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HOW TO BUILD SMALL IRRIGATION DITCHES.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., July 22, 1902.

SIR: I have the honor to transmit herewith copy of an article entitled "How to Build Small Irrigation Ditches," prepared by C. T. Johnston, C. E., and J. D. Stannard, assistants in irrigation investigations, Office of Experiment Stations, and originally published in the Yearbook for 1900 under the title "Practical irrigation." There has been, and still is, considerable demand for the information contained in the article, and its republication as a Farmers' Bulletin will make it available for general distribution, and is respectfully recommended. The article contains specific directions for building small irrigation ditches on the farm—phases of irrigation not covered by any other publication in the Farmers' Bulletin series.

Very respectfully,

E. W. ALLEN,
Acting Director.

Hon. JOSEPH H. BRIGHAM,
Acting Secretary.

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HOW TO BUILD SMALL IRRIGATION DITCHES.

INTRODUCTION.

Serious obstacles to be overcome.—When a farmer enters a new country where irrigation is necessary he must determine (1) how he may best deliver water to his land, and (2) what crops are adapted to the soil and for local uses. Everything with him is tentative. Unless he is fortified by an income outside of that obtained from his farm, the first few years he has a struggle for existence. That the pioneer is often overcome in this unequal fight is evidenced by many deserted homes and unfinished irrigation works. Owing to his inexperience in irrigation, he may lose his crops by not using the proper volume of water or by using it at the wrong time. One failure often means the abandonment of everything and a retreat to a region where conditions seem more favorable. In a new country where the rainfall is ample for the growth of crops serious obstacles must be overcome before returns are received for the labor expended. If, in addition to these difficulties, water must be brought to the land for irrigation and domestic purposes, the problems become much more complicated, and correspondingly greater credit is due when success rewards the attempt.

To the Eastern farmer, whose cultivated lands are rolling and broken, the problem of spreading water over the surface of the ground from ditches has some serious phases. Often the stream passing his farm is bordered by steep bluffs, and its fall seldom exceeds 3 or 4 feet per mile. In his judgment the cost of raising water from such a source in sufficient quantities for irrigation would not be justified by the slight increase in yields or the saving of an occasional crop.

The Western irrigator would arrive at the same conclusion if he had to deal with similar conditions. His agricultural land is nearly always smooth, and usually has a gentle slope with and toward some natural drainage channel, and would bear no crops without irrigation. The stream from which he proposes to draw his supply of water has a large fall, so that a ditch taken from it with a moderate grade can recede rapidly, and hence cover a large area in a short distance. A combination of these features makes it possible for individuals to construct irrigation works on the smaller streams. This paper will deal with the kind of ditch a settler of limited means could build in a region of abundant water supply.

SMALL DITCHES WITH VARYING GRADES AND CROSS-SECTIONAL AREAS.

The pioneer irrigator knew but little regarding the measurement of water, the carrying capacity of ditches, or the volume demanded by various crops. The experience of the first few years often convinced him that his ditch was too small, and he was compelled to enlarge it to provide an ample supply of water. The volume one man could handle he called an "irrigating head." This was his first unit of measurement, and his ditch carried one, two, or three irrigating heads, according to his estimate. Crude measurements were afterwards adopted to aid his judgment. He found it comparatively easy to measure the cross-sectional area of a stream. His first gaugings were made in this manner, usually disregarding the velocity of the current. Experience in building ditches taught him in a few years how to adjust the size and grade of his ditch so as to furnish an adequate supply of water for the area to be irrigated. Some of the following considerations have been suggested by his experience.

Proper grade of ditch.—Many things affect the ease with which ditches can be built and water distributed from them. The length of ditch necessary to cover any piece of land depends on its fall compared with that of the stream and upon the elevation of the land to be irrigated. The smaller the grade of the ditch and the greater the fall of the stream, other things being equal, the shorter the ditch. However, the grade of the ditch should not be too light; otherwise its section must be greatly increased to deliver the desired volume of water. The grade must not be excessive or the increased velocity of the current will result in the erosion of the ditch banks. Therefore the range of grade which a ditch may have is limited, and its length largely depends on the fall of the stream.

On the quality of the soil through which the ditch must be constructed depend the permanency of its channel, the rate of velocity at which water can safely be carried, the cost of first construction, and the economic value of the ditch as a water carrier. As cheapness is a requisite for the construction of the class of ditches to be dealt with in this paper, rockwork or expensive flumes and other structures will not be considered.

Difficulties to be met and overcome.—In order to more clearly show the difficulties to be met and overcome, a practical case will be considered. Assume that it is desired to irrigate an area of 40 acres lying near a creek furnishing a sufficient supply of water; assume, also, that the creek has a fall of 20 feet per mile, and that the highest point of the land to be irrigated is 15 feet above the bottom of the creek at the nearest point. It will be seen that a point on the creek three-quarters of a mile above is on the same level with the highest point of the 40 acres. It is evident that the head gate of the ditch must be above this point if we expect the water of the creek to flow to the farm, unless a dam be built in the creek to raise the water higher than its usual level.

Comparison of possible lines upon which a ditch might be built.—It may be interesting as well as profitable to compare a few of the possible lines upon which the ditch might be built. That water tends to seek its own level is a principle that needs no demonstration, and it might be supposed that the least grade would cause the water to flow through the ditch. While this is true, it does not entirely answer the purpose, for the ditch must not only be one in which water will flow, but it must allow the water to run fast enough to deliver at the place where used a definite volume in a given time.

The accompanying diagram (fig. 1) shows the relation between the grades of the ditches and the fall of the stream. The line *03* represents a level line through the bottom of the creek at the farm and running upstream from the farm. *A 15* is a level line through the highest point of the farm. The line *0 E* is the grade of the stream, 20 feet per mile. The numbers *0*, *1*, *2*, and *3* at the bottom of the diagram indicate miles upstream from the farm, and the numbers *15*, *20*, *30*, *40*, and *60*, at the right, show elevation, in feet, above the bottom of the creek at the farm. *A B*, *A C*, *A D*, and *A E* are the lines of ditches built on grades of one-half, 5, 10, and 15 feet per mile, respectively. The distances from the point *0* to the perpendiculars dropped from the points *B*, *C*, *D*, and *E* measure the approximate lengths of the ditches built on the corresponding grades. As above stated, the

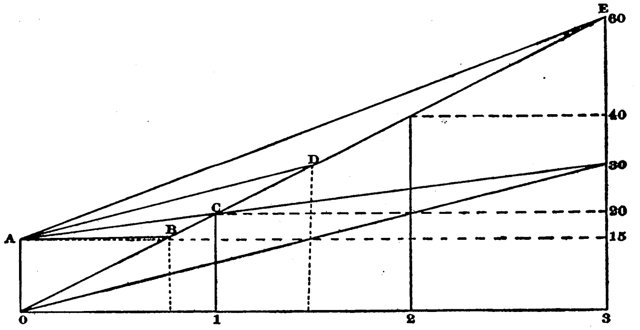

FIG. 1.—Diagram showing lengths of ditches with different grades.

grade of the stream is 20 feet per mile. If the grade of the ditch is 15 feet per mile, the two lines would approach each other at the rate of 5 feet per mile, and would come together at the point *E*, 3 miles above the farm. Following the line *E 3* to the base of the diagram, it is seen that the length of the ditch is 3 miles. If the minimum grade is taken at one-half foot per mile, the length is about three-quarters of a mile. The corresponding lengths of the ditches having grades of 5 and 10 feet per mile are 1 and 1½ miles, respectively.

To illustrate how the length of the ditch depends upon the fall of the stream, let the line *0 30* represent the grade line of a stream having a fall of 10 feet per mile. *A C* produced to *30* shows that a ditch having a fall of 5 feet per mile is 3 miles long.

The following table gives dimensions of a number of small ditches, with the corresponding velocities and discharges for different grades; also the volume of material, in cubic yards, to be removed per mile:

Velocities and discharges of ditches with different grades.

Dimensions of ditch.				Grade of ditch, 6 inches per mile.		Grade of ditch, 1 foot per mile.		Grade of ditch, 2 feet per mile.		Grade of ditch, 3 feet per mile.	
Top width.	Bottom width.	Depth.	Area of cross section.	Velocity.	Discharge.	Velocity.	Discharge.	Velocity.	Discharge.	Velocity.	Discharge.
Feet.	*Feet.*	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*
1.5	1	0.5	0.625	0.18	0.10	0.34	0.21	0.50	0.31	0.61	0.38
3.0	2	1.0	2.5	.35	.86	.48	1.21	.72	1.81	.87	2.27
4.5	3	1.5	5.625	.46	2.56	.67	3.77	1.00	5.60	1.20	6.72
6.0	4	2.0	10	.50	5.00	.85	8.50	1.24	12.40	1.49	14.90
7.25	5	2.25	13.78	.67	9.23	.96	13.23	1.38	19.02	1.69	23.29
8.5	6	2.50	18.12	.74	13.40	1.06	19.20	1.52	27.54	1.87	33.88
9.75	7	2.75	23.03	.81	18.65	1.15	26.48	1.66	38.23	2.04	46.98
11.0	8	3.0	28.50	.88	25.08	1.26	35.91	1.78	50.73	2.18	62.13
12.25	9	3.25	34.53	.93	32.13	1.34	46.27	1.93	66.64	2.36	81.49
13.50	10	3.5	41.12	1.00	41.12	1.44	59.21	2.04	83.88	2.50	102.78

Dimensions of ditch.				Grade of ditch, 4 feet per mile.		Grade of ditch, 5 feet per mile.		Grade of ditch, 6 feet per mile.		Grade of ditch, 7 feet per mile.	
Top width.	Bottom width.	Depth.	Area of cross section.	Velocity.	Discharge.	Velocity.	Discharge.	Velocity.	Discharge.	Velocity.	Discharge.
Feet.	*Feet.*	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*
1.5	1	0.5	0.625	0.71	0.44	0.81	0.51	0.91	0.57	0.96	0.60
3.0	2	1.0	2.5	1.01	2.53	1.16	2.89	1.29	3.23	1.37	3.42
4.5	3	1.5	5.625	1.39	7.84	1.59	8.97	1.78	9.97	1.88	10.56
6.0	4	2.0	10	1.74	17.40	1.99	19.90	2.21	22.10	2.34	23.40
7.25	5	2.25	13.78	1.96	27.00	2.18	30.04	2.43	33.48	2.63	36.24
8.5	6	2.50	18.12	2.20	39.86	5.45	44.39	2.68	48.56	2.90	52.54
9.75	7	2.75	23.03	2.36	54.34	2.63	60.56	2.88	63.20	3.12	71.85
11.0	8	3.0	28.50	2.56	72.95	2.86	81.50	3.13	89.20	3.38	96.32
12.25	9	3.25	34.53	2.73	94.26	3.05	105.31	3.34	115.33	....	....
13.50	10	3.5	41.12	2.86	117.18	3.22	132.40	....	....	....	....

Velocities and discharges of ditches with different grades—Continued.

Dimensions of ditch.				Grade of ditch, 8 feet per mile.		Grade of ditch, 9 feet per mile.		Grade of ditch, 10 feet per mile.		Volume of material to be removed per mile.[a]
Top width.	Bottom width.	Depth.	Area of cross section.	Velocity.	Discharge.	Velocity.	Discharge.	Velocity.	Discharge.	
Feet.	*Feet.*	*Feet.*	*Sq. ft.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*	*Feet per sec.*	*Cu. ft. per sec.*	*Cu. yds.*
1.5	1	0.5	0.625	1.04	0.65	1.09	0.68	1.17	1.04	122
3.0	2	1.0	2.5	1.48	3.70	1.55	3.88	1.66	.26	489
4.5	3	1.5	5.625	2.03	11.42	2.13	11.99	2.28	12.85	1,100
6.0	4	2.0	10	2.53	25.30	2.66	26.60	2.85	28.50	1,956
7.25	5	2.25	13.78	2.81	38.72	2.98	41.05	3.13	43.13	2,695
8.5	6	2.50	18.12	3.10	56.16	3.28	59.42	3.46	62.69	3,544
9.75	7	2.75	23.03	3.33	76.68	....	....	....	....	4,504
11.0	8	3.0	28.50	....	....	....	....	....	....	5,573
12.25	9	3.25	34.53	....	....	....	....	....	....	6,752
13.50	10	3.5	41.12	....	....	....	....	....	....	8,041

[a] In computing the volume of material in cubic yards per mile to be removed in the construction of each ditch it is assumed that the ditches follow the surface of the ground, thus maintaining a constant depth.

The ditches whose dimensions are given in the above table are of such sizes as would ordinarily be built. They vary from 1 foot to 10 feet in width on the bottom and from 6 inches to 3½ feet in depth. It will be seen that the velocity of the water depends largely upon the cross-sectional areas of the ditches. The velocity in the smallest ditch, with a grade of 6 inches per mile, is 0.18 of a foot per second, while the velocity in the largest ditch given in the table for the same grade is 1 foot per second, or about five and one-half times as great. By comparing the velocities given in any one column of the table it is seen that the water in the largest ditch has four to five times the velocity that it has in the smallest one. Knowing the quantity of water which the ditch must carry, and the permissible grade, the size can be determined by reference to the table.

For instance, 2½ cubic feet of water per second is delivered by a ditch 3 feet wide on the top, 2 feet wide on the bottom, and 1 foot deep, with a grade of 4 feet per mile. The table shows that practically the same volume is carried by a ditch 4½ feet wide on top, 3 feet on the bottom, and 1½ feet deep, with a grade of 6 inches per mile. It may be instructive as well as interesting to compare these two ditches to determine which is the more economical to construct and to use.

If built to convey water to the farm located as before described, the larger ditch would be about three-fourths of a mile long and would require the removal of 825 cubic yards of earth. The smaller ditch would be about 1 mile long, and 489 cubic yards of earth would be removed in its construction, a saving in the volume of earth of 41 per cent. The losses from seepage and evaporation in the two ditches would be in proportion to the surfaces exposed to the soil and to the air, and on this basis the loss in the larger ditch would be 12.5 per cent greater than that in the smaller. This comparison shows that the cost of construction of the smaller ditch is less, and that it is a more economical water carrier than the larger one.

A large head of water more economical than a small one.—In watering most crops the experienced irrigator knows that it is more economical to use a large head of water than a small one. A person can irrigate a given area in less than one-half the time with 2 cubic feet per second than would be required with 1 cubic foot per second, and it might be utterly impossible to irrigate the land with one-half a cubic foot per second, for the reason that the stream would likely be absorbed by the ground and sink into the subsoil instead of flowing over the surface.

In the irrigation of most crops a man can handle 2 or 2½ cubic feet of water per second with little difficulty. Assuming that 2½ cubic feet of water per second is the largest volume that will be required at any one time, the problem is to construct a ditch that will deliver this volume to the land. The size of the ditch and the grade upon which it is to be built are questions which should be decided approximately before the trial line is run.

METHODS OF RUNNING GRADE LINES FOR SMALL DITCHES.

The grades for many of the early ditches were established by plowing a furrow or digging a trench from the creek to the land to be irrigated and permitting the water to flow as the channel was opened. If the water flowed too rapidly the furrow was turned toward higher ground, and in case the water failed to follow the trench lower ground was sought. After running the preliminary furrow the final adjustment in the grade was made by plowing a second one, which eliminated the depressions and deviations in the first.

Accuracy in running grade lines.—The degree of accuracy which may be attained in grade lines run in this manner varies with the care taken in running the first and second furrows and in estimating the velocity of water flowing in them. If the banks of the ditch are high enough to prevent the water from overflowing them, time will usually even up the little inequalities in grade. Especially will this be true of those ditches that carry an appreciable quantity of silt, which is deposited wherever the current is slow. In this way depressions are filled up and the ditch is made even and uniform. This "leveling up" process is not confined to the ditch laid out in any particular way, but is constantly going on in all waterways where inequalities of grade exist. One advantage conferred by this method is that no mistakes are made in the location, that is, there are no stretches in the ditch where no grade is allowed, nor does the grade run in the wrong direction. Wherever water flows in a small trench or furrow it will flow more readily in the completed ditch.

TRIANGLE WITH PLUMB BOB.

One of the most common forms of leveling device is the triangle or "A." It has probably been used to run the grades for a greater number of ditches than any other except the engineer's level. The ease with which it can be constructed and the simplicity of its adjustment and use are the points that have appealed strongly to the pioneer ditch builder. The usual form is that of a triangle whose base and longest side is from 10 to 16½ feet in length. The different lengths which may conveniently be used are given in the table following:

Number of times triangles of different lengths are used in 1 mile and the amounts which should be allowed for various grades.

Length of base of triangle.	Number of times triangle must be applied in a mile.	Amount to be allowed in the length of the triangle for different grades.						
		4 feet per mile.	5 feet per mile.	6 feet per mile.	7 feet per mile.	8 feet per mile.	9 feet per mile.	10 feet per mile.
Feet.		*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*
10	528	1/16	1/8	1/8	3/16	3/16	3/16	1/4
11	480	1/8	1/8	1/8	3/16	3/16	1/4	1/4
12	440	1/8	1/8	3/16	3/16	3/16	1/4	1/4
15	352	1/8	3/16	3/16	1/4	1/4	5/16	5/16
16	330	1/8	3/16	3/16	1/4	5/16	5/16	3/8
16½	320	1/8	3/16	1/4	1/4	5/16	5/16	3/8

The headings "4 feet," "5 feet," etc., over the last seven columns of the above table are the number of feet of fall in the ditches per mile of length; the fractions in these columns give in inches the fall which must be allowed in the length of the triangle. These are correct to the nearest one-sixteenth of an inch, which is as close as the instrument can be read. The table shows that if the triangle be 12 feet long and a fall of three-sixteenths of an inch be allowed, the grade of the ditch will vary between 5.5 and 8.5 feet per mile.

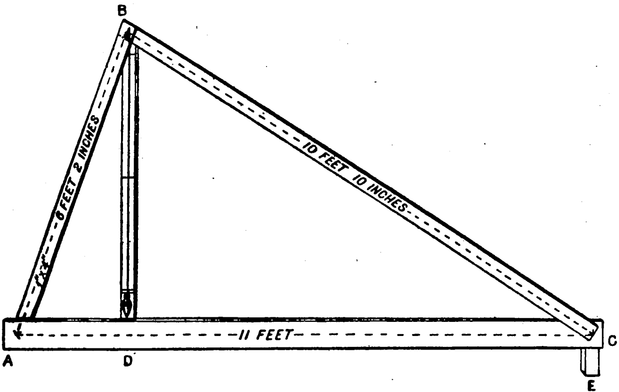

FIG. 2.—Triangle with plumb bob.

Fig. 2 shows a triangle with a base of 11 feet. Its construction requires a 6-inch board, *AC*, 11 feet long, for the base; for the other long side, *BC*, a 4-inch board 11 feet long, and for the short side, *AB*, a 4-inch board 6½ feet long. The 4-inch board, *BD*, along which the plumb line hangs, is 5 feet and 3 inches long. Two or three wide staples should be driven into this board over the plumb line to limit its swing. The plumb line is of such length that the point of the plumb bob just clears the upper edge of the base *AC*. The plumb bob for this device should have a long, slender point, so that its position can be more easily seen. A mark may be made on *BD* just above the plumb bob to indicate the center of its swing. The line is then read instead of the point of the plumb bob.

Manner of adjusting triangle.—The adjustment of the triangle consists in locating and marking the place where the point of the bob or line comes when the base is level. This is done in the following manner: Drive two stakes in the ground, making the distance between them equal to the length of the base of the triangle. The stakes should be driven so their tops will be as nearly level as can be estimated. Place the triangle with the ends of its base resting on the stakes; hold the triangle in a vertical plane and notice if the plumb swings clear of the staples; if it does not, drive the higher stake until it does. The plumb bob is allowed to settle, and a mark is made on the base directly under its point or back of the line on *BD*. The triangle is then reversed upon the stakes and another mark is made on the base or on the upright *BD*. A permanent line is then drawn across the top of the base midway between the two marks already made or between those on *BD*. When the triangle is held in such a position that the point of the plumb bob or the line comes to the last marks made, the base of the triangle is level. A leg shown at *E*, 6 inches long, may be fastened to the forward end of the triangle.

To use the instrument for the location of a ditch line, begin at the lower end of the ditch and proceed as follows: Drive a stake at the starting point, leaving its top 6 inches above the surface of the ground. Place the end *A* of the triangle on this stake and put *E* on the ground, along the line of the proposed ditch, and move to higher or lower ground as necessary in order to bring the point of the plumb bob or the line to the mark that serves to indicate when the base is level. Two points on the same level line are thus fixed. It is desired instead to find a point near *E* higher than the surface of the ground at *A* by an amount equal to the grade of the ditch in that distance. Shortening the leg *E* by this amount and moving it to higher ground, keeping the base *AC* level, the desired point is found. This point is marked by driving a stake in the ground, the top of which is 6 inches above the surface. The proper amount to be cut from the leg *E* may be determined in this manner: Divide 5,280, the number of feet in a mile, by 11, the length of the base *AC* of the triangle. The quotient 480 is the number of times the triangle must be applied to the ground in laying out a mile of ditch. Divide the number of inches in the fall of the ditch per mile by 480 and the result will be the amount in fractional parts of an inch by which the leg *E* must be shortened. In a ditch having a fall of 5 feet, or 60 inches, per mile, this is 60 divided by 480, or one-eighth of an inch.

Method of running grade lines.—The following method of running grade lines with this device is probably more commonly employed: The leg *E* is dispensed with, and after the point locating the center of the swing of the plumb bob has been located, a piece of wood of such thickness as to allow for the grade in the length of the base is tacked under one of the ends, as at *C*. The work of laying out the line can begin either at the head gate or at the farm. If a suitable location for the head gate is found, it may be desirable to commence there. In this case a stake, having its top 10 or 12 inches above the surface of the ground, is driven at the point selected for the head gate and the end *A* of the triangle is placed upon it. The end *C* is turned in the direction the ditch is to be run, and when the plumb bob comes to rest at the mark indicating that the base is level, a stake is driven so that its top is even with the lower face of the piece of wood fastened under *C*. The tops of the stakes will then have the proper grade, and the triangle can be moved forward with the end *A* on the stake just located and another stake driven as before. This operation is repeated until the entire line is run. The line so located need not follow the contour of the country, but can be made fairly direct. Knowing that the tops of the stakes are on grade, the cut at any place can easily be found. If the top of the first stake is 15 inches above the grade line at the bottom of the ditch, to locate the bottom at any other station it is only necessary to measure down 15 inches from the top of the stake there.

The plumb bob is placed near the rear of the frame, because its position can be more easily seen by a person holding that end upon a stake, and the motion communicated to it by the movement of the end *C* is less.

TRIANGLE WITH CARPENTER'S LEVEL.

How to make the frame.—The triangle is frequently used in connection with the carpenter's level, as shown in fig. 3. This device can be used in windy weather, when it would be almost impossible to run a line with a plumb bob. The frame may be made of two 3-inch boards, *AB* and *AC*, about 8 feet long, and a 2-inch by 4-inch piece, *DE*, about 6 feet long. The two pieces, *AB* and *AC*, are crossed at *A* and fastened with one nail; make the length of *AB* exactly equal to *AC*, say 8 feet, and make marks at *B* and *C* on the center line of the pieces. *BC* is a straightedge about 12 feet long, used temporarily in the construction of the frame. Mark upon its upper edge two points 11 feet apart. Bring the marks at *B* and *C* to the points on the straightedge, which is temporarily fastened with nails in this position. *AD* is now laid off equal to *AE*, say about four feet, and the two points *D* and *E* marked. The 2 by 4 piece, *DE*, is now laid across the frame, placing its upper edge on the points *D* and *E*. It is to be fitted and permanently fastened in this position. The 3-inch boards, *BE* and *DC*, are next put in place and nailed there. They hold the ends of the legs securely in position. The amount of fall in 11 feet is then calculated or taken from the table on page 13. It is laid off and marked on *AB*, measuring from the upper edge of *BC*. The piece *BC* is now loosened at *B* and the upper edge brought to this mark. The legs of the triangle are cut along the straightedge of *BC*. The leg *AB* should be marked in some way to indicate that it is to be used on the upstream end of the triangle.

To adjust the leveling device.—This method of constructing the leveling device assumes that the carpenter's level is in adjustment.

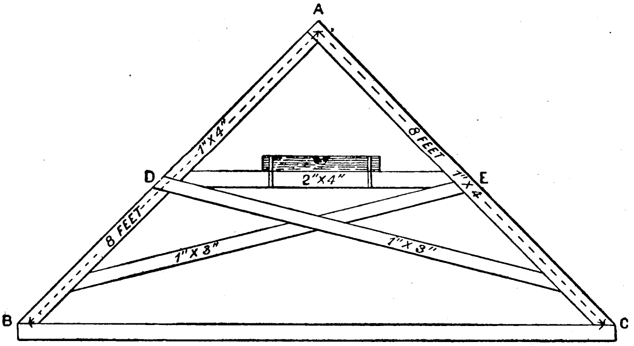

Fig. 3.—Triangle with carpenter's level.

If it needs adjusting, remove the level from the frame and proceed as follows: Drive two stakes, *A* and *B*, in the ground until their tops are nearly on the same level. Place one end, *A*, of the carpenter's level on the stake *A* and the other end, *B*, on the stake *B*. Drive one of the stakes until the bubble comes to the center of the tube. Place the end *A* of the level on the stake *B* and the end *B* on the stake *A* and note the position of the bubble. Reverse the ends of the level to their former position and see if the bubble returns to the center of the tube; if not, repeat the operation. If this can not be brought about, the level should not be considered trustworthy, and should not be used. After finding that the bubble returns to the center satisfactorily, place the end *A* upon the stake *B* and the end *B* on the stake *A* and correct one-half of the apparent error by the set screw which fastens the spirit level to the wood of the carpenter's level. Reverse the ends of the level and drive one of the stakes until the bubble comes again to the center. Repeat this operation until the bubble is in the center in both positions. The level is then in adjustment, and the tops of the stakes are at the same elevation.

Replace the carpenter's level on the frame and the device is ready for use. It should be tested each time before being used. This can be done as follows: The carpenter's level is in adjustment and the upper edge of *B C* (fig. 3) is a straight line. Place the level on this line and drive two stakes, one at *B* and the other at *C*, so that their tops are even with the upper edge of *B C*, when the bubble is in the center of the tube. The tops of the stakes should then be nearly level. By reversing the straightedge several times they can be more accurately driven, and any error of the carpenter's level can be eliminated. When the tops of the stakes are on the same level replace the carpenter's level on the frame and make its legs the same length by adding a piece of wood to the shorter one, *B C*. When the legs are set on the stakes the bubble should come to the center of the tube and should not change when the ends of the frame are reversed.

In use, whenever the bubble is in the center of the tube, the leg *B* will stand on the ground as much higher than the leg *C* as will give the proper grade to the ditch. The leg *C* is placed on a hub, a small stake driven flush with the surface of the ground at the lower end of the ditch line. A point 11 feet above on the ditch line is then found where *B* touches the surface of the ground when the bubble is in the center of the tube. This point is also marked by a hub. These two points mark the grade line of the ditch. The frame is then carried forward, placing the leg *C* upon the last hub, and this operation is repeated till the ditch line is entirely located. In order that the hubs may be easily found, a small stake is driven beside each.

SELECTION OF A SITE FOR THE HEAD GATE AND THE CHOICE OF DITCH LINES.

Fig. 4 shows the farm, the creek, and the ground over which the ditch is to be built. The grade assumed for the ditch *AB* is 5 feet per mile, or one-fourth the fall of the creek. Therefore the creek rises, in going upstream, four times as much as the ditch in going the same distance; hence, the line of the ditch will gradually approach the creek. The line and the creek will intersect at a point about 1 mile above the farm or about one-eighth of a mile above *B*.

Best location for head gate.—It frequently occurs, as shown in fig. 4, that the point where the preliminary line intersects the creek is not a suitable one for the location of the head gate. The banks of the creek are high, thus making a deep cut necessary, and owing to a bend in its channel the current is thrown toward the opposite side of the stream.

If for any such reasons the ditch can not be cheaply or conveniently taken out, the banks of the creek above should be carefully examined, to see if there is not a more desirable location. Suppose a point, *D*, is found about a quarter of a mile above, where the banks are not high and where an outer curve directs the current toward the head gate. If the stream is subject to sudden and heavy floods, it might be better for the head gate to be located on a straight portion of the channel rather than upon the curve.

Selection of ditch line.—After deciding that the head gate should be located at *D*, it is necessary to determine how to carry the water from there to the farm. The head gate *D* can either be connected with some point of the preliminary line, as *B*, or a new line can be run leading directly to the farm, as shown by the upper dotted line *DA*.

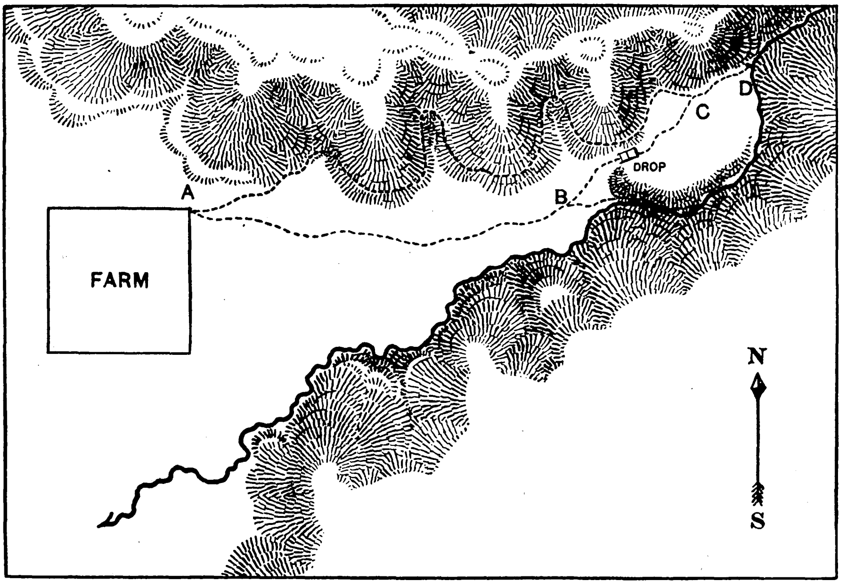

FIG. 4.—Sketch showing location of farm and possible ditch lines.

There are a number of questions to be taken into consideration before a choice between the two lines should be decided upon. Usually the higher the ditch line the rougher the country. Often rock is encountered, and the upper line is generally much more crooked if it follows the surface of the ground. A line run directly from the head gate to the farm has a grade of about 7 feet per mile. However, if this country is more broken than that along the preliminary line, the upper ditch will be crooked, and hence be longer than it has been estimated. This increased length will reduce the grade. Suppose in this case that, after examining the country along the upper line, it is found that a large quantity of rock would be encountered in the construction of the ditch. It is necessary then to go back to the head gate and examine the country between that point and the preliminary line. It is found that a short ditch, *DCB*, running from the head gate to connect with the preliminary line can be built. A uniform grade can be maintained by constructing a drop, located as shown in fig. 4. This compromise between the two lines is therefore decided upon. The fall of water over the drop is 3½ feet, thus allowing a grade of 6 feet per mile in the short ditch. If this precaution were not taken, its channel would be worn away in a short time, and the material thus washed out would be deposited in the lower ditch, from which place it would have to be removed. The drop (fig. 5) consists of a short flume, *D*, with a flaring approach and submerged platform, *A*. The floor *C*, on the grade of the ditch below the drop, breaks the force of the falling water. The flaring wings and submerged platform at *B* protect the ditch at that point. The dimensions are also shown in fig. 5.

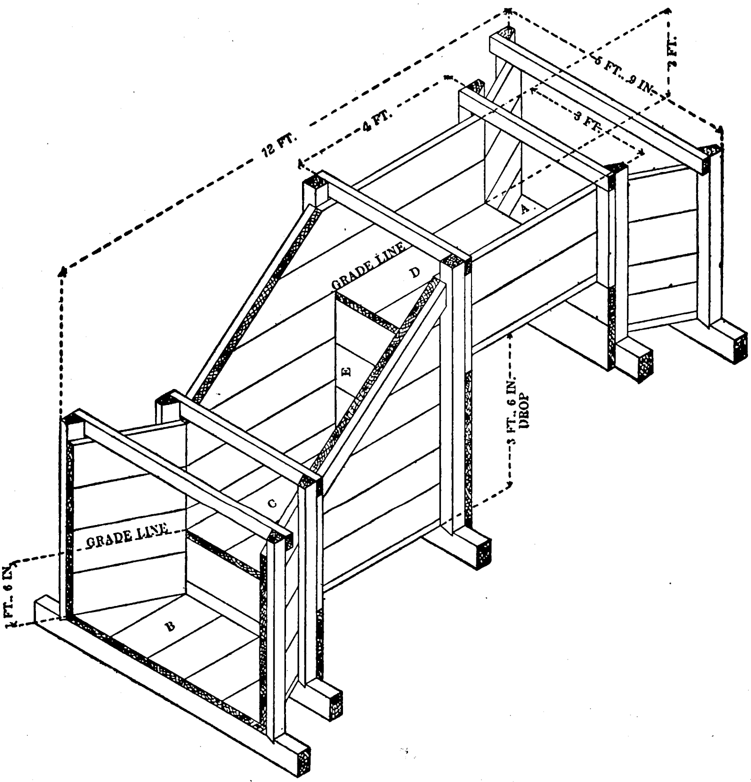

FIG. 5—Details of timber drop in ditch.

Method of marking ditch line.—To mark the line of the ditch with a furrow after it has been properly located, let one man guide the team, walking between the heads of the horses and holding a bit in each hand, while another holds the plow. If the surface of the ground will permit a wagon to be driven over the line, the plow may be attached to the rear axle, the driver directing the team from the seat of the wagon. The team is driven in such a direction as to turn the furrow to the lower side of the ditch. If the surface of the ground is comparatively level across the line of the ditch it is not necessary to follow the stakes closely in the bends. The ditch will be better for being straightened a little, which may be done by going above the stakes that locate the bends nearest the creek and a little below the stakes that locate the bends farthest away. If the ground slopes very much across the ditch line the stakes must be followed closely. After the line is marked, two or three furrows are plowed, turning them to the lower side. A ditch of this size may be built almost wholly with an ordinary plow, by going over the line a number of times. The loose earth in the bottom of the ditch may be removed with a plank scraper, shown in fig. 6. The tongue should be long enough to allow the team to work below the bank. The scraper is lifted over the loose earth as the team backs, and the load is dragged out as the team moves forward. A ditch of the size contemplated is rather too small to admit of using the ordinary scraper to advantage.

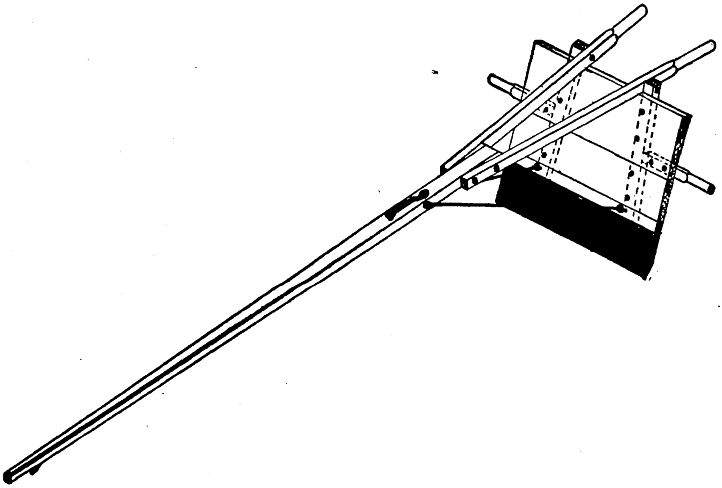

FIG. 6.—Plank scraper.

HEAD GATE.

A small ditch of the kind described might be used for years without a head gate. It will, however, be much better to have one, so the water can be shut off when it is not needed for irrigation.

Fig. 7 shows a common type of small head gate. It consists of a box or flume 6 feet long, 3 feet wide, and 3 feet deep, with a gate, *D*, at the end nearest the creek. At both ends the sides flare at an angle of about 30°. Under them, 1½ feet below the floor of the structure *C*, platforms *A* and *B* are built. Both of these platforms are covered with earth to the level of the floor *C*. Earth is also carefully tamped around the outside of the head gate.

All precautions should be taken to prevent water from working along the outside of the head gate. The structure may be undermined in a short time if only a small stream finds its way between the planks and the earth. The flaring wings and submerged platform are built to prevent this action, and also to make the structure secure in case of high water.

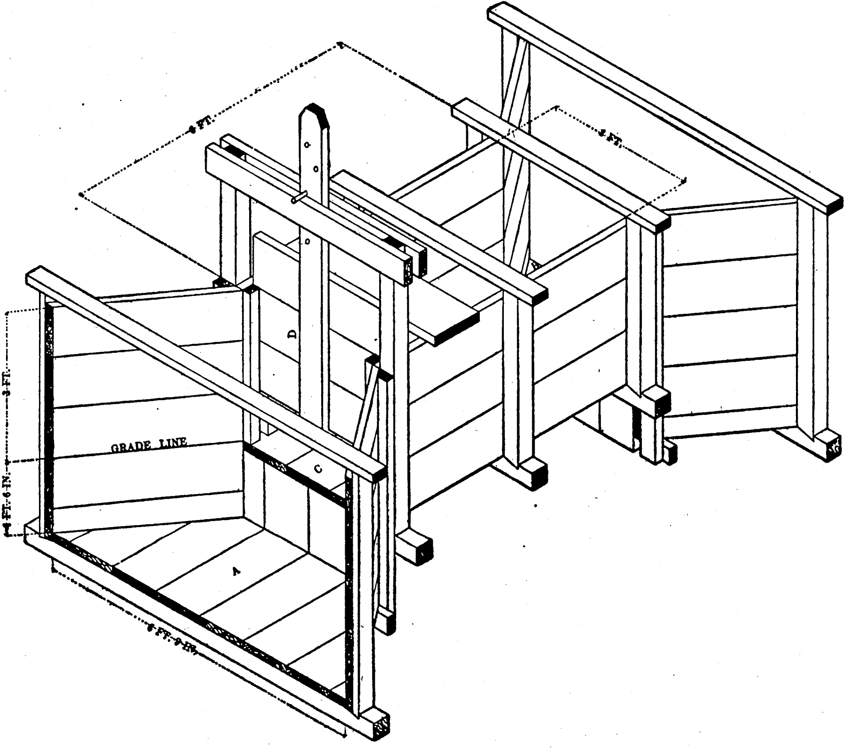

FIG. 7.—Details of head gate.

LAYING OUT FIELD LATERALS.

Location and grade.—The location of the laterals furnishes an opportunity for the irrigator to show his skill. While the land is new, spreading water over it will be a difficult matter. It may be impossible to properly locate the main laterals at first, and supplemental laterals and dikes may have to be constructed. Before the crops can be harvested these temporary channels must be filled in and the ground leveled. Theoretically, they should be given such a grade as will result in a moderate velocity for the water, but not sufficient to wash the earth along the sides and bottom of the ditch. One irrigator of considerable experience recommends that field laterals should have a fall of at least 10 feet per mile. The laterals should be located nearly at right angles with the direction of the greatest slope of the land, so that water will flow from rather than along them. Mistakes have been made in constructing them parallel with the steepest slope. When the water is turned from these it tends to follow rather than to flow away from them, thus adding greatly to the work of the irrigator. If the surface of the ground is somewhat uneven the problem of locating the permanent laterals becomes correspondingly more difficult, often rendering the use of the engineer's level necessary. It may be possible to cover all the ground by locating the laterals along the ridges, or there may be high points entirely surrounded by lower ground, making it necessary to build ditches on artificial ridges, or dikes, to carry the water to them. The inexperienced irrigator often considers that the ground occupied by the laterals is waste land, because it bears no crop. Accordingly, he makes them far apart, so that the water must flow a long distance to cover the surface between any two. This usually results in the overirrigation of that portion of the crop near the lateral in use, as the water must be kept flowing there until the entire surface to the next lateral is irrigated.

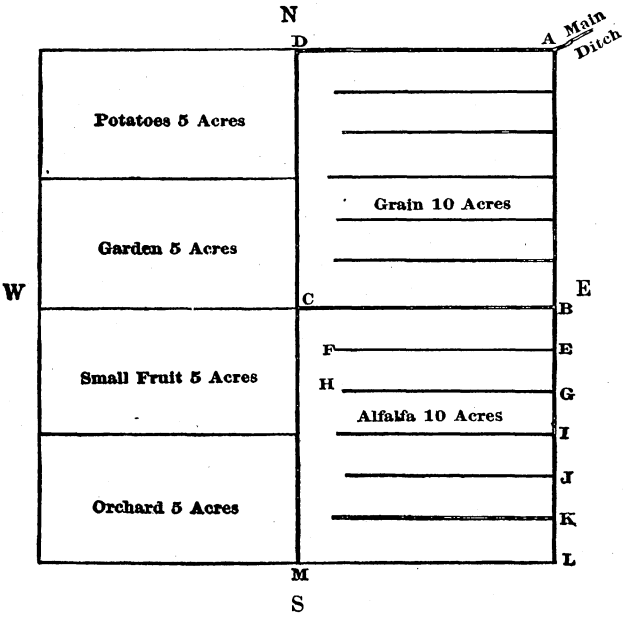

FIG. 8.—Plat of farm, showing laterals.

Preparation of surface.—It will usually pay to do some work in smoothing off the little irregularities in the surface of the farm. This may be done with a plank scraper, or drag, after the ground has been plowed. The drag cuts away the higher points and leaves the dirt in the hollows. This preparation of the surface is quite important, as it reduces the time and labor required in irrigating. A more uniform distribution of water is also obtained, which increases its efficiency. Theoretically, the surface of the ground should be a plane surface, with just slope enough to allow the water, when delivered at the highest point, to flow in a thin, uniform sheet.

We will assume that the farm is planted to such crops as are ordinarily found in the arid region, say 10 acres of alfalfa, 10 acres of grain, 5 acres of potatoes, 5 acres of garden, 5 acres of small fruits, and 5 acres of orchard, as shown on the plat of the farm. (Fig. 8.)

If it be assumed that there is a fall of 4 feet across the farm from north to south and 2 feet from east to west, the water can be made to flow either west or south from any point. The greatest slope of the land is a little south of southwest, and this is the direction the water takes if left to itself. If the laterals are run south from the main ditch they will make an angle of about 70° with this line. Such an arrangement permits the water to flow away from rather than along the laterals. The main ditch divides at *A*, as shown in fig. 8; one branch runs south to *L*, while a second runs west to *D*, the middle of the north line of the farm, where it turns and flows south to *M*. The field laterals receive their supply of water directly from these ditches.

METHODS OF APPLYING WATER TO CROPS.

Flooding.—Alfalfa is irrigated by the method known as flooding, which may be described as follows: Nearly parallel ditches, *B C*, *E F*, etc., are made 100 to 150 feet apart through the field. In the present case six ditches are made, 110 feet apart, dividing the field into six strips. As these laterals will remain as long as the field is in alfalfa, we may put division boxes (see fig. 9) at *B*, *E*, *G*, etc., where the laterals are taken from the main ditch. This will avoid cutting through the ditch bank and refilling with earth when the water is changed from one lateral to another. The division box is simply a short flume placed in the ditch with a channel leading away, usually at right angles. Vertical cleats are provided for holding flashboards in place for checking the water. These boards may be placed either in the branch or the main ditch as desired.

The division box at *A* (fig. 8) is set so the water will flow to *B*. At this point the division box is so adjusted that water runs into the lateral (*B C*), and the lower bank of the lateral is cut a few feet from *B*. Just below the cut a canvas dam is thrown across the ditch to force the water over the surface of the ground. The canvas dam is a piece of heavy cloth, 5 or 6 feet long and 3 or 4 feet wide, one edge of which is tacked to a pole long enough to rest on the banks as it is thrown across the ditch. The cloth rests against the bottom and sides of the ditch above the pole, where two or three shovelfuls of dirt are placed to hold it in position. When the water from lateral *B C* flowing over the surface reaches the lateral *EF*, entirely covering the intermediate area, another cut is made in *B C*, 100 to 150 feet farther from *B*. The canvas dam is again used to check the water, which is allowed to flow out as before. This operation is repeated till the entire surface of the first strip has been covered. The division box at *B* is then set to shut the water from the lateral *B C* and allow it to flow to *E*, where it runs into the lateral *EF*, and from it over the surface of the next strip. In this manner strip after strip is irrigated till the entire field is covered. The field laterals are not as large as the main ditch, and it may

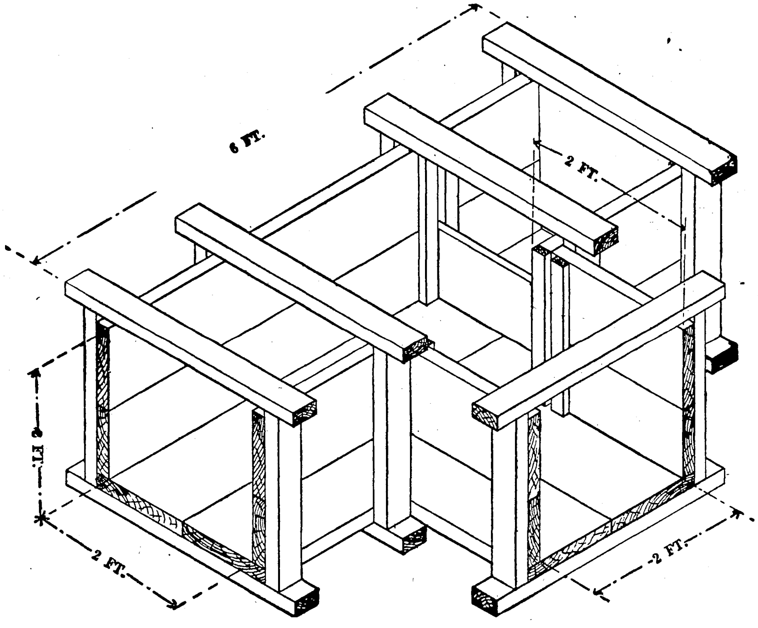

FIG. 9.—Details of division box.

be necessary to divide the water between two or more of them. Assuming that it will require a quantity of water sufficient to cover the field to a depth of 6 inches, in order to give it a thorough irrigation, it will take about twenty-four hours to irrigate the entire field. The ditch must carry 2½ cubic feet of water per second to accomplish this.

The grain crop is irrigated in the same manner. The laterals in the grain field may be made about the same distance apart as those in the alfalfa field. They may be built with an ordinary plow by turning two furrows away from each other, or they may be made with a special plow having two moldboards. This tool throws the dirt out of the ditch on both sides and completes the lateral in one operation. These laterals are used only for the one crop, and are filled with the plow just before the harvest, so that the binder may cross them in cutting the grain. If the grain is sown with a drill running east and west the small furrows made by it form miniature ditches, which the water follows. The irrigator must see that the water reaches those places where, on account of elevations or obstructions, it does not run readily.

Furrow irrigation.—For the irrigation of the crops on the south half of the farm, furrow irrigation is employed. The potatoes are planted in rows and are "furrowed out" before being irrigated. This is done by running a shovel plow between the rows, making small ditches, into which the water is turned and allowed to flow until it has reached the other end of the field. The water is "set" on a certain number of rows, allowing only a small stream to flow in each. The surface is not flooded, but the water is confined to the furrows and percolates laterally into the soil. The water is taken out of the permanent lateral *DM* at the corner of the field and carried along in a temporary ditch parallel to it. After a strip 100 to 150 feet wide, containing 40 or 50 rows, has been irrigated from the first opening, the main lateral is cut farther down, and the process is repeated. The garden may be irrigated in a manner similar to that described for the potatoes.

The small fruits and the orchard are crops of a more permanent character, and will occupy the same ground for a number of years. For these reasons division boxes are placed in the main lateral where it is desired to take out water. Ordinarily, small fruits are irrigated by the furrow method. It is thought better practice by many irrigators to allow a small stream of water to flow between the rows for a considerable time than to allow a large stream to run for a short period. This gives more opportunity for the water to soak into the soil, leaving it in the same condition as does a heavy rain.

The orchard is irrigated either by flooding or by furrows. Of the two, the furrow system is perhaps more often used. Parallel furrows 3 to 6 feet apart are made and small streams of water are allowed to flow in them until the ground is thoroughly saturated.

In some localities the best results are obtained from the orchards when the entire surface of the ground is flooded. Care is taken, however, to keep the water away from the trees, as it is found that they thrive better when the water does not touch them, but percolates into the soil and reaches the roots. When all of the ground between the trees is moistened the roots spread uniformly. Where furrows are used for irrigating orchards they are often plowed in after water has been applied. The ground is then leveled and the surface finely pulverized. As long as the surface of the ground remains in this condition evaporation is greatly reduced. This method requires considerable work, as the laterals have to be made some time prior to the irrigation of the orchard.

There are other methods for applying water to crops, but all of them require a more elaborate preparation of the surface of the ground, and need not be described here.

Cultivation should follow irrigation.—When it is possible, cultivation should follow each irrigation as soon as the ground is dry enough to be worked. If all crops could be cultivated in this way the amount of water which would have to be applied would be greatly reduced. The duty of water is uniformly small for corn, potatoes, orchards, and other crops which can be easily cultivated. If the ground can not be cultivated after it has been irrigated, the surface will often bake. This is injurious to some kinds of plant growth, and evaporation is thereby greatly increased, making another irrigation necessary much sooner than it would otherwise be.

WHEN TO IRRIGATE.

In order to determine just when crops need water and when to apply it so that they will not suffer from drought, nor be injured by too frequent or too generous applications, requires a knowledge and experience that can be gained only by practice and a close observation of various crops under irrigation. It is the experience of many practical irrigators that if an unlimited supply of water is available crops more frequently suffer from overirrigation than from drought. It is difficult to determine when the development of the crop is first arrested on account of a lack of moisture in the soil. Some experimenters maintain that this point can be more definitely decided by an examination of the soil than by the appearance of the plant, as the latter shows evidence of the check in its growth some days after it has occurred. Usually it is then too late to prevent serious loss, as the crop rarely recovers from such treatment, and seldom reaches the development it would have attained if it had been irrigated at the proper time.

Plants will usually indicate by a change in color or by their general appearance whether they need water or when they have been overirrigated. Most field crops turn to a darker green when in need of water, and the leaves and stems show a tendency to droop or curl. The lower leaves assume a pale yellow. A crisp or dead appearance in the lower leaves is one of the best indications that a plant needs water. Grain which has suffered from drought may mature, but the straw will be small and short and the kernels will be shrunken and inferior in quality. Alfalfa and similar crops have the appearance of cured hay. Where field crops are overirrigated the color of the foliage becomes a yellowish green and the plants have a sickly appearance. These indications vary with the quality of the soil, so that it is impossible to lay down fixed rules to govern the number or frequency of irrigations. Only close observation for a number of years on the same farm will enable a person to tell by the appearance of the plants whether they need water or not.

The amount of moisture in the soil may be determined with sufficient accuracy for the needs of the plant by examining a sample taken a few inches from the surface of the ground. If it clings together when molded in a ball and shows the print of the fingers, there is moisture enough present. If the earth falls apart when the hand is opened, irrigation is needed. As stated above, this point is passed some days before the plant shows indications of suffering.

COST OF BUILDING AND MAINTAINING A DITCH.

The cost of a small system of irrigation, similar to that already described, may properly be considered here. The ditch is 1¼ miles long, and the main laterals on the farm are of the same cross-sectional dimensions, and are five-eighths of a mile long. The laterals in the alfalfa and grain fields have a total length of 1¼ miles, and are slightly smaller. A short calculation shows that nearly 1,250 cubic yards will have to be moved in the construction of these ditches. This volume at 5 cents per cubic yard makes the cost of the work $62.50. The head gate requires 360 feet B. M. of 2-inch planks and 2 by 4 inch scantling, at a cost of $15 to $18 per thousand. The 30 division boxes are made of 2-inch lumber and require nearly 4,000 feet B. M. The head gate, drop, and division boxes will cost, in place, not far from $125. This will make an investment of about $200 in the completed ditches.

Quantity of water required for ordinary field crops.—It has been demonstrated by experiment that it requires a volume of water sufficient to cover the area to a depth of 2 or 3 feet to mature ordinary field crops. Basing the calculation on these figures, and assuming that there is no rainfall during the irrigation season, it will require an aggregate of from sixteen to twenty-four days to complete the work of irrigation if the ditch delivers 2½ cubic feet of water per second and the work is carried on day and night. Assuming that twenty days is a mean period for this work, the cost of irrigation therefore approximates $1 per acre. Since some crops require that the water be watched continually during irrigation, the cost per acre is increased somewhat, owing to the necessity of employing a man to work at night. The average cost probably does not exceed $1.20 per acre.

After the first year the cost of repairs will amount to something like 10 per cent of the original outlay in building the ditch, or about $20.

The following summarizes the original cost of the ditch and laterals and the yearly outlay for repairs and labor:

Cost of ditch and laterals.

Making level and running line	$12.00
Cost of excavation of ditch and laterals	62.50
Cost of head gate, drop, division boxes, etc	125.00
Total	199.50

Yearly cost of irrigation and maintenance of ditches.

Labor in irrigating	$48.00
Repairs to ditches	20.00
Total	68.00

In the above estimate the labor has been included at average prices for such work. If the farmer has time to do the work himself, his only cash outlay will be for lumber.

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