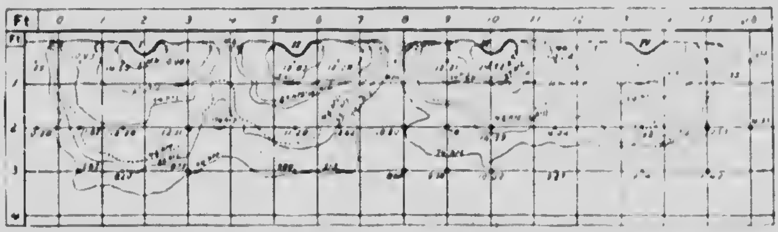


Fig. 54.—Outlines of percolation under four shallow furrows in heavy loam.
(O. E. S. Bulletin 203, U. S. Dept. Agr.)

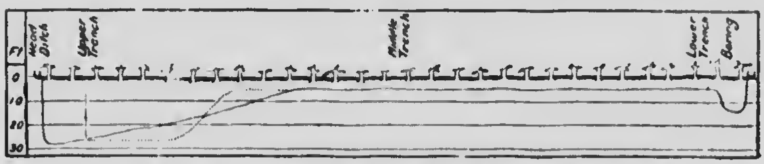


Fig. 55.—Curve showing probable lower limit of percolation from head to foot of furrows in sandy loam.
(O. E. S. Bulletin 203, U. S. Dept. Agr.)

V.—IRRIGATION AND CULTIVATION OF ORCHARDS.

DISTRIBUTION OF WATER.

For the orchards of British Columbia, as well as for other field crops, with the exception of some level lands devoted to growing hay, furrow irrigation is the only feasible method.

The success in obtaining uniform distribution of water by furrow irrigation depends largely on the method used to divide the water equally between the furrows. The earliest method of carrying the water to the head of the furrows is by means of the earthen head ditch located along the upper boundary of the orchard at the upper end of the furrows. The division of the water is effected by cuts made in the side of the earth ditch. This method is still used by many, but because crude and unsatisfactory, it has led some orchardists to adopt improved methods of division such as lath tubes or iron spouts placed in the ditch bank, while some of the best orchardists have replaced the earth ditch by wooden flumes or the more permanent concrete flume or concrete pipe distributing system.

Where the orchard is small and the slope regular, one head ditch or head flume carrying the water from the point of delivery and placed on the highest part of the land to be irrigated, may be all that is necessary. But for larger orchards and for irregular slopes, it is necessary to have two or more head ditches or flumes to which the water is carried by a supply ditch, pipe, or flume. In laying out such a distribution system the irrigator should study the topography of the land and subdivide his orchard with sufficient head ditches to give furrows which are not too long and too steep. Usually it is desirable to make the furrows not over 600 for ordinary sandy loam and 300 feet for more porous sandy soil.

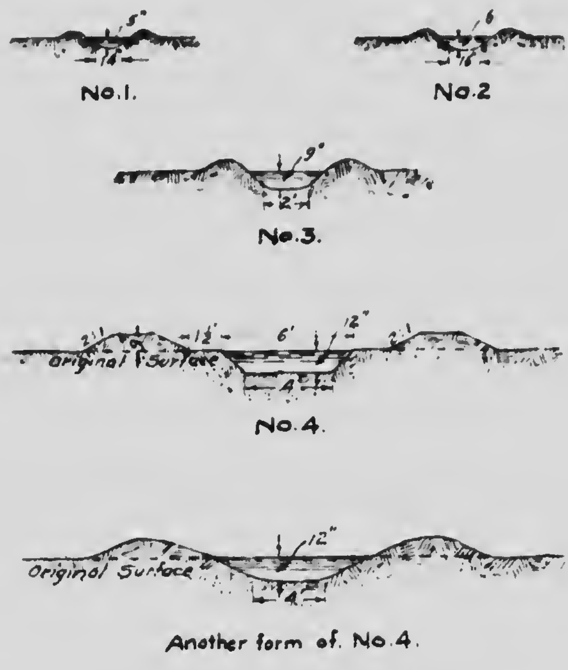


Fig. 56.—Typical forms of earth ditches.

1.—Earthen Head Ditch.

The head ditch is placed along the highest boundary of the orchard or if there is a ridge through the center of the orchard, it is placed on this ridge and supplies the furrows running down the slope on both sides. The proper grade depends on the volume of water to be carried and on the character of the soil; the velocity must not be too great or it will erode the soil. On the other hand it is best to have sufficient velocity to prevent the growth of water plants. Velocities of 2 to 2½ feet per second are desirable. The diagram (Fig. 56) and accompanying table to which has been added the last column, are taken from Bulletin No. 4: Guide to Irrigation Practice on the Pacific Coast, by S. Fortier, issued by the Publicity Committee of the Fifteenth National Irrigation Congress.

Table Giving the Mean Velocity and Discharge of Ditches With Different Grades.

Farm Ditch No. 1.

Grade. Inches per rod.	Grade. Feet per 100 feet.	Grade. Feet per mile.	Mean velocity in feet per second.	Discharge. Cubic feet per second.	Discharge. British Columbia miners' ins.
½	.25	13.33	1.01	.67	24
¾	.38	20.00	1.23	.81	29
1	.51	26.67	1.12	.93	33
1¼	.63	33.33	1.59	1.05	37
1½	.76	40.00	1.75	1.16	41
2	1.01	53.33	2.04	1.35	48
2½	1.26	66.67	2.28	1.50	53
3	1.51	80.00	2.50	1.61	58
3½	1.77	93.33	2.70	1.78	63

Farm Ditch No. 2.

Grade. Inches per rod.	Grade. Feet per 100 feet.	Grade. Feet per mile.	Mean velocity in feet per second.	Discharge. Cubic feet per second.	Discharge. British Columbia miners' ins.
¼	.13	6.67	.82	.80	28
½	.25	13.33	1.16	1.00	36
¾	.38	20.00	1.42	1.30	46
1	.51	26.67	1.64	1.50	53
1¼	.63	33.33	1[illegible]	1.70	60
1½	.76	40.00	2.[illegible]	1.80	64
1¾	.88	46.67	2.18	2.00	71
2	1.01	53.33	2.[illegible]4	2.10	75
2½	1.26	66.67	2.61	2.10	85

Farm Ditch No. 3.

Grade. Inches per rod.	Grade. Feet per 100 feet.	Grade. Feet per mile.	Mean velocity in feet per second.	Discharge. Cubic feet per second.	Discharge. British Columbia miners' ins.
⅛	.06	3.33	.79	2.08	74
¼	.13	6.67	1.13	3.00	106
½	.25	13.33	1.60	4.20	150
¾	.38	20.00	1.97	5.20	185
1	.51	26.67	2.28	6.00	213
1¼	.63	33.33	2.57	6.80	242

Farm Ditch No. 4.

Grade. Inches per rod.	Grade. Feet per 100 feet.	Grade. Feet per mile.	Mean velocity in feet per second.	Discharge. Cubic feet per second.	Discharge. British Columbia miners' ins.
1-16	.03	1.58	.84	4.20	150
⅛	.06	3.33	1.08	5.40	192
¼	.13	6.67	1.51	7.70	274
⅜	.19	10.00	1.89	9.50	338
½	.25	13.33	2.20	11.00	390
⅝	.31	16.67	2.45	12.20	434
¾	.38	20.00	2.69	13.40	475

Ditches of the above forms can be made by first plowing four furrows and then removing the loose earth either with shovels or a narrow scraper, or the loose soil may be thrown up on the sides by using a V scraper or crowder as illustrated below (Fig. 57, 58).

To turn the water into the furrows the water is checked and the water surface raised by placing in the ditch dams of canvas or metal tappoons, or by making dams of earth or manure. When the ditch is permanent a wooden or concrete check gate can be placed in the canal. The greatest difficulty in irrigating from an earthen head ditch is the care necessary to give a satisfactory division of the water in the furrows. A skilled irrigator may adjust the size and depth of openings made in the ditch bank so as to secure a fairly uniform flow in the furrows, but it requires attention to prevent the washing of the soil at some of the openings which will cause greater discharges through these openings and lower the water level in the ditch so that other furrows receive little or no water. To prevent

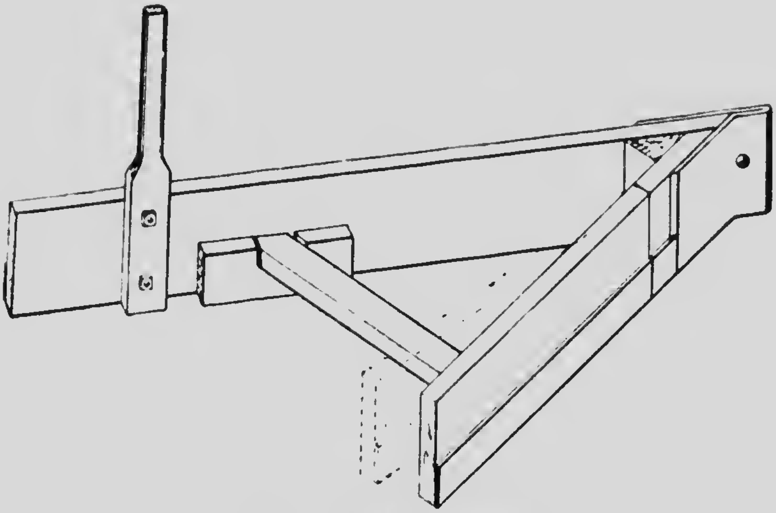


Fig. 57.—Adjustable V crowder.

Fig. 58.—Using adjustable V crowder.

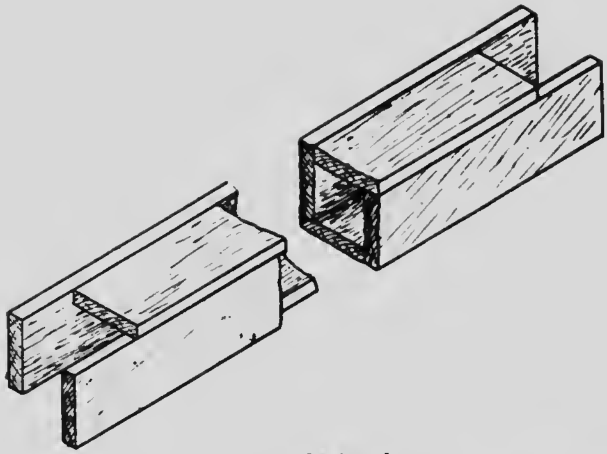


Fig. 59.—Lath tube.

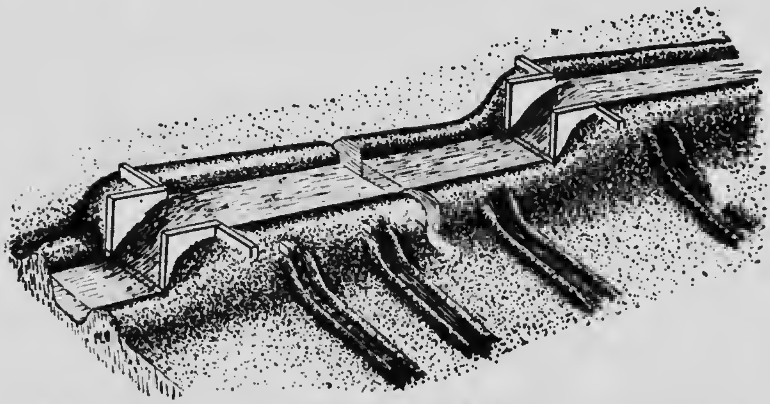


Fig. 60.—Method of placing lath tube in ditch bank for furrow irrigation.
(Farmers' Bulletin 373, U. S. Dept. Agr.)

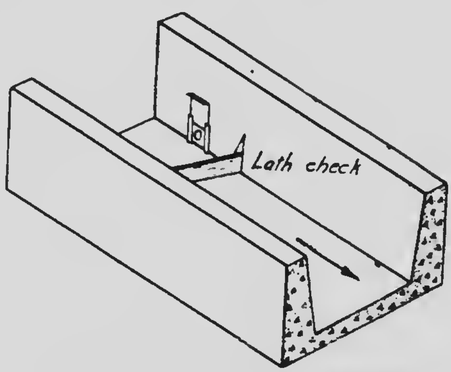


Fig. 63.—Concrete distributing flume.

this some use pieces of sacks or canvas, others use pieces of shingles or small rocks, etc. A better improvement is the use of short tubes placed in the bank of the head ditch. These tubes may be made of laths nailed together and cut in two foot lengths or may be pieces of discarded pipes ½ inch to 2 inches in diameter. A lath tube having an inside opening 1 inch square placed 8 inches below the water level will give a discharge of 1 miners' inch. The flow through the tube can be regulated by a slide. The surface of the water can be kept at the proper height by means of check gates regulated by flashboards and spaced according to the grade of the ditch. The accompanying sketches show the lath tube and the manner of placing them, and also the check gates in the ditch bank. (Figs. 59, 60).

2.—Wooden Head Flumes.

Wooden flumes with small openings in one side give more accurate division of the water and are used very extensively in Eastern Washington. They can also be elevated above the ground to carry water over shallow depressions which is an advantage over earthen ditches. However, the height above the ground must not be over two or three feet or the water falling through the opening into the furrows will cause excessive washing. The flumes usually vary in width from 8 to 12 inches and from 6 to 10 inches in height, and the openings are controlled by metal or wooden slides.

3.—Concrete Head Flumes. (Figs. 61, 62).

The short life of wooden flumes has led most of the orchardists of southern California to use either concrete flumes or cement pipes. A concrete head flume is made of the same form as the wooden flume and galvanized iron spouts or tubes from ¾ to 1½ inch in diameter are inserted in the side of the flume before the concrete has hardened, there being one spout for each furrow (Fig. 63). On steep slopes where the velocity is high, to give an even distribution through the spouts, checks made of short pieces of lath are inserted below each opening as shown in the accompanying sketch. To hold the checks in place, one end of the lath fits into a groove cut in the side of the flume by means of a trowel before the concrete is hard.

The thickness of the floor for all sizes up to 24 inches in width is 2 inches. The side walls for all depths up to 12 inches are 2½ inches thick at the top and 3 inches at the bottom. The flumes are made almost any size. The dimensions and cost of some of the sizes commonly used in southern California are as follows:

Bottom width. Inches.	Depth. Inches.	Cubic feet of concrete per lineal foot of flume.	Cost per lineal foot in cents.
8	11	.54	20
9	12	.60	22
10	12	.63	24
10	14	.66	25
10	16	.69	26
10	18	.71	27
10	20	.74	28
10	22	.77	28½
10	24	.80	29
12	12	.71	25
12	14	.74	26
12	16	.76	27
12	18	.79	28
12	20	.82	29
12	22	.85	29½
12	24	.88	30

Fig. 61.—Distribution of water in furrows from concrete head flume.

Fig. 62.—Concrete distributing flume connected to weir take out box.

The cost of labor and materials for which the above costs were obtained are: Labor $2.00 to $2.50 for 9 hours, cement $3.50 a barrel, and gravel $1.50 a cubic yard.

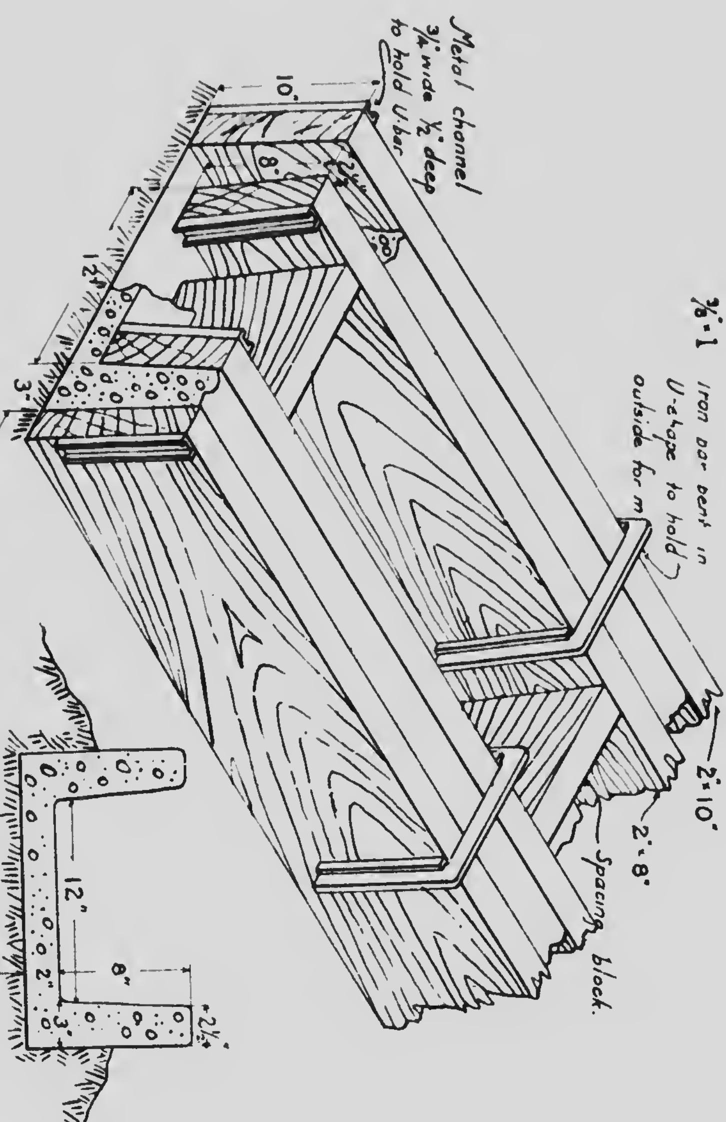


Fig. 61.—Forms for construction of concrete flumes.

The flumes are constructed on the ground by using a set of forms or moulds into which the concrete is placed (Fig. 64). The moulds consist of an inside bottomless trough similar to the form used for lining ditches, but made with the same dimensions as the inside of the flume, and outside walls or sheathing held the proper distance apart from the inside form by means of spacing blocks and heavy U shaped iron, straddling over the outside wall and inside wall. Instead of the U shaped iron, the outside walls could be held in place by stakes driven in the ground. To build the floor and sides at the same time the inside walls are held above the ground by the spacing frames a height equal to the thickness of the floor. The flume is built in sections 12 feet long, which is the length of the forms. No provision is made for contraction and small shrinkage cracks occur. These could be eliminated by inserting at the edges a metal tongue 2 or 3 inches wide imbedded about halfway into each section. This tongue should be well painted with oil or soap to prevent the adhesion of the concrete and it will then act as a tongue and groove joint.

To permit the quick removal of the forms, which is necessary unless sufficient forms are used to build a considerable length at one setting, the concrete is mixed comparatively dry and requires careful tamping. A mixture of 1 part of cement to 5 of well graded pit gravel is generally used. It is important that the concrete be kept moist by sprinkling or otherwise for a period of at least one week. When completed the side walls are partly backfilled with earth up to about one-half of their height. It is better to have the spouts at least 4 inches long and preferably six to prevent the washing away, by the action of the water coming out of the spout, of the soil from under the flume, which will cause it to settle and crack. These galvanized iron spouts are made by local metal workers at a cost of $4\frac{3}{4}$ to $5\frac{1}{4}$ cents each.

I.—Cement Pipes and Distributing Stand Pipes. (Figs. 65, 66).

In southern California many hundreds of miles of cement pipes have been used for the distribution of water to orchards and in recent years its use has been extended to some of the orchards in Washington and Idaho. While many orchardists in southern California still prefer the open flume, there are the following objections to open flume:

1st. Teams and farm implements can not cross the flume and there is always a strip of land on each side that can only be partially cultivated because it can not be crossed in the opposite direction.

2nd. The flume is liable to be damaged by the teams and farm implements.

3rd. The flume may settle and crack if the earth underneath is washed away by the water passing through the spouts into the furrows.

4th. The furrows can only be made with teams and cultivators up to 15 feet from the flume and they must be completed by hand.

5th. Leaves may fall in the flume and stop up either partially or completely the openings of the distributing spouts, which requires extra time on the part of the irrigator.

These disadvantages have led many of the orchardists to the use of underground pipes which do not interfere with cultivation.

A complete underground pipe distributing system consists of.

1st. A main pipe line which carries the water from the measuring box or point of delivery to the lines of distributing stands which take the place of head ditches.

Fig. 65.—Distribution of water in furrows from stand pipe.

Fig. 66.—Line of distributing stand pipes for distribution of water from cement pipe.

2nd. The distributing lines which conduct the water from the main pipe line, and which are connected to the distributing stands

3rd. The distributing stands or basins by means of which the water is brought to the surface and distributed into the furrows through small galvanized iron spouts inserted in the sides of the basin.

4th. Regulating boxes and accessories

A typical system is shown in the accompanying sketch (Fig. 67). The pipe lines are made of hand tamped pipe placed in trenches of such depth that there is at least one foot of earth covering. The method of making the pipe sections and joining them, as well as the properties of the pipe and the cost of making and laying have been fully described (pages 47 to 57.) The main pipe line or feed line is not necessary where only one line of stands is necessary, such as where the orchard is small and can be irrigated with one set of furrows 330 or 660 feet long. But for larger orchards it is desirable that the orchard be supplied by two or more head ditches or distributing pipe lines in order to limit the length of the furrows to not over 660 feet and preferably 330 feet for sandy soil. The main supply pipe feeds the distributing lines and conducts the water from the measuring box or point of delivery to the head of the line of stands. At the junction of the line of stands with the main pipe, turnout boxes with suitable gates are necessary to control the flow into each line. The lines of distributing stands extend across the direction of the furrows. At the head of each tree row and in line with the trees a stand is connected to the distributing line.

There are various ways of making the stands and of regulating the flow. They vary only in details and can be classified into two distinct systems, one known as the overflow system, and the other, the pressure system.

The overflow system is best adapted where the line of stands is placed on a flat uniform grade. The pressure system is best where the slope of the ground is steep and not uniform. These two systems are illustrated in the accompanying diagram (Fig. 68). With the overflow system the lines of stands must usually be divided by means of overflow boxes or pressure regulating boxes into a number of sections depending on the grade, and each section includes a number of distributing stands, the tops of which are placed at the same level. The overflow box acts as a check in a head ditch and by closing or regulating the gate of the overflow it causes the water to rise in the distributing stand and maintains the water surface in the stands at about a uniform level. If the gate of the overflow box is closed the water which is not distributed through the stands above it, passes over the overflow to supply the stands below; this makes the system practically automatic. The distributing stands are seldom made higher than 16 inches above the ground; when it exceeds this a new section or group of stands is made by inserting another overflow box. On steep grade the cost is much increased because of the great number of overflows.

The pressure system, or valve system, is so called because the distributing line is divided into a number of sections, depending on the grade, so that each section is under a water pressure which the pipe will safely stand. Because of the pressure it is necessary to regulate the flow into [illegible] basin by means of a valve. Usually the sections should not be longer [illegible]0 feet and the pressure head should not exceed 15 feet. The boxes w[illegible]h divide the line in sections control the pressure by means of a gate.

The diagram shows the position of this gate which is placed on the upstream or inlet side of the box. The pressure of the water tends to push the gate away from the gate frame and cause leakage. To prevent this the gates, which are named pressure gates to distinguish them from the cheaper slide gates, are so designed that when the gate is closed turning the handle brings the gate tight against its frame. This is obtained through some

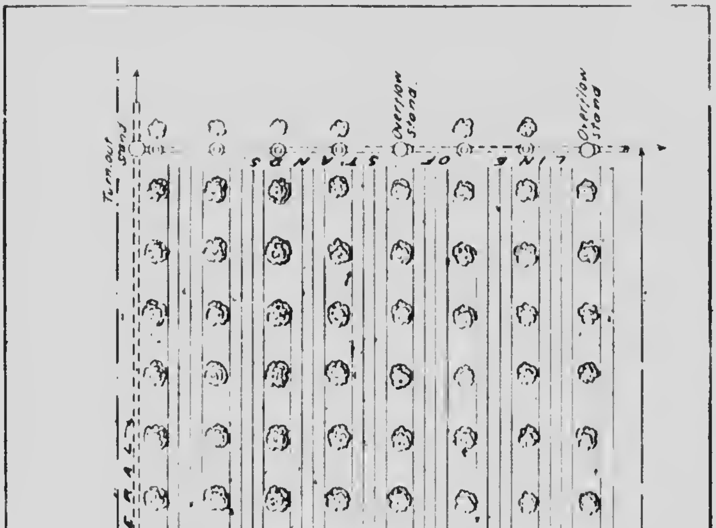


Fig 67 Cement Pipe system of distribution of water for Orchard furrow irrigation.

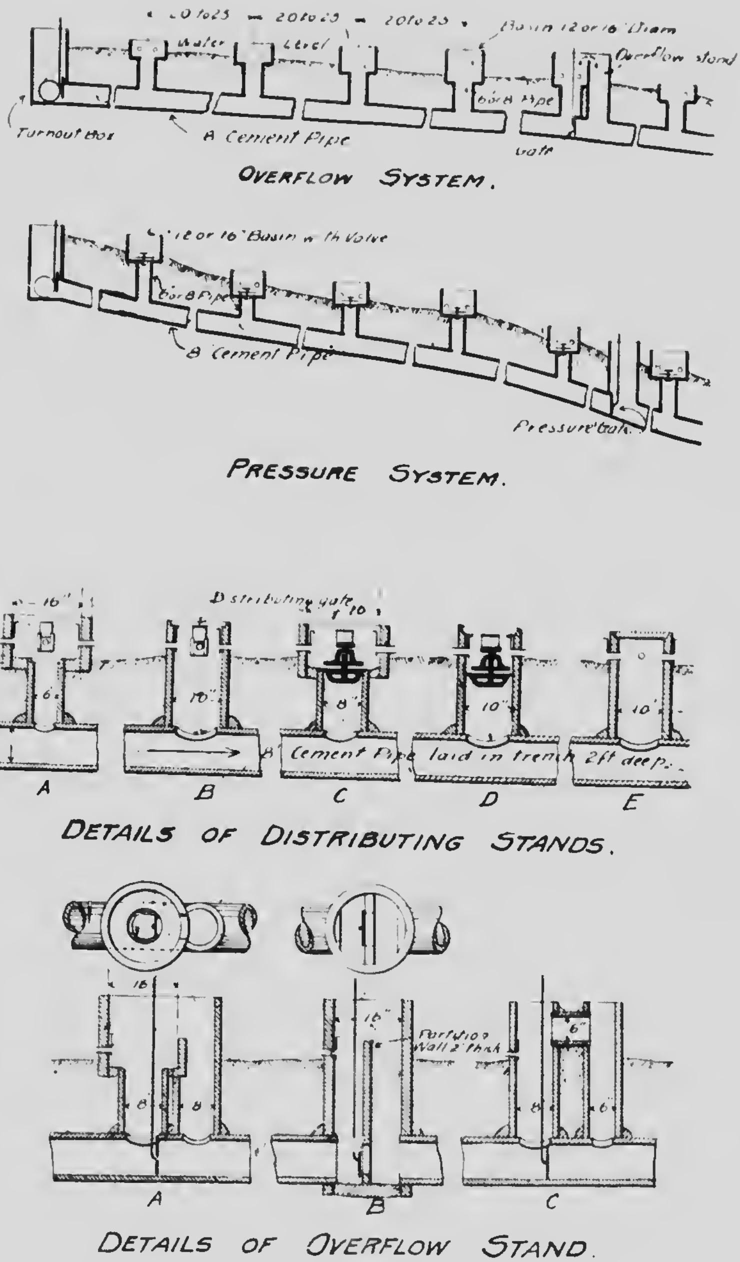


Fig. 68.—Details of cement pipe distributing lines.

mechanical device which varies in construction with the different manufacturers. Instead of using pressure gates, the ordinary slide gate can be used by placing it on the downstream side or outlet to the box, but in this case the box must be built so that its top is higher than the highest distributing stand of the section. This may require a height of 10 or 15 feet above the ground, which is objectionable. The pressure system can be used where the distributing line has to cross shallow depressions. In all cases the line must be divided into sections so that the maximum head will not exceed 15 feet.

Details of stands.

The stands are shown in detail in the accompanying diagram. Stand A, used for the overflow system, consists of a section of 6 or 8 inch pipe placed vertically with the lower end cut to saddle over a 6 or 8 inch hole made in the pipe line by means of a sharp pick. The joint is made with a rich cement mortar mixed in the proportion of 1 part of cement to 2 of sand. Around the upper end of the pipe, at the surface of the ground, is placed the distributing basin and the space in the basin around the smaller pipe is filled with cement mortar. The basin is usually a section 6 to 18 inches long of 16 inch pipe. Around the circumference of the basin, near the floor, from 4 to 6 distributing gates or spouts are inserted and cemented in holes cut as soon as the basin has been made or cast in the basin when making it in the metal moulds.

Stand B is also used for the overflow system and consists of a single length of pipe 8 to 12 inches in diameter in which the spouts are inserted. (Fig. 69). The larger basins of the type A are preferable where the furrows tend to wash together.

Stands C and D are used for the pressure system. They are made as stands A and B with the addition of the regulating valve cemented in the upright pipe (Fig. 70). Stand E. can be used also for the pressure system. It is similar to basin B with the top closed by a cap of cement mortar. This stand requires that spouts be opened from the outside and unless they are properly made, the pressure will cause them to leak. With the other stands the spouts may open either from the outside or inside.

Overflow stands.

Overflow A is ordinarily made of a section of 16 inch [illegible] the top of which is cut an overflow notch 5 or 6 inches deep and 4 inches wide and against this 16 inch pipe and cemented to it is a semi-circular or 2-3 circular section of an 8 inch pipe. The gate in the upstream compartment is a simple slide gate.

Overflow B consists of an overflow wall 2 inches thick built in a 14 or 16 inch pipe. Overflow C is made of two stand pipes connected with a short piece of 6 inch pipe.

Draining the pipes.

In order to empty the pipe to prevent bursting by freezing and also to flush out any silt, it is necessary that at all the lowest points openings controlled by valves or gates be provided.

Accessories.

The accessories needed for a pipe system are: (1) the galvanized iron spouts, (2) regulating gates, which are either the simple cast iron or steel slide gates or the pressure gates, (3) the valves. These devices are made by several manufacturers in southern California and vary in detail. Prob-

Fig. 69.—Construction of distributing stand pipes.

Fig. 70.—Distributing pressure stand pipe, type D.

ably the largest factories are those of Kellar and Thomason Manufacturing Company at Los Angeles, and the Pomona Manufacturing Company at Pomona. The prices given below are for California. The first firm will deliver their appliances at Vancouver for the same prices as quoted for California points and for orders amounting to $1 000, a discount of 10 per cent. is given, but to this the duty of 33 per cent. must be added. No doubt the second firm would give about the same prices.

Cost of Galvanized Iron Distributing Gates.

Diameter.	Price for light weight.	Price for heavy weight.
1 inch	1¾ cents	7 cents
1¼ "	5 "	
1½ "	5¼ "	10 "

Cost of Valves.

No. of valve.	Size of opening.	Price.
5	2½ inches	$ .70
6	2½ "	.75
8	5 "	.85
10	6 "	1.10
12	8 "	1.80
14	10 "	2.75

Cost of Gates.

Size of opening.	Cast iron slide gates.	Cast iron pressure gates.
6	$1.60	$ 3.40
8	1.75	3.85
10	2.50	4.60
12	3.60	5.90
14	4.60	7.85
16	5.70	10.25
18	8.20	12.50

Approximate Cost of Stands in Place.

Type of stand.	Price complete.
A	$1.00 to $1.50
B	.90 to 1.25
C	1.75 to 2.00
D	1.65
Overflow	2.75 slide gate.

5.—Pressure Pipe Lines and Valves.

On some of the orchards in the Okanagan and Grand Forks districts and also on orchards in Idaho and southern California, the water is distributed over the orchards in high pressure, wood-banded pipe lines. The pipe lines take the place of the head ditches; they are tapped at each row or wherever desired by a standpipe formed by screwing in the wood short sections of galvanized iron pipe capped by an ordinary garden valve to regulate the flow. Where the land is very irregular and it is desired to keep the water under pressure, this form of construction is the most desirable and in fact the only feasible one, but if it is possible to break the pressure and maintain it within the safe pressures for cement pipes by proper regulation, the cement pipe distributing system has the advantages of lowest cost, greater durability and better division of the water between furrows.

6.—Laying Out Furrows: Number, Length, Depth and Slope.

The number of furrows varies greatly with the opinion and judgment of the irrigator. For young orchards frequently only two furrows are used for each row of trees, one on each side of the trees. For older orchards usually at least three furrows are used, one on each side of the tree rows and one in the center between tree rows. To obtain a more uniform distribution of moisture, as many as six or eight furrows to each row of trees are used. The present tendency is to use deeper furrows and space them farther apart (Fig. 71). A depth of 8 inches is frequently used. In southern California orchards are usually furrowed with plows attached to the frames of wheeled cultivators in the place of the cultivator teeth (Fig. 72). Furrows 9 inches deep have a bottom width of 10 inches and a top width of 15 inches.

The experiments described under the distribution of water in furrow irrigation gave some interesting results which should guide the orchardist in adopting the best arrangement of furrows. These experiments showed that for a sandy soil with furrows 4 feet apart it took about 24 hours for the water to spread sideways and meet between the furrows; for a clay loam about 12 hours was sufficient. These experiments also showed that for a deep furrow the sideways spread was greater than for a shallow furrow. The sideways spread for sandy loam was limited to about 2 feet on each side of the furrow and for clay loam about 3 feet; this would indicate that the distance apart of furrows should be not over four feet for sandy loam and six feet for clay loam. The furrows on either side of the row of trees should be placed as near as possible to the tree to moisten the soil directly under the tree.

Fig. 73.—Method of laying out zigzag furrows.
(O. E. S. Bulletin 236, U. S. Dept. Agr.)

Fig. 71.—Applying water in deep furrows.

Fig. 72.—Making deep furrows with plows attached to wheeled cultivator.

Fig. 71.—Applying water in zigzag furrows.

Usually the furrows are made parallel to the rows of trees. As the trees grow older it is not possible to get the furrows near the trunk which leaves a space between the trees in a row which is comparatively dry. To wet the soil more uniformly the land is cross furrowed so as to form zigzag furrows around the trees (Figs. 73, 74). The furrows indicated by the dotted lines are first made, then crossed at right angles and the necessary cuts and fills made with a shovel. Because of the greater length, slower velocity and the larger area wetted, the zigzag furrows receive a larger stream. Frequently only the lower half, third, or fourth of the furrows is zigzagged. This will tend to give the lower part of the orchard as much water as the upper part which otherwise receives a greater quantity.

The length of the furrows ranges usually from 330 to 1320 feet, which is the length of a 40 acre tract. As a rule the furrows should not exceed 660 feet and preferably 330 feet. On sandy soil, especially, short furrows not over 330 feet long are desirable; otherwise the upper side of the orchard receives a large excess of water before the lower part has received sufficient.

The grade of the furrows varies widely with the topography or lay of the land. Some orchards on flat valley soils do not permit of a steeper grade than 1 inch to 100 feet while orchards on steep side hills may require placing the furrows on much steeper grades. The proper grade depends much on the character of the soil. On ordinary soil a flat grade of 3 to 6 inches in 100 feet is preferable. On steep hillsides flat grades for the furrows can often be obtained by setting out the trees so that the furrows will run across the slope. Some soils that do not wash badly are irrigated successfully with furrows as steep as ten or twelve feet to the hundred, but usually such grades are excessive and require that very small streams be turned into the furrows and great care taken to prevent washing of the soil. Where steep grades are not avoidable short furrows should be used.

APPLICATION OF WATER.

1.—When to gate Orchards and Quantity of Water to Use.

Most orchardists have their opinion as to when irrigation is necessary. They may be guided by the appearance of the fruits and the leaves, but the best way to determine the necssity for irrigation is by a study of the soil. This is best done by borings or excavating trenches to determine where the roots are and how much free moisture there is in the soil. The method of taking soil samples and the determination of percentage of free moisture in the soil have been explained (page 65). After the o ardist has become familiar with his soil and knows the best percentage of moisture for his trees, he may be able to tell readily by taking a sample of the soil in his hand whether there is sufficient moisture or not.

It has been stated above (page 65) that the minimum amount of free soil moisture in four feet of soil to keep apple trees in good growing condition has been found to be from 2.5 to 3 per cent. by weight. Dr. Loughridge found in his experiments on citrus orchards in southern California that the moisture content in the upper four feet varied from about 4.7 per cent. by weight before irrigation, to 9.64 per cent. immediately after irrigation for a sandy soil, from about 6.81 per cent. before irrigation to 11.27 per cent. immediately after irrigation for a sandy loam, and from about 5.47 to 10.86 per cent. for a heavy loam. The percentage of free moisture

6 weeks after irrigation was reduced by soil evaporation and plant transpiration to about the same or slightly higher than just before irrigation. Based on these figures with irrigation at six week intervals, the percentage of free moisture to add at each irrigation would be about 5 per cent. for sandy loam and 4.5 for clay loam or heavy loam, or about 5 pounds of water to 100 pounds of soil. For a soil air dried weighing from about 100 to 110 pounds, this is equivalent to about 1 inch of water to 12 inches depth of soil. This gives for the correct quantity of water to put in the upper six feet of soil in order to maintain the proper quantity of soil moisture, a depth of about 6 inches of irrigation, applied at six week intervals during the growing season.

These figures are based on results obtained for full grown citrus orchards which in California usually require about twice as much as apple trees or other deciduous trees. Therefore about 3 inches of irrigation water at each irrigation separated by intervals of 45 days should be ample. That this amount may be sufficient for a young orchard at least is shown by the following case in Idaho described by Don H. Bark, in charge of Irrigation Investigations for the U. S. Department of Agriculture. The orchard is a thrifty 5 year old orchard located at Twin Falls where the annual precipitation varies from about 8 to 18 inches. During the growing season of 1910 the rainfall was 1½ inches and the depth of irrigation water applied was about 7¼ inches. The soil was kept well mulched by frequent cultivations and the moisture at the end of the season in the fall was fully as high as at the beginning of the season. This one case is not conclusive but it shows the possibilities of small quantities of water carefully used. The examples of net duty of water on orchards in eastern Washington and Montana given on page 61 indicate the quantities used with ordinary care in irrigation and cultivation. It is interesting to notice that the measurements made on citrus orchards showed that the amount of soil moisture supplied to sandy loam soil was practically the same as for heavy loam soil and clay loam. This is probably true of any soil which is sufficiently deep and not underlaid with a very open sandy or gravelly soil, in which case the soil should be irrigated more frequently and less depth of water applied at each irrigation.

2.—Number of Irrigations Per Season.

The number of irrigations will depend on the capacity of soil to retain water. The orchardist should be guided mainly by the examination of his soil and should try to keep the moisture content within the limits stated above; that is, the free moisture should be between 5 and 10 per cent. of the weight of the soil. For an open soil, well drained, or for a shallow soil, light irrigations applied frequently are best; for a deep retentive soil three to four irrigations 4 or 6 inches deep are ample. The practice in some of the fruit growing districts of Washington, Idaho, Montana and Colorado is described by Professor Fortier in U. S. Department of Agriculture, Farmers' Bulletin 404, on Irrigation of Orchards, as follows:

"In the Yakima and Wenatchee fruit-growing districts of Washington, the first irrigation is usually given in April or early in May. Then follow three to four waterings at intervals of 20 to 30 days. At Montrose, Colo., water is used three to five times in a season. At Payette, Idaho, the same number of irrigations is applied, beginning about June 1 in ordinary seasons and repeating the operation at the end of 30 day intervals. As a rule, the orchards at Lewiston, Idaho, are watered three times, beginning about

June 15. From two to four waterings suffice for fruit trees in the vicinity of Boulder, Colo. The last irrigation is given on or before September [illegible], so that the new wood may have a chance to mature before heavy freezes occur. In the Bitter Root Valley, Montana, young trees are irrigated earlier and oftener than mature trees. Trees in bearing are, as a rule, irrigated about July 15, August 10, and August 20, of each year."

R. W. Fischer, Horticulturist for the Montana Agricultural College, states the following:

"As a general rule, young trees need not be irrigated more than once or twice during a season. Old bearing trees will require from two to four irrigations. Young trees are irrigated about June 15th and possibly July 15th. Old trees are irrigated about June [illegible], July 1, July 20, and August 15th. In connection it may be added that the mean annual rainfall is about 12 to [illegible] inches, about half of which comes in the months of May, June, July and August."

3.—Fall and Winter Irrigation.

Experience shows that irrigation too late in the summer keeps the tree in growing condition and the immature growth is easily damaged by the early frost in the fall. This is one of the causes of winter killing of trees. On the other hand when irrigation is stopped too early in the summer and the soil is not retentive, there is insufficient water to meet the demands of soil evaporation and of tree transpiration during the fall and winter, and the soil becomes too dry for the trees, which are consequently damaged or killed. In many orchards the practice is not to irrigate after the beginning of August. In some cases, especially on porous non-retentive soils, it would be well to irrigate in the fall or mid-winter after the leaves have fallen and when there is no danger of starting a second growth. The proper time for this last irrigation would be in late October or in November and only sufficient water should be added to moisten the soil.

4.—Running Water in the Furrows.

The stream of water or heads used in orchard irrigation depend on the manner of delivering and the depth applied on the land. Some canal companies deliver a continuous flow in proportion to the area irrigated, others deliver the water in turns or rotation and each irrigator receives a larger head than by continuous flow for a portion of the time. The second method is preferable. It lessens the losses of evaporation and seepage, eliminates the waste of a continuous flow when not in use, enables the irrigator to apply the water in a short length of time, and encourages proper application of water.

The heads delivered to the irrigator for orchard irrigation by furrows may range from a few miners' inches to 100 or more miners' inches. For small orchards heads of from ½ a cubic foot per second to 1 cubic foot per second or 20 to 40 miners' inches are desirable. The table below gives the time necessary to irrigate 4 inches deep, different size orchards with different sizes of streams:

Size of stream, miners' inches.	Number of days required to irrigate 4 inches deep, orchards of 5 acres.	10 acres.	15 acres.	20 acres.	30 acres.	40 acres.
5	6 days	12 days	18 days	24 days	36 days	48 days
10	3	6	9	12	18	24
20	1½	3	4½	6	9	12
30	1	2	3	4	6	8
40	¾	1½	2¼	3	4½	6

The number of furrows into which the irrigating head may be divided will depend much on the character of the soil and grade of furrows. In some cases one half a miners' inch or even less may be run into each furrow while for some sandy soils it is necessary to use 3 or 4 miners' inches in order that the water will reach the lower end of the furrow and not be all absorbed at the upper end. On tight soil a small stream must be used in order that it will run slowly in the furrows and give time for the water to percolate into the ground without a waste at the lower end. To prevent the upper end of the furrows from receiving too much water it is always desirable to begin with a large stream into each furrow and rush the water to the lower end, then reduce the size of stream to obtain an even distribution.

With furrows 330 feet long, 6 feet apart, and a British Columbia miners' inch to each furrow, the time which the water must run to give an average depth of water on the soil of 6 inches is about 10 hours. Depending on the nature of the soil and length of the furrow, the time the water is run into the furrows varies from 4 to 48 hours. Prof. R. W. Fischer, of Montana, found that on the clayey loams of the apple orchards on the east bench of the Bitter Root River, it requires from 12 to 18 hours to moisten the soil in furrow irrigation, 4 feet deep and 3 feet sideways.

5.—Prevention of Losses of Water Applied; and Cultivation.

The losses which occur in the application of water to the soil are:

1st. The losses due to unequal distribution of water in the soil caused by deep percolation and waste at the upper end of the fields, unequal division of water between furrows, and excessive use of water which is not retained by the soil.

2nd. Loss from neglect, because of careless irrigation which allows waste in the low places and at the ends of the furrows, causing injury to roads and adjoining orchards or farms.

3rd. Loss by evaporation of the water in the furrow itself and especially of the soil moisture from the wet soil.

The remedies to minimize the losses due to unequal distribution of water in the soil and the waste due to deep percolation have been fully discussed in the preceding pages. The loss from neglect can be largely prevented by care. The losses due to evaporation can be lessened by applying the water in deep furrows and by thorough cultivation.

Irrigation with deep furrows places the water well below the surface and does not wet the surface soil to the same extent as with shallow furrows; this decreases the evaporation loss and permits cultivation of the orchard soon after irrigation. It also encourages deep rooting which is always desirable except where the soil is very shallow.

Cultivation is one of the most important factors not only to prevent evaporation, but to improve the condition of the soil. To prevent evaporation the soil should be cultivated immediately after each irrigation. Professor Fischer, Horticulturist for the Montana Agricultural College, states that as a general rule orchards should be cultivated every ten days during the growing season until about August 1st. Cultivation should stop at that time, especially in young orchards in order to induce the trees to mature, thus putting them in better condition to endure freezing temperatures in the early fall and winter. He describes the process of cultivation in Montana as follows:

"Orchard soils are usually plowed in the spring during April or early May. This plowing may be done with a two horse team using a fourteen inch plow. The plowing should be from six to eight inches deep. The soil is turned towards the trees one year and away from them the following year. The last one or two furrows near the trees can be plowed with a one horse eight inch plow plowing only from four to six inches deep so as not to interfere with the roots near the trunk. On soils that work easily it is sometimes possible to cultivate the soil deep enough with the disc harrow, thus doing away with the spring plowing. After plowing the land should be smoothed using a smoother or leveler. After smoothing the soil is cultivated with a spring tooth harrow going at least two ways in the orchard. This is followed with a spike tooth or smoothing harrow."

A deep granular mulch 6 to 8 inches thick is much more effective for deep soils than one only 3 or 4 inches thick. If thorough cultivation is practiced, frequent irrigation is not necessary. Irrigation water can not take the place of frequent and thorough cultivation. The effects of irrigation in furrows of different depths and of mulches of different thickness have been determined quantitatively by the experiments previously described (pages 68 to 72).

VI.—IRRIGATION OF POTATOES.

1.—Selection of Soil.

Potatoes are grown very profitably in many of the irrigated districts. They may be grown separately as a commercial crop on land devoted to this purpose, or they may be planted between tree rows in order to obtain some income from the land while the trees are young and for this purpose they are preferable to deep rooted plants which are always more or less detrimental to the proper growth of an orchard. They can also be grown on land which is to be planted in fruit trees, for the purpose of improving the texture of the soil.

Potatoes which are grown on orchard soils either prior to planting the orchard or while the trees are young, can not be expected to give as large yields as obtained on soils which are selected for the purpose of growing potatoes. Orchard soils are not always well suited for large yields of potatoes. This is especially true of a soil which is deficient in organic matter, but the continuous cultivation, the irrigation and the digging up of the soil when harvesting the crop in the fall will very much improve the condition of the soil.

When potatoes are to be grown separately and for the chief purpose of obtaining maximum production, the soil should be carefully selected and given proper treatment. The best soil is a sandy loam of fairly porous soil, well drained, with sufficient humus or decayed organic matter to put it in good condition and increase its power to retain moisture.

2.—Treatment of Soil.

To otbain heavy yields sandy soils must usually be prepared by growing a foundation crop which will add humus to the soil. The best crops for this purpose are alfalfa, clover, and peas. To keep the land in good productive condition the rotation of crops is usually advocated. A common practice in Colorado is to grow either clover or alfalfa for two years, potatoes for two years, and grain or peas for one year; this last crop is sometimes omitted.

Where alfalfa is the foundation crop it is rather difficult to plow it up. This is usually done by plowing the alfalfa when it is blooming, first shallow to a depth of 3 or 4 inches, in order to turn over the plant and cut off the crown at that depth to expose the roots to the sun. This is followed by a deep plowing in the fall which leaves the land in good condition for the potato crop.

New land is broken up in the fall previous to growing crops by plowing deeply and allowing it to stand in that condition until spring when it is either worked up by a shallow plowing 4 to 6 inches deep and then harrowed, or simply pulverized and worked up with a disk or spring tooth harrow.

3.—Planting Potatoes.

The time of planting varies with climatic conditions and the kind of potatoes. Early potatoes are planted in the spring as soon as the frost is out of the ground and when there is no danger of late hard frosts. Late potatoes may be planted as late as the middle of June, but usually earlier is more desirable, especially where there is a deficient water supply in the late summer.

The depth of planting depends on the condition of the soil and the kind of potatoes. Early potatoes planted in moist retentive soil are placed 2 to 2½ inches deep; where the soil is not retentive and is dry, or where there is danger of heavy frost, 4 inches is better. The rows are spaced 36 to 42 inches apart and the hills in the rows 12 to 15 inches apart; on rich land they may be placed as close as 8 inches apart.

The seed may be either whole or cut. Good size seed must be used. In Colorado medium size whole seed as large as two ounces is preferred. Four ounce potatoes are cut in two and six ounce potatoes in three. Potatoes raised on irrigated land are not considered the best for seed, and dry land seed from Wisconsin, Minnesota or from non-irrigated land of Colorado, are generally used in that State. It is important that the seed be properly selected. A uniform size is desirable. Seed averaging 1½ ounces in weight and spaced 12 inches apart in rows spaced 40 inches apart will require about 1200 pounds of seed to the acre.

For small areas the seed is placed in the furrow and pressed by hand, then covered with plow or harrow. For large areas mechanical planters drawn by a horse are used. They will open the furrow, place the seed, cover it, and pack the soil.

4.—Cultivation.

The cultivation should begin soon after planting. The first cultivation between the rows which are indicated by the tracks of the planter, begins a week after planting. This cultivation should be 8 or 10 inches deep in order to well aerate the soil and kill the alfalfa which may have a tendency to sprout again. The cultivator drawn by two horses, has four shovels, two for each side of the row; they are 4 to 5 inches wide and 14 to 15 inches long. The cultivator is followed by a harrow. Cultivation is continued with the harrow passed over the land in both directions once a week, if possible, until the plants are 5 or 6 inches high. Shallow cultivations after each irrigation until the plants cover the ground is desirable.

5.—Quantity of Water Required for Potatoes.

Experiments made by the Agricultural College of Utah on the relation of yield to quantity of water used, gave the following results:

Locality.	Depth of water applied in inches.	Yield in bushels per acre.
Salt Lake County......	7½	210
	10	217
	11¾	258
	16¼	270
	20½	265
Morgan County.........	17¾	257
	19¼	323
	19¾	227
	21½	250
	25½	282
	26	205
Experiment Station Plat	9	121
	15	217
	20	416
	27	362
	40	523

The above results show that 16 to 20 inches of water will give a yield nearly as great and in some cases greater than a larger quantity. This is also corroborated by measurements made by D. H. Bark in Idaho in 1910. The results obtained are given below.

Number of irrigations.	Date of first and last irrigation.	Total depth applied in inches.	Yield, tons per acre. Marketable.	Culls.	Total.	Percentage marketable.
3......	May 13-July 15	10½	2.16	.99	3.15	68½
5......	May 13-Aug. 9	18	1.40	1.56	5.96	75
6......	May 13-Aug. 18	24½	3.93	2.54	6.47	61

These potatoes were planted June 1st and 2nd at the rate of 1,000 lbs. to the acre on fall plowed land which had been in grain during the season of 1909. The land received one irrigation before planting. The water was applied in deep furrows 220 feet long and the land was cultivated six times. Mr. Bark states that the yields were very unsatisfactory owing to the poor stand secured, but it is thought that the amounts applied would have been sufficient for maximum crops had the stand been good.

While these experiments are not conclusive, they are of value in showing that the bigger yields are not always obtained with the largest quantity of water and that above a certain depth of water the increase in yield, if any, is small as compared to the increase in quantity of water applied. The yield does not depend entirely on the quantity of water applied but on the time of application and the care in planting and cultivation.

6.—Time to Irrigate.

Soil which is moist and retentive does not need any irrigation before planting, but for dry soil or for late planting one irrigation before planting followed by cultivation, is necessary. During the first stages of growth thorough cultivation is more important than irrigation and no irrigation may be necessary until July. The number of irrigations will vary from two to four for ordinary sandy loam, but on porons, sandy soil or on shallow soil which does not retain moisture, five or even six shallow irrigatins may be preferable. Frequent irrigation, especially early in the season when the water is cold, will retard the growth. The moisture in the soil should be kept fairly uniform until the tubers begin to form, when a large quantity of water is required. The need of irrigation may be indicated by the appearance of the plants such as the darkening of the leaves, or preferably by an examination of the soil under the surface where the tubers form. The soil is in good condition when a ball of earth squeezed in the hand will retain its shape.

The last irrigation should be applied before the growth of tuber ceases in order to give about one month and a half to two months for ripening in dry earth. Where potatoes are grown between tree rows, late irrigation and cultivation after the first of August will keep the orchard in growing condition too late in the fall and will not give the wood sufficient time to mature before the first hard frosts.

7.—Method of Irriagtion.

Potatoes are irrigated by furrows made midway between the rows. The furrows are made by a double mouldboard plow which forms a V trench, the bottom of which should be about 6 to 12 inches below the crown of the plant. The length of the furrows should not be over 200 or 300 feet for porous sandy soil and not over 500 to 600 feet for more retentive loam. Greater lengths give unequal distribution of soil moisture with an excess or waste at the upper end due to deep percolation.

A common practice in Colorado is to open alternate furrows for the first irrigation, and for the next irrigation open the furrows in the intervals between rows which were left unopened in the first irrigation. For more than two irrigation the alternation is repeated.

The division of water between furrows, the size of the stream delivered to each furrow, the length of time the stream is run into the furrows, are the same and controlled by the same factors as the irrigation of orchard and alfalfa by furrows previously described.

Potato vines are shallow rooted and the frequent application of cold water no doubt retards their growth; for this reason some irrigators prefer to apply the water at night when the soil and water have had all day to warm up in the sun. This practice also has the advantage that the loss of moisture by evaporation is decreased. Many growers object to night irrigation because of the night work necessary to distribute the water. However, this may be cut down to a minimum by a proper preparation of the ground and the regulation of the water delivered to the furrows by placing spouts in the banks of the head ditch at the head of each furrow or by using for the head ditch a flume with auger holes as described for orchard irrigation.

Additional information on the agricultural phase of potato growing may be otbained by consulting the following bulletins:

Potato Investigations, Bulletin No. 94, Agricultural Experiment Station, Pullman, Washington.

Potato Culture on Irrigated Farms of the West, Farmers' Bulletin 386, U. S. Department of Agriculture, Washington, D. C.

VII.—IRRIGATION OF ALFALFA.

The value of alfalfa as a forage crop and as a foundation crop for orchards or potatoes to be grown on soils lacking fertility, make it desirable that information on the proper methods of irrigation of this crop be included in this bulletin. The growing of alfalfa is not widespread in British Columbia, but its rapid spread in almost every state of the United States makes it reasonable to expect that it will become a more important crop

1.—Methods of Irrigation.

The methods of irrigation given for alfalfa will apply to practically all forage crops as clover, peas, etc. Because of the rolling character of most of the irrigable land of British Columbia, the method best adapted to the irrigation of alfalfa is the furrow method, almost universally used in the Yakima Valley of eastern Washington, and often spoken of as the Yakima or corrugation system. Another system adapted to rolling land and used extensively in the Rocky Mountain states—Colorado, Montana, Wyoming and Utah—is known as the flooding method. It consists in running small parallel ditches through the fields, 50 feet to as much as 200 feet or more apart, and running the water over the bank of the ditches down the slope of the fields. This method requires an irrigating head of from 40 to 100 miners' inches or 1 to 2½ cubic feet per second and is more wasteful than the corrugation method. The other methods of irrigation commonly used are known as the border method and the check method. These are adapted only to comparatively level land and require large heads of water. Only the first method will be described as it is the one best adapted to most of the irrigable land of British Columbia. The other methods are fully described in Farmers' Bulletin 373 on Irrigation of Alfalfa, which can be obtained from the U. S. Department of Agriculture, at Washington, D. C.

Furrow method of alfalfa irrigation.

The water is run in shallow furrows from which it spreads laterally and moistens the soil on each side. The laying out of the head ditches or flumes, the length and slope of the furrows, and the application of the water is much the same as for orchards. The farmer often makes his furrows too long in order to avoid many head ditches. This is poor practice for it causes unequal distribution of water with a loss by percolation at the upper end of the furrows. It is best to plan the distribution system so

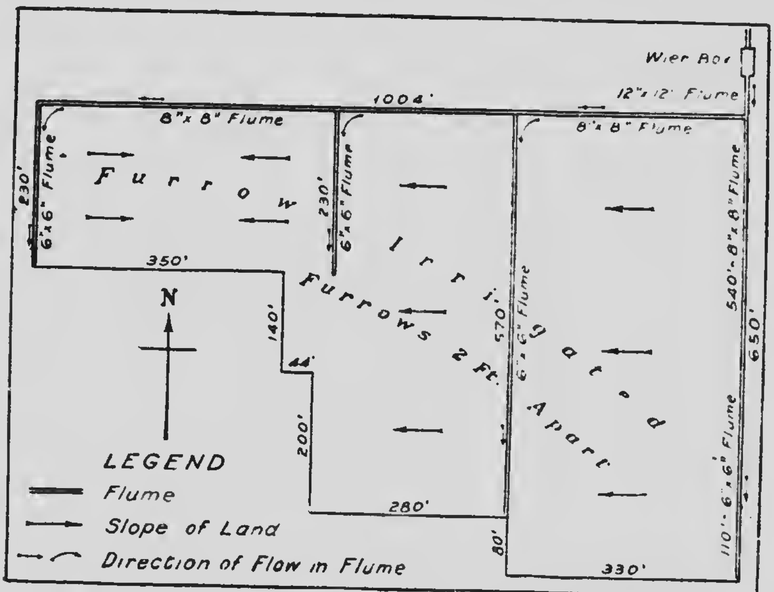


Fig. 75.—Distribution system for ten acre tract, Kenewick, Wash.
(O. E. S. Bulletin 188, U. S. Dept. Agr.)

that the furrows do not exceed 660 feet for ordinary loam soils and 330 or even 220 feet for porous sandy soils. This requires that the field be cut up by two or more head ditches or head flumes fed by the supply lateral. A typical wooden flume distribution system for an alfalfa field at Kennewick, Washington, is shown in the accompanying diagram (Fig. 75). The furrows are made 3 to 6 inches deep, about the same width, and spaced from 18 inches to 4 feet apart, depending on the character of the soil. The furrows are commonly made by the use of a marker or furrowing sled which may be a rough implement made of logs fastened together and spaced the right distance apart, but preferably made of timber as shown below (Fig. 76). This leaves a smooth furrow without clods to interfere with the flow.

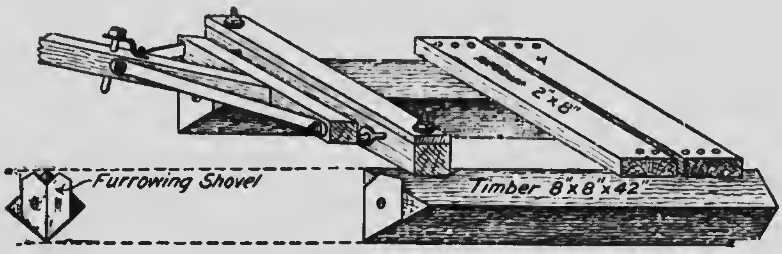


Fig. 76.—Furrowing Sled.
(Farmers' Bulletin 392, U. S. Dept. Agr.)

The water is divided and distributed into the furrows from the head ditch or flume as for orchard irrigation, usually from spouts placed in the ditch bank or from holes bored in the side of the flume. At first a larger stream is turned into each furrow to rush it through to the lower end and then the opening is regulated to give a small stream which is allowed to run 12 to 24 hours for furrows 330 to 660 feet long and 24 to 48 hours for furrows 660 to 1320 feet long. For porous soil a larger stream for a shorter time should be used. With furrows 2 feet apart and 330 feet long it will require about 1-5 miners' inch to each furrow, running for 24 hours, to give a depth of 9 inches of water on the land. The practice in the Yakima Valley is to make the furrows 18 inches apart when the land is first seeded and to abandon every other one after the plants are well rooted.

2.—Amount of Water Required.

The duty of water measurements given for alfalfa (page 62) show the great variations in quantity of water applied by different irrigators in different localities. These quantities do not give any idea of the correct quantity of water to use. The maximum yield of alfalfa obtainable in any case will depend not only on the quantity of water used, but on the time when it is applied. When properly applied it has been found that different quantities of water will give different yields but that the increase in yield is not in direct proportion with the increase in quantity of water applied and there is no doubt for every particular case, a depth of water which will give a maximum yield and any quantity applied above that is not only wasted but decreases the yield because of the excess moisture in the soil. Professor Fortier in 1903, when director of the Montana Experiment Station, made experiments on seven plats of alfalfa to determine the relation between quantity of water applied and yield. The results obtained are given in the following table taken from U. S. Department of Agriculture, Farmers' Bulletin 373 on Irrigation of Alfalfa.

Quantities of Water Applied to Alfalfa and Yields Secured, Montana Experiment Station.

Plat number.	Depth of irrigation.	Depth of rainfall.	Total depth.	Yield per acre of cured alfalfa
1..........	.5 ft.	.70 ft.	1.20 ft.	1.61 tons
2..........	None	.70	.70	1.95
3..........	1.0	.70	1.70	4.12
4..........	1.5	.70	2.20	3.77
5..........	2.0	.70	2.70	6.35
6..........	2.5	.70	3.20	7.20
7..........	3.0	.70	3.70	7.68

Mr. Alex. McPherson, Secretary of the Idaho Board of Horticultural Inspection, states that in southern Idaho 24 inches of water applied produced the maximum crop of alfalfa amounting to seven tons of baled hay, while thirty-six inches produced six and one-third tons; besides the field was damaged to some extent by excessive use of water.

Mr. Don H. Bark, in charge of Irrigation Investigations in Idaho, has carried on during the past two seasons some very interesting experiments on the water requirements of plants and duty of water. The method used was to select fields averaging about 15 acres on typical farms of the state. These fields were divided into three equal parts. On one part the owner used the same manner of irrigation and same quantity of water as had been his usual custom. On the second part a greater amount was used and on the third part, a smaller amount. The water was carefully measured and the yields weighed to determine the amount giving the greatest yield. The results obtained for the different crops, grain, alfalfa, and clover, are given in the Eighth Biennial Report of the State Engineer of Idaho.

The only experiment for red clover was made on a two year old clover field with very sandy and gravelly soil. Below 2 feet from the surface and extending to a depth of at least 100 feet, the subsoil was of 35 to 40 per cent. sand and 60 to 65 per cent. coarse gravel. The water table was 55 feet from the surface. The field was irrigated by flooding, the water being run over the surface distances from 910 feet to as much as 2359 feet. The results obtained were as follows:

Number of Irrigations.	Total depth of water applied.	Yield per acre.
7	6.92 feet	3.78
9	8.40	4.85
10	11.74	1.60

The greatest yield was obtained with the medium amount of water. But in all three cases the quantities used are very large and include a waste due to the very open character of the soil and to the long distance the water is run. A large proportion of the water is lost by deep percolation, especially at the upper end of the field. The waste could be lessened by running the water shorter distances, preferably less than 500 feet.

The experiments for alfalfa were made on a variety of soils. A very sandy and gravelly soil, very similar to the above, was irrigated in the same manner, the water being flooded distances from 1979 to 2550 feet. Alfalfa five years old gave the following results:

Number of irrigations.	Total depth of water applied.	Yield per acre.
4	6.35 feet	3.78
6	6.92	2.65
7	9.10	5.2

The greatest yield was obtained from the greatest amount of water. In this case also water was flooded much too far and the loss by deep percolation is no doubt very great. The waste could be very much lessened by using frequent light irrigations and shortening the distance the water has to travel. Because of the waste in both of the above gravelly soils, these results do not represent the correct quantity of water to use.

On a very sandy loam of fine texture down to a depth of 6 feet or more, the yields obtained for four year old alfalfa were as follows:

Number of irrigations.	Total depth of water applied.	Yield per acre.
3	1.61 feet	4.11
5	2.65	4.28
7	1.82	4.57

The field was well prepared for irrigation. The yields were nearly the same for the different depths of water applied.

For a clay soil 6 feet or more deep with a thin layer of hardpan 2 or 3 feet below the surface, the yields of an alfalfa field 5 years old were:

Number of irrigations.	Total depth of water applied.	Yield per acre.
8	1.89 feet	4.00
8	2.85	3.66
9	3.45	4.37

While the yield was greatest for the largest quantity of water used, it was not much greater than that obtained where the smallest quantity of water was used.

On a clay loam of the same character as the above clay soil the yields from a one year old alfalfa field were:

Number of irrigations.	Total depth of water applied.	Yield per acre.
7	1.13 feet	2.85
7	2.11	1.93
7	2.25	4.35

The results obtained from these experiments show that on gravelly soil a much larger quantity of water may be used than on more retentive soil. But the quantities used do not represent the amount of water required for they include large losses due to deep percolation which can be very much reduced by running the water shorter distances and using light irrigation applied more frequently. As a rule the yield seems to increase with the quantity of water applied, but the increase in yield in most cases is slight for a considerable increase in quantity of water and in some cases a greater yield was obtained with the smaller quantity.

The U. S. Department of Agriculture has made experiments on thirty plats of alfalfa at the University Farm at Davis, California, to determine the best use of water on alfalfa. The yields obtained for varying amounts of water are as follows:

Depth of water applied.	Yield in tons per acre In 1910.	In 1911.
None	1.08	6.03
12	1.79	7.52
24	6.43	8.38
30	8.09	9.50
32	....	9.20
36	7.60	9.33
48	8.45	9.65

The plants were two years old in 1910 and three years old in 1911. The rainfall during the fall, winter and spring preceding the summer of 1910 was about 12 inches, and preceding the summer of 1911 it was about 22 inches. The rainfall during the growing season from the beginning of April to the end of October in both years was less than 1 inch. The soil was a sandy loam of great depth and the substantial yields obtained without irrigation show the power of this soil to retain the moisture produced by the winter and spring rains. The results show that the yield increases materially with an increase in the amount of water applied up to 30 inches, which gave a greater yield than 32 or 36 inches and almost as great as 48 inches.

The experiments made in Montana, Idaho and California, described above seem to indicate that 30 inches of water carefully applied will give almost maximum yields. While greater yields may be otbained by adding greater quantities of water, the increase is only small and will in most cases not pay for the extra water. Where water is valuable it may be more economical to use even less than 30 inches. The best practice in southern California where water is valuable compares closely with the experiments mentioned. At Pomona, California, the rainfall for 1903-4 was about 9 inches; the quantity of water applied by pumping averaged 2.3 feet in depth and the yield of cured hay averaged 1 to 1.5 tons per acre per cutting, five or six cuttings being common.

3.—Number of Irrigations.

Where there is sufficient moisture in the soil due to rainfall no irrigation may be necessary for the first crop. For each succeeding crop it is common practice to apply one irrigation either before or after cutting. On gravelly porous soil and on shallow soils, two or even three irrigations for each crop may be preferable. Irrigation before cutting is the custom in the Yellowstone Valley of Montana. It has the advantage that the soil being shaded by the plant, the evaporation of soil water is decreased. It also tends to prevent baking of the soil and permits an earlier irrigation for the last crop, which is an advantage if the available water runs short before the end of the season. The disadvantages of irrigating before cutting are that the plants interfere more or less with the distribution of water and that the soil may take considerable time to dry out sufficiently to permit harvesting. For these reasons many irrigators prefer to irrigate after each cutting.

4.—The Proper Time to Irrigate Alfalfa.

Farmers' Bulletin No. 373 on Irrigation of Alfalfa, written by Samuel Fortier of the U. S. Department of Agriculture, gives the following information on the proper time to irrigate alfalfa winter irrigation, winter killing and seeding of alfalfa:

"The general appearance, and more particularly the color of the plant, are the best guides, perhaps, as to when water is needed. When healthy and vigorous, alfalfa is of a light-green color; but when the supply of moisture is insufficient the leaves take on a darker and duller shade of green and begin to droop, and unless water is provided both stems and leaves wither and die. Another test is to remove a handful of soil 6 inches or so beneath the surface and compress it in the hand. If it retains its ball-like shape after the pressure has been removed, and shows the imprints of the fingers, the soil is suff' 'ntly moist, but if it falls apart readily it is too dry. In connection with such tests it is well to bear in mind that they are more or less influenced by both soil and climate. It is therefore necessary to observe the growth of the plant closely on all new alfalfa fields to determine if possible Iow far such tests may be relied upon, the chief object being to maintain at all times as nearly as practicable the proper amount of moisture in the soil surrounding the roots of the plants to prevent a checking of the'r growth.

"Alfalfa commonly receives careless treatment at the hands of western irrigators. When water is available and is not needed for other crops it is usually turned on the alfalfa fields or meadows whether these need it or not. There is no question that yields of alfalfa might be considerably increased if more care was used in finding out when to apply water. In each kind of soil and under any given set of climatic conditions there is a certain percentage of soil moisture which will give best results. Under the present unskillful practice it is impossible to maintain uniform soil-moisture conditions for any length of time. The soil is apt to re ive too much or too little water, or else it is deluged with cold wate, at time when it needs only heat and air. The number of irrigations requir d depends upon the depth and nature of the soil, the depth to ground w er, the number of cuttings, and the rainfall, temperature, and wind moveme t. Other things being equal, more frequent waterings are required in th warm sections of the South than in the cooler portions of the North. The number of irrigations per year for alfalfa ranges from 4 in Montana and Wyoming to as many as 12 in parts of California and Arizona. In localities where water is scarce during part of the season the number of waterings as well as the amount used each time depends on the available supply. It is a common practice to apply frequent and heavy irrigations in spring when water is abundant and to water less often and more sparingly when the supply is low."

5.—Winter Irrigation of Alfalfa.

"When water is applied either to bare soil or to crops outside of the regular irrigation season it is termed winter irrigation. The practice thus far has been confined largely to the warmer parts of the arid region. It has become well established in Arizona and California and is being quite rapidly extended to parts of Oregon, Kansas, and the Rocky Mountain States.

"Ex ence has shown that a deep retentive soil is capable of storing a larg antity of water. On account of the fluctuation of western streams of all nds, from the small creek to the large river, the greatest flow of wate ten comes at a season when there is least demand for it. In a few local, es adequate storage facilities have been provided to retain the surplus, but as a rule it is allowed to go to waste. The passage of so much waste water led to the introduction of winter irrigation and in nearly every case the results have been satisfactory. The chief differences between winter and ordinary irr'gations are the larger volumes used, the crude manner of conveying and applying the water, and the dormant or partially dormant condition of the plants at the time of irr'gation.

"Besides furnishing a supply of much-needed moisture, winter irrigation when conditions are favorable, prevents winter killing and improves the mechanical condition of the soil."

6.—Winterkilling of Alfalfa.

"In the colder portions of Montana, Wyoming, Colorado, Utah, and the Dakotas alfalfa is apparently winterkilled from a variety of causes and sometimes from a combination of causes. The percentage of loss around Greeley, Colo., has been placed at 2 per cent. per annum. In this locality and throughout the Cache la Poudre Valley in northern Colorado most of the winterkilling is done in open dry w ters and is quite generally attributed to a scarcity of moisture in the soil. In the winter of 1907 considerable damage was done to the alfalfa fields around Loveland, Colo., on account of the long dry spell in midwinter. The old alfalfa fields suffered most. It was the opinion of the farmers that a late fall irrigation would have prevented the loss.

"Near Wheatland, Wyo., the higher portions of the fields suffer most damage in winter, and here also the cause is said to be lack of moisture in the soil, combined with the effects produced by cold and wind.

"At Choteau, in northern Montana, a farmer watered, late in the fall, part of an alfalfa field which was 2 years old, and it winterkilled, while the unwatered portion escaped injury. This and other evidence along the same line which might be given go far to demonstrat that under some conditions too much moisture is as detrimental as too little.

"Probably the chief cause of the winterkilling of alfalfa is alternate freezing and thawing. The damage from this cause is greatly increased when any water is left standing on the surface. A blanket of snow is a protection, but when a thin sheet of ice forms over portions of a field the result is usually fatal to plants. The bad effects of alternate freezing and thawing on alfalfa may be observed at the edge of a snow bank. This crop is likewise injured by the rupture of the tap roots caused by the heaving of the soil.

"From present knowledge of the subject, the means which may be used to protect alfalfa fields from winterkilling may be summed up as follows: Where both the soil and the air are dry the plant should be supplied with sufficient water for evaporation, but the land should be drained so thoroughly that none of the top soil is saturated; a late growth should not be forced by heavy irrigations late in the growing season; if the soil is dry, irrigate after the plants have stopped growing; and the latest growth should be permitted to remain on the ground, unpastured, as a protection.

"It may be stated in conclusion that the loss to the farmer from the winterkilling of alfalfa is not as great as might appear at first. The damage is done in winter, and there is ample time to plow the plants under and secure another crop, which is usually heavy, owing to the amount of fertilizers added by the roots of alfalfa. The Montana farmer who increased his average yield of oats from 50 to 103 bushels per acre by ploughing under winterkilled alfalfa illustrated this point."

7.—Seeding Alfalfa on Land to Be Irrigated.

"In the upper Snake River Valley, in Idaho, alfalfa is usually preceded by a grain crop. The stubble is plowed 6 to 9 inches deep in the fall, and early in the spring it is double-disked, harrowed, and smoothed. From 8 to 20 pounds of seed is then drilled in 0.75 inch to 1.5 inches deep in rows 6 inches apart. When oats is used as a nurse crop it is seeded first, 80 to 100 pounds per acre being used. From 8 to 12 pounds of alfalfa seed are then drilled in, in the opposite direction. Some farmers use a combination drill which seeds both at the same time. When no nurse crop is used the alfalfa plants are clipped when they reach a height of 8 to 12 inches. This is necessary to hold the weeds in check and to cause the plants to stool.

"In the Yakima Valley, March and April are preferred for seeding alfalfa, both on account of the climate and the abundant water supply of that period. The ground is plowed deep, graded, smoothed, and harrowed. From 10 to 20 pounds of seed are then put in with a broadcast seeder and harrowed lightly. The furrows are then marked off and irrigation begins. The ground is kept moist constantly until the young plants are fairly well established. The use of so much water at the start is due largely to the tendency of the soil to bake if allowed to become dry.

"The alfalfa growers of Montana are about equally divided in opinion as to the advantages of using a nurse crop. Those who seed grain with alfalfa claim that they get more out of the land the first season, while those who are opposed to this practice believe that the injury done to the alfalfa plants by the grain crop extends through several years and that the small gain of the first year is more than offset by the lessened yields of alfalfa in subsequent years.

"In northern Colorado, rotation of crops is practiced and alfalfa seed is sown with a nurse crop, usually wheat or barley. The seed is drilled early in the spring with a common force-feed press drill equipped with an auxiliary seed box for alfalfa seed, which is scattered broadcast between the grain rows and covered by the disk wheels of the press drill. From 12 to 20 pounds of alfalfa seed are sown. Irrigation before seeding is not practiced. There is, as a rule, sufficient rainfall to furnish both crops with moisture until the grain is ready to head out and the alfalfa is 4 to 6 inches high, when the field is irrigated.

"At Wheatland, Wyoming, various methods of seeding alfalfa are in use, but the one which gives the best results may be described as follows: Drill in 1 bushel of barley to the acre; then in a week or ten days cross drill the field, sowing 12 to 15 pounds of alfalfa, setting the press drill so that the seed will be covered 0.75 inch to 1.5 inches deep."

Information on the various agricultural questions involved in alfalfa growing and its use can be obtained in the following bulletins:

Alfalfa Growing, Farmers' Bulletin No. 215, U. S. Department of Agriculture, Washington, D. C.

Alfalfa Bulletin No. 66, Agricultural Experiment Station, Moscow, Idaho.

VIII.—THE USE OF SMALL PUMPING PLANTS FOR IRRIGATION IN BRITISH COLUMBIA.

While British Columbia is favored with a system of large rivers such as the Thompson, the Fraser, the Kettle Valley and lakes such as the Okanagan, these splendid large bodies of water are practically not available for gravity irrigation because of the topography of the irrigable land. The irrigable land exists usually in separate small valleys formed on both sides of smaller streams, or in small benches high above the rivers or lakes, generally with considerable slope towards these bodies of water. This position of the irrigable land combined with the flat grade of the rivers makes diversion by gravity flow directly from these sources an economical impossibility. These conditions have made it necessary to utilize the smaller streams or creeks, the flow of which is irregular, being abundant at the beginning of the irrigation season but in many cases decreasing to an insufficient volume before the close of the season. Most of the watersheds of these streams are favored with reservoir sites which can be utilized at a moderate cost to regulate the flow. Up to the present the natural stream flow, supplemented in some cases with storage water, has been the usual source of supply. Naturally the systems most easily constructed were installed first and the best available sources have been taken up. With the increasing demand for water to put new land under irrigation, less favorable sources of water supply must be utilized and the cost of development will become greater. There will still remain bodies of land for which no gravity water is available or only available at a very high cost, and which may be situated at a moderate elevation above the large rivers or lakes. For these conditions the development of a water supply by pumping may be the best solution. The information given below applies to small pumping plants, irrigating from about 10 to 100 acres.

CONSIDERATIONS CONTROLLING THE SELECTION OF A PUMPING PLANT.

The proper selection of a pumping plant depends upon many factors which should be carefully considered by the intending purchasers. These factors are: (1) capacity of plant and period of operation, (2) the kind of pump, (3) the class of engine or driving power, (4) the first cost, (5) fuel cost, (6) cost of fixed charges and attendance. These factors are interdependent and should be considered together. Their relative importance will vary with local conditions and for that reason it is not possible to state definite rules which will apply in all cases. A study of the conditions affecting each factor is therefore necessary in each case.

1.—Capacity of Plant and Period of Operation.

The required capacity of the plant will depend on the area irrigated, the duty of water or depth of water required on the land and the period of operation. For ordinary orchard soil in the arid part of British Columbia a total depth of 12 inches of water during the irrigation season will be sufficient for young orchards. For a full bearing orchard 18 inches should be ample, while for alfalfa and other forage crops 24 to 36 inches is plenty. Where the cost of pumping is high, such as for small plants and high lifts, it will usually not be feasible to grow at a profit anything but orchards. To reduce the cost of pumping, no excess water should be used, all losses should be prevented by careful irrigation and thorough cultivation, in which case a young orchard on fairly deep retentive soil may not require more than 6 to 9 inches of irrigation water and a full bearing orchard not more than 12 or 15 inches during the irrigation season. To put a depth of 2 feet of water on one acre, it takes a flow of very nearly 1 cubic foot per second for 24 hours; this is equivalent to 450 U. S. gallons per minute for 24 hours. This relation can be applied to any case to obtain the size of the pump. For example, if it is desired to irrigate a 40 acre orchard 1½ feet deep in an irrigation season of 120 days, this requires 60 acre feet in 120 days, or ½ of an acre foot per day. This will be obtained by a pump giving ¼ of a cubic foot per second, or 110 U. S. gallons per minute, when the pump is operated continuously 24 hours a day every day during the irrigation season of four months. For a 10 acre orchard the required capacity based on the same conditions would be ¼ the above or 28 gallons per minute or 1-16 of a cubic foot per second, or about 2¼ British Columbia miners' inches.

The above two examples are based on a pump operating continuously at the rates given above. While continuous operation decreases the required size of plant, it is usually preferable to select a plant of larger capacity and operate it only a part of the time. This is especially desirable for very small orchards in which case continuous operation gives a stream too small to irrigate with. The other disadvantages of continuous operation are:

1st. Continuous operation requires continuous irrigation and constant attention to operate the pumping plant. For very small tracts a regulating reservoir may be used, but it must be of considerable capacity to be of any service and it must be lined with concrete to prevent seepage losses of the water which when pumped is too valuable to lose. Usually it is preferable to purchase a larger plant and do without a reservoir.

2nd. Continuous operation means that the water can not be applied to the different parts of the orchard within a short time, so that only a small part of the orchard or farm receives the water when most needed, and the remainder must be irrigated either too early or too late.

3rd. Continuous operation gives a small stream which can not be applied economically.

4th. A small plant is less efficient and requires a proportionately larger fuel consumption than a larger plant to pump the same quantity of water.

On the other hand a very short period of operation requires a comparatively large pumping plant which will greatly increase the first cost of installation, the interest on the capital invested, the depreciation and fund necessary to provide for renewal.

Usually it is desirable to operate the pump not over 1-2 or 1-3 of the time during the irrigation season and often a shorter period is desirable. This requires a pumping plant two or three times or more the size required for continuous irrigation. The capacity of the pump must be sufficient in all cases to give a large enough stream to irrigate economically; even for the smallest orchards a stream of at least 5 miners' inches or about 63 U. S. gallons per minute, is desirable.

For a full bearing orchard 18 inches of irrigation water applied in about 3 irrigations of 6 inches each at intervals of 30 to 40 days should be ample in most cases. As stated above, where the water has to be pumped to a high elevation the higher cost of the water demands great care in its use and 12 to 15 inches total depth of irrigation water would be sufficient.

The table below gives the required pump capacity for various sizes of orchards or farms and for different periods of operation. It is based on a depth of irrigation water of 6 inches each month, or 18 inches in 3 months, which is taken as the irrigation season. The period of operation is given in number of 24 hour days that the pumping plant is operated each month. These days need not be consecutive; for instance if the operation period is 10 days, instead of applying 6 inches of water in one irrigation lasting 10 days, the soil may be so porous and gravelly that it will not retain moistur in which case it may be preferable to apply 3 inches at a time in two irrigations during the month, of 5 days each. The required pump capacity is given in U. S. gallons per minute instead of Imperial gallons because the pumps sold in British Columbia are mostly rated in U. S. gallons per minute.

Necessary Capacity of Pumps in U. S. Gallons Per Minute to Give a 6 Inch Depth of Water on the Land Each Month When Operated the Following Number of 24 Hour Days Per Month.

Area Acres.	30 days.	20 days.	15 days.	10 days.	5 days.	$2\frac{1}{2}$ days.	1 day.
5	19	28	38	56	113	225	563
10	37.5	56.25	75	112.5	225	450	1125
15	57	85	113	170	340	675	1690
20	75	113	150	225	450	900	2250
30	113	169	225	338	675	1350	3375
40	150	225	300	150	900	1800	4500
60	226	338	450	675	1350	2700	6750
80	300	450	600	900	1800	3600	9000
120	150	675	900	1350	2700	5400	13500

The capacity of pumps for smaller or greater depths of water applied per month can be easily computed by proportion from the values given. For different areas and different periods of operation the capacity may be obtained by interpolation.

2.—Kind of Pump.

The kinds of pump commonly used to raise water for irrigation are (1) centrifugal pumps, (2) power plunger pumps, (3) deep well pumps, (4) air lift pumps, (5) hydraulic rams.

Deep well pumps and air lift pumps are used for pumping underground water from deep wells. In British Columbia the underground water supply is unknown and need not be considered at present when the water supply is obtainable from the large streams and lakes adjacent to irrigable area. For pumping from these sources the centrifugal pumps and the power plunger pumps are the best adapted. Hydraulic rams are used for small quantities of water such as for domestic purposes or for irrigation of small pieces of land. They are economical in operation, but require special conditions such as a nearby stream with sufficient fall in a short distance. The choice between a centrifugal pump and a power plunger pump will depend on the capacity required and the height of lift.

Centrifugal pump.

A centrifugal pump consists of a circular casing with the inlet or suction end connected to the center and the outlet or discharge end formed tangent to the perimeter. Inside the casing is the runner or impeller keyed on the shaft and revolving with it. It is formed of curved vanes closely fitting the casing and corresponds to the piston or plunger of a plunger pump. When in operation the impeller by revolving imparts a velocity to the water between the vanes and forces it away from the center of the casing towards the perimeter or rim of the casing through the outlet and up the discharge pipe. This produces a partial vacuum at the center of the impeller which induces a flow through the suction pipe into the casing. The number of revolutions of the runner or speed of the pump has an exact relation to the head or lift against which the pump is working and for every head there is a speed for which the pump works most efficiently. This speed can be obtained from the pump manufacturers. It is important that the pump be connected to an engine or motor which will give it the proper speed. Overspeeding is preferable to underspeeding but either reduce the pump efficiency.

Simple centrifugal pumps specially designed and driven at a sufficiently high rate of speed may be used for lifts considerably over 100 feet, but usually the sock pump obtainable from the manufacturers is not suitable for lifts over 75 feet and for the smaller sizes the total lift should not exceed 50 feet. For higher lifts compound or multi-stage centrifugal pumps are used. These consist of two or more pumps connected in series, the discharge of the first pump or stage is delivered into the suction of the next pump and the operation is repeated according to the number of stages. Usually 75 feet to 125 feet is allowed to each stage.

Where the required capacity of the pump is over 100 or 150 gallons per minute and the total life less than 75 feet, the centrifugal pump is no doubt the best adapted.

Centrifugal pumps are usually denoted by a number which represents the diameter of the discharge in inches. The efficient capacity of each size will vary to some extent with the speed of the pump which depends on the total lift pumped against. The pumps can, therefore, not be rated accurately. The capacities given in the accompanying table are worked out from the ratings given by a reliable pump manufacturer and are subject to considerable variations either above or below the values given.

No. of pump or diameter of discharge in inches.	Capacity in U.S. gallons per minute.	Capacity in second feet or acre inch per hour.	Capacity in British Columbia miners' ins.	Number of acres irrigated, 6 in. deep each month for operation period, during the month, of						
				30 days.	20 days.	15 days.	10 days.	5 days.	2½ days.	1 day.
2	100	.22	8	27	18	13	9	4½	2¼	9-10
2½	150	.33	12	40	27	20	13	6½	3¼	1 3-10
3	225	.50	18	60	40	30	20	10	5	2
3½	300	.66	24	80	53	40	27	13	6½	2 2-3
4	400	.90	32	110	71	55	36	18	9	3 2-3
5	700	1.60	57	190	127	95	63	32	16	6 1-3
6	900	2.00	71	240	160	120	80	40	20	8
7	1200	2.70	95	320	213	160	107	54	27	10 2-3
8	1600	3.50	125	430	287	215	143	72	36	14 1-3

To start a centrifugal pump the suction pipe and the pump must be filled with water or primed. This may be done by closing the discharge pipe with a check valve and connecting the suction end of a hand pump to the top of the casing. Where a steam engine is used a steam ejector may take the place of the hand pump. For small pumps and low lifts a foot valve on the end of the suction pipe may be used and the pump primed by pouring water in the casing,or suction pipe. The disadvantage of a foot valve is that if the water is not clear a small stone or twig may lodge itself in the foot valve and prevent priming. This will necessitate that the suction pipe be uncoupled and the obstruction removed.

The pump must be placed as near as possible to the water level to keep the suction lift down. While theoretically the suction lift may be as great as 33 feet at sea level and about 30 feet at an elevation of 3000 feet, it is desirable not to exceed 20 feet and less is preferable.

The plant efficiency can be increased by reducing the friction in the suction and discharge pipes. As few bends as possible should be used and these should be made by using long turn elbows. The suction and discharge pipes should be larger than the intake and outlet openings of tho pumps and joined to the pump with an increaser. The diameter of the suction pipe and especially of the discharge pipe should be 1½ times the diameter of the intake and if the discharge pipe is long it may be economy to make its diameter even larger. Enlarging the lower end of the suction pipe will further decrease the friction. This may he done by a funnel-shaped section whose length is about 3 times the diameter of the suction pipe and whose large end is about 1½ times the diameter of the pipe. The larger opening at the entrance to the suction pipe will decrease the tendency to suck up sand or gravel. When the water carries weeds, gravel, or other material a strainer should be used and the total area of the strainer should be at least twice the area of the suction pipe. The discharge pipe should not carry the water any higher than necessary.

Power piston or plunger pumps.

This type of pump consists of one or more cylinders in each one of which a piston or plunger moving backwards and forwards sucks the water in the cylinder and forces it up the discharge pipe. When the cylinder has only one suction valvo and one discharge valve the motion of the piston in one direction causes suction and displacement in the opposite direction forces the water through the discharge pipe. With two sets of valves so arranged that there is a discharge for each displacement of the piston, the pump is known as a double acting pump. When the pump has two cylinders it is known as a duplex pump, with three cylinders it is a triplex pump, and in either case may be either double acting or single acting.

The capacity of the pump will depend on the diameter of the cylinder, the length of the stroke of the piston, and the number of strokes or revolutions per minute. The capacities of a few sizes of double acting, single piston pumps, single acting triplex pumps and of double acting duplex pumps are as follows:

Capacity of Double Acting, Single Piston Pump.

Diameter of water cylinder.	Length of stroke.	Revolutions or strokes per minute.	U. S. gallons per minute.
3 inches	5 inches	40	12.4
4	5	40	21.6
5	5	40	34
6	6	40	58
7	6	40	80
8	6	40	104

Capacity of Single Acting, Triplex Piston Pump.

3	4	50	18
4	4	50	32
4	6	50	50
5	6	50	76
5	8	45	91
6	8	45	131
7	8	45	180
7	10	42	210
8	10	40	270
8	12	40	310
9	10	40	310

Capacity of Double Acting, Duplex Pumps.

2¼	4	75	29
3	4	75	36
3½	6	60	58
4	6	60	78
5	6	60	120
6	6	60	174
5	10	50	170
6	10	50	247
7	10	50	331
8	12	50	522
9	12	50	660

The sizes of pumps and the capacities vary with the different manufacturers. The values stated above show the approximate range of the different sizes. For small capacities the double acting single piston pump may be used. For larger capacities usually the single acting triplex pump and in some cases the double acting duplex pump is used. The triplex pump is generally preferable; it has the advantage that the power is constantly applied because of the strokes overlapping and this gives an even flow with little pulsation. The suction and discharge pipe should be larger than the suction and discharge openings of the pump as for centrifugal pumps. The suction pipe should be as short as possible and the pump placed as near the water surface as possible in order to keep the suction lift low.

A plunger pump must be given proper care in order to work efficiently and keep it in working condition. It should be carefully cleaned and oiled and at the close of the pumping period it must be emptied in order that it will not be damaged by freezing and the cylinders and water passages cleaned and oiled to prevent rusting.

Choice between Centrifugal pump and power plunger pump.

The choice between a power pump and a centrifugal pump will depend on the lift and capacity.

In irrigation work power pumps are best adapted to high heads above 75 feet and to small or moderate volumes of water, usually under 200 gallons per minute. For these conditions the efficiency of a power pump is usually greater than that of a centrifugal pump. For greater volumes the plunger pumps are comparatively expensive and centrifugal pumps are usually preferable unless the lift is excessive. The centrifugal pump has the advantage that it is simple in construction with no parts to get out of order, and that it is cheaper than a power pump. The selection should be made only after careful consideration of the first cost of the pump and the annual cost of fuel, operation and maintenance. Where the lift is high the fuel cost will be considerable and it is good economy not to select the cheapest pump obtainable but one that is guaranteed for a high efficiency. On the other hand if the pump is only to be operated a very small portion of the season it would be poor economy to invest a large capital in a high grade pump to save in fuel cost.

3.—Classes of Engines or Driving Power.

Methods of connection of pump and engine.

Centrifugal pumps and power pumps are generally driven either by gasoline engines, steam engines or by electric motors. The pumps are usually either direct connected or connected by means of belts, gears or chains. Direct connection is preferable when possible. It is more economical in fuel consumption and does away with the adjustment of belt or chain necessary with belt or chain driven pumps.

The connection of the pumps and driving power must be such that the pumps will be given the speed or number of revolutions per minute for which they are designed and for which highest efficiency is obtained. For this reason direct connection can only be used where the driving power and the pump have the same speed.

The speed of centrifugal pumps is usually high and so is that of electric motors and for that reason they can, if properly designed, be direct connected; this is done usually by means of a flexible coupling. Gasoline and steam engines are generally operated at a much lower speed than centrifugal pumps and for that reason are not direct connected unless the engine and pump are specially designed. This is done by some manufacturers.

Power plunger pumps are operated at a slow speed and for that reason are not direct connected to the driving power.

When connected by gears, belts or chains the driving gear and driven gear, and the driving pulley and driven pulley must be proportioned so that the pump will be given its correct speed. When a plunger pump is built as a single machine with a steam engine, with the piston or plunger of the water cylinder on the same driving rod as the piston of the steam cylinder it is called a direct acting steam pump. The fuel consumption of a steam pump is greater than that of a steam driven power pump and for that reason steam pumps will not be considered.

Capacity of engine.

The power necessary to lift water is indicated in horse powers. A horse power represents the energy required to lift 33,000 pounds 1 foot high in one minute; this is equivalent to 3960 gallons of water per minute raised 1 foot high. This relation enables one to find the horse power required in any case by multiplying the discharge of the pump in gallons per minute by the total lift in feet and dividing by 3960. The result obtained represents the useful water horse power necessary to lift the water. The horse power delivered by the engine to the belt or gears when the pump is belted or geared to the engine, or to the pump itself when direct connected, is the brake horse power and must be greater than the useful horse power to allow for the loss of energy in the pump and transmission. The horse power developed within the engine itself is the indicated horse power and must be greater than the brake horse power to allow for the energy loss in the engine itself. Gasoline engines and motors are rated on brake horse power. Steam engines are rated on indicated horse power.

The combined efficiency of a pumping plant represents the ratio of the useful water horse power to the rated horse power of the engine, and will vary considerably with the type of pump, method of connection of engine with pump and the care taken in operating both pump and engine at the proper speed. In ordinary field practice a good pumping plant, properly installed, should easily reach the efficiency given in the following table:

Efficiency of Centrifugal Pumping Plants.

No. of centrifugal pump.	Discharge in U. S. Gallons per minute.	Water horsepower per foot of lift.	Efficiency.	Brake horsepower per foot of lift.
2	100	.025	30 per cent.	.081
2½	150	.038	35	.11
3	225	.057	40	.14
3½	300	.08	45	.18
4	400	.10	45	.22
5	700	.17	50	.34
6	900	.23	50	.46
7	1200	.31	50	.62
8	1600	.41	55	.75

The efficiency of power plunger pumps varies with the size of the pump and with the lift. A greater efficiency is obtained with the higher lifts and with the larger sizes. The efficiencies of properly installed plunger pumps and the horse power for various lifts are given in the following table:

Brake Horse Power Required to Operate Plunger Pumps.

Diameter of cylinder.	Length of stroke.	Capacity in U. S. gal. per minute.		Efficiency and Brake Horse Power for lifts of				
				50 ft.	100 ft.	150 ft.	200 ft.	250 ft.
3 inches	4 inches	18	Efficiency	.30	.40	.42	.45	.45
			Horse Power	.75	1.1	1.6	2.0	2.5
4	4	32	Efficiency	.35	.50	.60	.65	.65
			Horse Power	1.2	1.5	2.0	2.5	3.1
4	6	50	Efficiency	.35	.50	.60	.65	.65
			Horse Power	1.9	2.5	3.1	4.0	4.8
5	6	76	Efficiency	.40	.55	.65	.70	.70
			Horse Power	2.4	3.5	4.4	5.5	6.7
5	8	90	Efficiency	.40	.55	.65	.70	.72
			Horse Power	2.8	4.1	5.2	6.5	7.8
6	8	131	Efficiency	.45	.60	.65	.70	.72
			Horse Power	3.6	5.5	7.5	9.3	11.4
7	8	180	Efficiency	.45	.60	.65	.70	.72
			Horse Power	5.0	7.5	10.5	13.	15.5
7	10	210	Efficiency	.50	.65	.70	.75	.78
			Horse Power	5.25	8.0	11.	14.	17.
8	10	270	Efficiency	.50	.65	.70	.75	.78
			Horse Power	6.75	10.25	14.50	18.25	22.1
9	10	310	Efficiency	.50	.65	.70	.75	.78
			Horse Power	8.5	13.	18.	23.	28.

Type of Engine.

The above table will give the size of the engine. The driving power must be either a gasoline engine, steam engine, or electric motor. The methods of connecting the engine with the pump have been already considered. Other factors being equal, direct connection is preferable when possible. A few general considerations of the types of engine are given in the following paragraphs.

Steam Engine.

For small plants irrigating a few acres, the steam engine, although very reliable, is practically out of the question because it requires a licensed engineer whose salary would be prohibitive. However, for larger areas and where coal is cheap, it may be cheaper than either a gasoline engine or electric motor. For large plants operated continuously it may be economy to install an efficient boiler and a high grade compound condensing, triple expansion, or quadruple expansion, steam engine, in order to decrease the fuel cost. For small plants operated only for short periods during the irrigation season it is much more important to decrease the cost of installation. The interest on the capital invested and the depreciation of the plant are very important items of cost as compared to the fuel cost. For these reasons unless the acreage is large and the lift very high, the steam plant will consist of a semi-portable locomotive type boiler and an ordinary slide valve steam engine.

Gasoline Engines.

A gasoline engine is fairly reliable if it is strongly built and operated with care. Cleanliness and proper attention are necessary. All parts and bearings should be kept in fine adjustment and properly oiled, by examining the engine at least every two or three hours. The circulating water should be kept fairly hot but not too hot. It should be nearly boiling as it comes out of the jacket.

The engine should be regulated by means of the governor to give the proper speed to the pump. To keep down the fuel consumption the gasoline feed should be so adjusted that there will be a miss in every ten or twelve explosions, and the engine should be worked up to its full rated capacity.

Over 75 per cent. of the troubles happening to gasoline engines are due to the sparking device. This can usually be remedied by cleaning all connections free from oil, scraping the ends of wires, tightening screws or replacing the batteries.

Electric Motors.

Electric motors are reliable and easy to operate, requiring very little attention.

4.—First Cost of Plant.

The first cost of a pumping plant depends on the grade of machinery, the cost of transportation, the expense of installation. Because of these factors accurate estimates of cost can not be given. However, the approximate cost values given below will be of value to the land owner who is considering the feasibility of a pumping plant. The values given represent the prices at Vancouver and do not include transportation and installation.

Approximate Cost of Single Stage Centrifugal Pumps.

No. of pump.	Capacity in U. S. gallons per minute.	Cost.
2	100	—
2½	150	$ 70
3	225	85
3½	300	95
4	400	110
5	700	120
6	900	140
7	1200	190
8	1600	240
		285

The cost of two step centrifugal pumps of the same sizes will be about four times the values given above.

Approximate Cost of Triplex Single Acting Power Pump.

Diameter of water cylinder.	Length of stroke in inches.	Capacity in U. S. gals. per minute.	Height of lift.	Cost.
4	8	65	75 to 100 ft	$ 270
5	10	130		400
6	12	220		550
4	6	48	[illegible]	300
5	8	91		410
7	8	180	"	600
8	10	270	"	950
8	12	310	"	1000

Approximate Cost of Electric Motors, Gasoline Engines and Simple Slide Valve, Non-condensing Steam Engine, With Locomotive Boiler and Auxiliaries.

Power. Horse	Cost of electric motors. 1200 rev. per minute.	Cost of gasoline engines.	Cost of steam engines.
2	$ 90	......	......
3	110	......	......
5	160	$ 475	$ 650
10	260	725	800
15	280	900	1,000
20	340	1,100	1,200
25	...	1,300	1,350
30	110	1,600	1,500
40	...	2,100	1,700

Cost of accessories and installation.

The above costs are for the pumps and engine and do not include the accessories, the foundation, the labor of installation, and the housing. For an electric plant the cost of transformers should be added unless these are supplied by the electric company. The accessories will include the suction and discharge pipes, the valves and fittings, the priming pump, the connection between pump and engine. The suction pipe is usually made of steel; the discharge pipe may be steel or wood banded pipe and should cost delivered at different points in the arid part of British Columbia about as follows:

Cost of Pipes Safe for 150 Feet Head.

Diameter of pipe.	Cost per foot of wood banded pipe.	Cost per foot of steel pipe.
4 Inches	$ .20	$ .30
6	.30	.50
8	.40	.80
10	.55	1.10
12	.65	1.35
14	.75	1.60
16	.95	2.00
18	1.10	2.50
20	1.44	3.00

For a rough estimate the total cost of valves, priming pump, all fitttings and suction pipe, but not discharge pipe, may be taken as about 10 per cent. of the cost of pump and engine for a gasoline or steam plant and 20 per cent. for an electric plant. The cost of installation should not exceed 5 per cent. The cost of a building to house the plant will range from about $25 for a small plant to $100 or more for a larger plant. The cost of transportation and hauling will depend on the railway charge from Vancouver and on the distance from the station to point of installation.

5.—Fuel Consumption and Fuel Cost.

The selection between a steam engine, gasoline engine and an electric motor will depend to some extent on the comparative cost of coal, gasoline, and electrical energy.

A gasoline engine is usually guaranteed for a fuel consumption of 1-9 to 1-10 of an Imperial gallon of gasoline per rated or brake horse power per hour. A new engine well adjusted will come up to this efficiency, but an engine that has been operated some time will consume about 1-7 of an Imperial gallon of engine gasoline or distillate per brake horse power per hour.

The fuel consumption of a steam engine will vary greatly on the type of boiler and engine. A small slide valve non-condensing engine under 25 horse power will use probably 50 to 60 pounds of steam per brake horse power per hour. A locomotive type of boiler should give 5 or 6 pounds of steam for 1 pound of coal. Therefore, a small steam engine under 25 horse power should consume about 10 pounds of coal per brake horse power per hour. Steam engines of the same type from 30 to 50 horse power will consume from 5 to 8 pounds of coal per brake horse power per hour.

Electrical energy is measured in Kilowatts. A Kilowatt is equal to 1 1-3 horse power, but because of the loss of energy in the motor, 1 Kilowatt will usually give about 1.1 brake horse power. Based on this figure 1 brake horse power hour is equal to 9-10 of a Kilowatt hour.

The above values show that to produce 1 brake horse power per hour, it requires either 1-7 of an Imperial gallon of distillate, about 10 pounds of coal, or 9-10 of a Kilowatt hour. Based on these figures the table below shows the cost of fuel per brake horse power per hour for several equivalent cost values of fuel. In the table is also given the fuel cost of pumping one acre foot of water through a lift of one foot, assuming plant efficiency of 50 per cent. and 75 per cent.

Equivalent units costs of fuel.			Fuel costs (in cents).		
Cost of gasoline in cents per Imp. gallon.	Cost of coal in dollars per ton (2,000 lb.)	Cost of electricity in cents per K. W. hour.	Per brake h. p. per hour in cents.	Per acre foot of water lifted 1 foot high. 50% efficiency.	Per acre foot of water lifted 1 foot high. 75% efficiency.
14	$4.00	2.25	2.0	5.5	3.65
16	4.55	2.50	2.30	6.3	4.20
18	5.15	2.85	2.55	7.0	4.70
20	5.70	3.20	2.85	7.8	5.25
22	6.30	3.50	3.15	8.65	5.75
24	6.85	3.80	3.45	9.5	6.30
26	7.10	4.15	3.70	10.20	6.80

The price of engine gasoline bought in drums is about 24 cents per gallon delivered at Kamloops and 26 cents per gallon at Okanagan points. These prices are equivalent to coal at $6.85 to $7.40 a ton or electricity at 3.80 to 4.15 cents a Kilowatt hour. The fuel cost is, however, only a part of the total cost of pumping.

6.—Fixed Charges and Attendance.

A.—Fixed charges.

The cost of installation represents a capital which if invested would bring in an income represented by the interest. It is therefore necessary to consider this interest as part of the cost of operation. To this should be added the annual cost of repairs, maintenance and renewal. These items of cost represent the fixed charges. After 6 or 8 years a gasoline engine may need to have its cylinder rebored and a new piston provided, the cost of which is about one-fourth the cost of a new engine. With ordinary care the life of a gasoline engine may be taken as 10 years; the life of an electric motor about 15 to 20 years. The fixed charges on the entire plant may be taken as follows:

Fixed Charges.

	Gasoline engine plant.	Electric plant.	Steam engine plant (small)
Depreciation and renewal	8 per cent.	5 per cent.	8 per cent
Repairs and maintenance	3	1	2
Interest	6	6	6
	17	12	16

B.—Attendance.

An electric motor requires a minimum of attend nce, small gasoline plants require frequent inspection, and steam engines require a licensed engineer and for that reason can not be economically used for small plants operated during short periods. The cost of attendance for an electric motor pumping plant should not exceed 5 cents per hour, for a gasoline engine plant 10 cents per hour and for a steam engine plant 40 cents per hour. While electric motors and gasoline engines are usually operated by the orchardist or irrigator, his time is valuable and a charge should be made for it.

7.—Final Selection of Type of Plant.

The final selection of a pumping plant should be based on a careful consideration of the factors stated above. The best size of plant, the period of operation, the kind of engine or driving power, can only be correctly determined by a final consideration of cost of installation and cost of operation. For small plants operated for short periods during the irrigation season steam engines are not to be considered even where coal is cheap because they must be operated by a licensed engineer whose salary would be excessive in proportion to the saving obtained by using cheap coal. Where electric power is available the choice is between a gasoline engine and an electric motor. The electric motor requires minimum attendance, it is reliable and its first cost is much less than that of a gasoline engine. For these reasons if electric power is available, an electric motor is preferable to a gasoline engine and will prove far more economical than a gasoline, even should the cost of electrical energy be higher than the fuel cost for a gasoline engine, which is not likely to obtain in British Columbia because of the high cost of engine gasoline or distillate.

At Grand Forks, British Columbia, electricity was sold for pumping plants at the rate of 3 cents per Kilowatt hour; as far as fuel cost is concerned this is equivalent to gasoline at about 19 cents a gallon. This is less than the cost at which gasoline can be obtained and in addition gives the advantages stated above.

The application of the above information and cost data to any particular case is illustrated by the following examples:

First example: A 20 acre orchard is to be irrigated by pumping. The quantity to be applied is 6 inches per month and the total depth in one season, 18 inches. The lift is 50 feet and the discharge pipe 200 feet long. Engine gasoline costs 24 cents per Imperial gallon. Assuming the pump is operated 1-3 of the time or ten twenty-four hour days each month, this will require a pump capacity of 225 gallons per minute (page 102) which is obtained with a No. 3 centrifugal pump (page 104) and 7 horse power engine (page 107). The discharge pipe will be 4 inches in diameter. The first cost and total cost of operation will be about as follows:

First Cost of Plant.

No. 3 centrifugal pump	$ 95
7 H. P. gasoline engine	600
Priming pump, suction pipe, fittings, etc	70
Freight charges and hauling	30
200 feet of 4 inch wood banded discharge pipe	80
Installation, 5% of cost	40
Building to house plant	40
Total cost	$955

Total Annual Cost of Operation.

Fuel cost of 7 brake H. P. engine for 3 periods of 10 days each or 720 hours is equal to (page 111) 720x7x3.15=17,000c or	$170
Fixed charges at 17 per cent. of first cost	160
Attendance 720 hours at 10 cents	72
Total cost for 20 acres	$402
Cost per acre	$20.10

Where electric power is obtainable the first cost of plant and annual cost of operation for the same conditions, assuming the unit cost of electric power to be 3 cents per Kilowatt hour would be:

First cost of plant	$530.00
Total annual cost of operation	245.00
Cost per acre	12.25

Tabulated below are the first costs of gasoline engine pumping plants and the costs of operation for orchards of 20, 40 and 80 acres for lifts of 50 feet and 150 feet and for different periods of operation. For the higher lift single acting triplex pumps are used. The costs given are based on gasoline at 24 cents a gallon, for a depth of irrigation of 18 inches for the lower lift and depths of 18 inches and 12 inches for the higher lift, it being assumed that by careful use of water, if the soil is retentive, 12 inches may be sufficient. The discharge pipe is assumed to be 200 feet long.

Cost of Pumping With Gasoline Engines and Centrifugal Pumps for 50 Foot Lift, Gasoline 21 Cents a Gallon.

Area in Acres	Number of 24 hour days pump is operated monthly	Capacity of pump Gallons per minute.	Number of Pump	Horse power of engine	First cost of installation	Annual Cost of operation per acre; 18 in. depth of water applied. Fuel	Fixed charges	Attendance	Total
20	5½	400	4	12	$1,225	$ 8.25	$10.50	$1.90	$20.65
	10	225	3	7	955	8.75	8.10	3.60	20.45
	20	113	2	5	725	12.00	6.20	7.20	25.40
40	5	900	6	25	1,855	7.75	7.90	.90	16.55
	11	400	4	12	1,225	8.25	5.25	2.00	15.50
	20	225	3	7	955	8.75	4.10	3.60	16.45
80	10	900	6	25	1,855	7.75	4.00	.90	12.65
	22	400	4	12	1,225	8.25	2.60	2.00	12.85

Cost of Pumping With Gasoline Engines and Single Acting Triplex Pumps for 150 Foot Lift.

Area in Acres	Number of 24 hour days pump is operated monthly	Capacity of pump in gallons per minute	Horse power of engine	First cost of installation	Annual cost of operation per acre for a depth of irrigation water of 18 inches: Fuel	Fixed Charges	Attendance	Total	of 12 inches: Total
20	8 1-3	270	15	$2,370	$15.50	$20.00	$3.00	$38.50	$32.30
	12 1-2	180	10	1,740	15.50	11.80	4.50	34.80	28.40
	25	90	6	1,280	18.75	10.90	9.00	38.65	29.90
40	13 1-1	370	18	2,760	15.90	11.70	2.40	25.40	23.20
	16 2-3	270	15	2,370	15.50	10.00	3.00	28.50	22.30
	25	180	10	1,740	15.60	7.40	1.50	27.50	20.80
80	26 1-2	340	18	2,760	15.00	5.85	2.40	23.25	17.35

The capacities of pumps, especially plunger pumps, and the sizes of engines, vary with the different makes, and for that reason the sizes given are not always obtainable, but sizes approximating these can be used in place.

The above cost estimates are only approximate. They are based on the conditions stated above and are not applicable to all cases because of the varying conditions which make the installation of nearly every pumping plant a special problem. The estimates are made for gasoline engines and are considerably higher than for electric motors. The first example showed that with an electric plant the cost of pumping was only 60 per cent. of the cost with a gasoline plant. The tabulated values show the following interesting results:

1st. The cost per acre of pumping is much larger for a small area than for a large area.

2nd. The cost per acre does not vary considerably with the period of operation, and in some cases a plant moderately large operating for a shorter period will cost less per acre than a smaller plant operating a longer period. This is due to the lower fuel cost obtained with the larger more efficient plant and the decreased cost of attendance for the shorter period of operation which overbalance the larger fixed charges. Even should the resulting cost be smaller for the smaller plant, the inconvenience due to pumping for a long period and the extra labor in irrigation may overbalance the saving in cost.

3rd. For the lifts assumed a period of operation equal to about ten twenty-four hour days during the month or one-third of the time during the irrigation season seems to be preferable with the centrifugal pump. With the higher price triplex plunger pumps a period of operation of one-third to two thirds of the time is preferable.

CO-OPERATIVE PUMPING.

The lower cost per acre for larger areas shows the advantages to be gained by cooperation between small owners. By uniting and installing a large plant instead of several smaller plants the cost of installation and operation is very much reduced and the plant can be given more competent attention which relieves the orchardist and increases the life of the plant.

Where by such cooperation several hundred acres can be brought together, a central steam plant to generate electric power, which is transmitted to the several electric motor pumping plants, is the most economical and best solution.

For separate plants above 20 or 40 horse power, gas producer plants connected to gas engines will furnish the cheapest power. These plants are reliable and easily operated. They consist of the producer in which hard coal is placed and through a process of partial combustion, in presence of air and steam, forms the gas which operates the engine. Gas producers operated on hard or anthracite coal have been in successful operation for a number of years and those operated on soft or bituminous coal are coming into use, but have not been very successful. The fuel consumption is very low, usually from 1 to 1½ pounds of coal per horse power for one hour, or ½ to ¾ of a cent per horse power for one hour with hard coal at $10 per ton. This is from 5 to 7 times less than the fuel cost with gasoline at 24 cents a gallon. Producer gas plants are more expensive than gasoline engines and for smaller plants the fuel economy will be overbalanced by the larger interest and depreciation charges. For very large single plants high duty steam engines will be the most economical form of installation.

LIMIT OF ECONOMICAL PUMPING.

The cases previously worked out for gasoline engine pumping plants show that for small tracts of 20 to 80 acres the cost of lifting sufficient water to give a depth of irrigation water of 18 inches will range for a lift of 50 feet from about $12.50 per acre for the larger area to about $20.00 per acre for the smaller area, and for lifts of 150 feet the respective costs are about $23 and $35 per acre. These costs may seem high as compared with gravity water, but to obtain an idea of the economy and feasibility of developing water by pumping, comparisons must be made with the value of irrigation water in the irrigated districts of British Columbia and also in other localities under the same conditions. In British Columbia, up to the present, gravity water obtainable without pumping has been quite plentiful. For that reason pumping has not been necessary, and very few pumping plants have been constructed. However, water is becoming [illegible] the steps which many irrigation companies in British C[illegible]ing to conserve water and prevent losses of transport[illegible] water in concrete lined canals and in pipes construc[illegible]xpense, show that water has become sufficiently va[illegible]ping. If a comparison is made with water thus obt[illegible] cost of construction of a well constructed system may [illegible] an acre and even higher. This cost is charged up t[illegible] sold to the orchardist and in addition reasonable profit [illegible] the value of the land. It is probably conservative to assume that land under an irrigation system will cost at least $100 an acre more than similar land for which there is no gravity supply. The chief advantage of gravity systems is the low annual cost of operation, usually less than $6 per acre, but if to this be added the interest on the difference in cost between land under the irrigation system and land which is to be supplied by pumping, assumed at $100, the total annual cost may be $10 to $15 an acre. This is about equal to the cost of pumping with gasoline engines to a height of 50 feet and about half as large as for lifts of 150 feet. Where electric power is available or for large pumping plants the cost of pumping would compare very favorably with gravity water even for higher lifts than those stated above. There are many contemplated hydro-electric power installations in the irrigated regions of British Columbia which, if materialized, will be of great value in extending the area irrigated by pumping.

A consideration of pumping in other districts is of interest to show its feasibility. In eastern Washington water is being pumped in one case to an elevation of 250 feet above the source of supply. In the citrus district of southern California lifts above 200 feet are not unusual and it is considered profitable to pump 460 feet. In the Pomona district of southern California, the cost of pumped water averages $15 per acre for one acre foot when purchased from irrigation companies, while for smaller private plants the cost is often greater. In 1905 the Irriagtion Investigations Office of the United States Department of Agriculture made tests on various pumping plants and these show that the cost of pumping at private plants of 10 to 100 horse power with lifts of 100 to 300 feet, varied from $10 to $90 per acre for one acre foot of water.

There is a limit beyond which it is not economically feasible to pump. In the California citrus districts lifts above 400 feet have been profitable. For the orcoard lands of British Columbia equally high lifts should be profitable, for the net return per acre from a good apple orchard is usually more than that from a citrus orchard. A citrus orchard 10 years old should average a net profit of $100 to $150 per acre. The net profits from apple orchards 10 to 12 years old in the Yakima Valley are given in bulletins of the United States Department of Agriculture as $200 to $600 per acre. With profits larger than those obtained from citrus orchards in southern California, what has been considered feasible in pumping there is at least equally so for the apple orchards of British Columbia when no other more economical source of water supply is available. However, for small pumping plants and small areas the writer believes that it is well not to exceed 200 feet, while for larger plants lifts of 400 feet may be economically feasible.

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