OFFICIAL PUBLICATION OF
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

Vol. XVII October 9, 1918 No. 19

RECOMMENDATIONS FOR FARM DRAINAGE

19-27071

By
W. J. SCHLICK

BULLETIN 51
ENGINEERING EXPERIMENT STATION

Ames, Iowa

"Acceptance for mailing at special rate of postage provided in section 1103—Act of Oct. 3, 1917. Authorized Sept. 23, 1918."

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THE purpose of the Engineering Experiment Station is to afford a service, through scientific investigations, evolution of new devices and methods, educational technical information, and tests and analyses of materials:

For the manufacturing and other engineering industries of Iowa;

For the industries related to agriculture in the solution of their engineering problems;

For all people of the State in the solution of the engineering problems of urban and rural life.

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Drainage Engineer

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"Don'ts" for the Land Owner

Don't try to do the work for which you should employ an engineer.

Don't let your contractor do both his work and the engineer's. You may reduce the first cost thereby, but the chances are that in the end you will have lost much more than the cost of the engineer's services.

Don't employ any but a capable engineer. The fee for the services of a capable engineer will be higher than for those of a poor or inefficient man, but he will really cost you much less. The mistakes of an incompetent man cost more than the fee of the best engineer.

Don't have your drainage planned piecemeal. If you cannot put in a complete system at first, have the entire plan worked out and then construct it as you are ready. If your work is planned a little at a time the chances are that in the end you will have an inefficient, overlapping system.

Don't destroy the records of your drainage system. If you have a complete record of those drains which have already been constructed, it will be easy to plan your additions so that they will render efficient service. This record will also be of considerable value if your farm is offered for sale.

Don't expect yourself or your engineer to be able to look at a tile and judge its strength. The appearances of tile in this respect are deceiving. Have a sufficient number of them properly tested to assure yourself that they meet your requirements.

Don't try to save money by using poor tile or poor construction. Low first cost may mean a high maintenace cost with small benefits.

Don't be discouraged if your drainage system does not come up to your expectations the first season. All soils, and especially the "closer" ones, drain more readily the second and third years than they do the first.

Don't be satisfied with any system that is not designed and superintended by a capable engineer, and constructed of good materials by a reputable workman.

Recommendations for Farm Drainage

Farm drainage is responsible in large measure for the high productivity of Iowa soil. Not only has it greatly increased the yield of many thousands of acres of good land, but it also has entirely reclaimed many other thousands of acres which originally were untillable. Farm drainage, probably more than any other one extensive operation, has added enormously to Iowa's wealth, both rural and urban. It is, therefore, of common interest to layman and engineer alike.

While this bulletin is prepared for the general guidance of landowners who wish to construct farm drainage systems, it contains information needed by the young drainage engineer. Some paragraphs are really addressed to the engineer, but they should also serve as a guide to the landowner in the formulation of his plans for the proposed drainage system, and later enable him to issue intelligent and correct instructions to his engineer.

These recommendations are intended to give a good general knowledge of the main features of the farm drainage system. Should the reader desire to make a more detailed study of the subject, including the results of drainage investigations, he should write for Bulletins 50 or 52 of this Station.

DOES UNDERDRAINAGE PAY?

Every landowner who has given any thoughtful observance to this subject will answer this question in the affirmative, and the more thoro has been his study of the question the more emphatic will be his answer.

During the reconstruction period, when our farm products must be sufficient not only for our own needs but for those of portions of war-torn Europe as well, it is the duty of every landowner to increase the production from his land to the maximum.

During the spring of 1917 the writer put the above question to a number of owners and tenants of tiled land in north-central Iowa. They estimated that the underdrainage had increased the production of corn from ten to twenty bushels per acre on land which had formerly produced a partial crop in dry years. In other cases they stated that land which had formally been too wet to cultivate was producing, on an average, as much as the higher and dryer land.

In answer to another question, they stated that they could begin cultivation three days to fourteen days earlier in the spring because of the drainage; and that after a rain they could cultivate their crop on underdrained land in about one-third to one-half the time they had to wait for undrained land to become dry enough to work.

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*Bulletin 50 gives discussions of the forms of soil-moisture, their relation to crop production and drainage, the movements of ground water to and in the drain, and the design of the drainage system.

Bulletin 52 includes data for several typical Iowa underdrainage systems on rates of runoff and the fluctuation in the ground water level, and their relation to the spacing and depth of laterals.

In none of these fields were the drains spaced closer than one hundred feet, so that the cost of drainage per acre underdrained was probably not more than forty dollars in any case. Even with corn at only fifty cents per bushel, which is only about one-third the present market price, the ten bushel increase due to drainage will pay the interest on the investment and leave enough surplus to repay the principal within a few years, and do this with a decrease in the cost of producing the crop.

Does tile drainage pay? Study it; watch the results in your neighbor's field; the result will be an enormous increase in the production and wealth of Iowa.

THE EMPLOYMENT OF AN ENGINEER.

It is especially recommended that the landowner employ a competent engineer to plan his drainage system, and to superintend its construction, or at least to specify the materials and general methods of construction. The agriculturist should no more expect to act as his own engineer than as his own attorney. In either case his lack of special knowledge will probably result in financial loss. The drainage system is an investment; it is constructed only when the landowner believes that it will yield good returns on the amount invested in it. Because the engineer gives the solution of each problem the benefit of his special knowledge and bases his conclusions upon the accurate information obtained from a survey of the area to be drained, the amount expended for his services will yield far greater returns than any other part of the cost of the system.

PLANNING THE SYSTEM.

A correctly planned and constructed farm drainage system is much more nearly everlasting than any other farm improvement, and has a much lower annual maintenance cost. The useful life of such a system will be terminated only when the knowledge of underdrainage has advanced to a point where it will be profitable to replace the old system with a new and more efficient one.

In planning his drainage system the landowner should look to the future as well as at the present and not be "penny wise and pound foolish" in attempting to reduce the cost of his system. A few dollars saved in time or expense in designing the system may cause an annual loss of a greater amount in the returns from the system. Every detail of the system should be carefully studied and investigated before the final design is decided upon. Such study will result in a more efficient system at a decreased cost.

THE OUTLET.

The outlet is the first essential of a good underdrainage system. No matter how well it may be designed and constructed, any system of underdrainage which is deprived of a satisfactory outlet will fail to give satisfactory service. Therefore, the first step, in planning underdrainage for any area is to locate, definitely, the most suitable outlet.

The ideal outlet provides for a free flow from the main at all times; allows the construction of the main drain at a good grade; and requires a depth of cut just sufficient to permit of ready flow from the submains and laterals. It may be either a natural drainage channel, a county drain or an open ditch. Usually a small amount of reconnoissance by an experienced engineer will enable him to decide upon the feasibility of any proposed outlet. There may be cases, however, where the capacity of the outlet will need to be carefully investigated to determine whether it will care for the flow reaching it without submerging the tile outlet too greatly or for too long periods. This should be done after the tile system has been designed tentatively.

SURVEY AND PLANS.

Having decided upon an outlet, a complete survey should be made of each area which may eventually be included in the district served by the one system. A complete drainage system can then be outlined. It may be that the landowner will wish to construct at first the underdrainage for only a small part of his total area, but if the plan for the complete system is worked out in the beginning any part may be constructed at any time and yet contribute toward the finally complete and efficient system. If the work is planned only a litttle at a time, and so constructed, the result will very probably be a collection of overlapping small systems which make one large, inefficient system. As each section is constructed, it should be noted exactly on the plan so that additional work may easily and accurately be joined to that already constructed.

LOCATION OF LINES OF SYSTEM.

The location of the main drain will be controlled largely by the position of the outlet, the size, shape and slopes of the area to be drained, and by the location and depths of the laterals. The main and submains should be so located as to provide good grades and to permit easy construction and efficent operation of the lateral system. In large measure, the location, alignment, depth, and grade of the main and submains will control the form, depths, cost, and efficiency of the lateral system. So far as possible the mains should follow the line of the lowest elevation thru the area to be underdrained, so that the laterals will have a good fall and yet not be too deep.

THE LATERAL SYSTEM.

Considerable study is often necessary to plan a lateral system which will best suit the needs of the area to be drained. This study should be complete, as the thoroness of drainage will depened very largely upon the effectiveness of the lateral system.

Certain general principles are found to govern the spacing and depths of lateral drains. These are particularly applicable to different parts of the system located in the same general area.

Th flow of water thru the soil to the drain is governed by the same laws which control the flow of water thru the drain, or in a ditch along the road. The rate of flow in either case is dependent upon the fall or grade, the roughness of the sides of the channel and its size and shape.

The rate of runoff from the tile system is but the rate at which the water moves thru the soil to the drain, providing that the tile lines have a large enough capacity to care for all the water as it reaches them As will be seen from the diagram in Fig. 1, the watertable rises in a curve from each drain and reaches its highest point midway between two adjacent drains. Since for any field the size and shape of the soil pores, and the resistance to the passage of the water thru them, are the same at any one time for different spacing and depths of laterals, it follows, that, in general, either decreasing the distance betweeen laterals or placing them deeper will increase the slope from the crest of the watertable to the drain, so long as the crest of the watertable rises to the same elevation in respect to the surface of the ground. This will increase the rate at which water reaches the drain.

By increasing the depth of laterals, and accordingly lowering the groundwater line after each rain, a larger volume of soil is freed from surplus moisture. As it is only in that portion of the soil which is free from surplus moisture that plant roots can obtain food and live, it becomes one of the important functions of underdrainage to maintain the groundwater line at each such level as will best serve vegetation.

Any change in the system by which the groundwater can reach the underdrains more rapidly will hasten the drying of the soil after rains and permit of earlier cultivation.

The effects of spacings and depths of laterals may be summarized as follows:

Decreasing the distance between drains not only increases the rate of runoff but decreases the time necessary to remove the surplus moisture after each rain.

Increasing the depth of the drains increases the rate at which the drains remove water from the ground and lowers the average level of the groundwater, thus providing a larger food supply for growing crops.

A correct understanding of these principles and the diagram in Fig. 1 will assist the landowner in deciding upon the general features of a system to serve his area. In considering different spacings and depths it should be remembered that the rate of movement of water thru a close, fine-grained clay soil is always less than that thru the more open loam. This point should be considered when contemplating any increase of depth which will place the laterals in a more impervious soil.

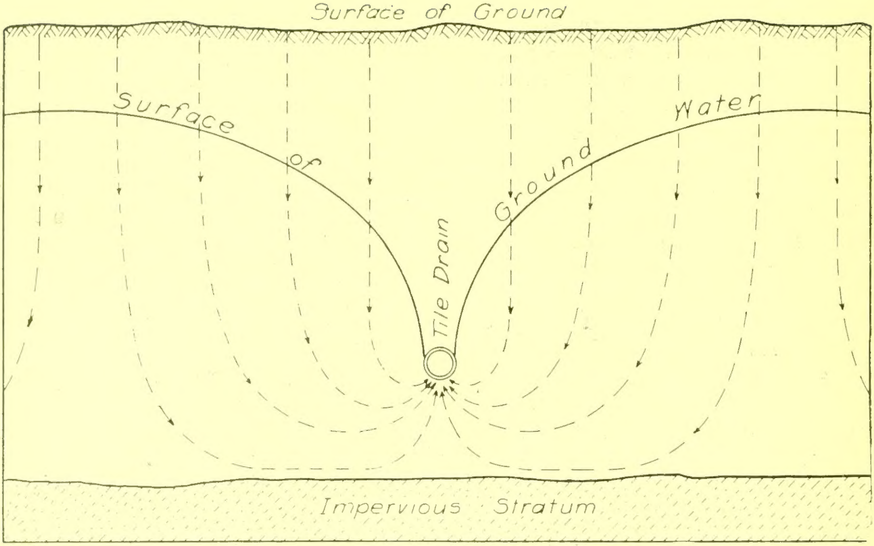


Fig. 1. Diagram Illustrating the Movement of Water from the Surface to the Drain.

The increased depth might thus be a detriment for the first few years. It is doubtful, however, if there are any soils in Iowa in which the lateral drains should not be placed as deep as recommended hereinafter.

Thus it is seen that the success of any underdrainage system depends upon the freedom with which water may pass thru the soil. Many persons hold the erroneous belief that the water falling on an underdrained area moves directly from the surface to the top of the drain. Such is not the case. No water ordinarily enters a drain from the top except that which falls upon the surface directly above the tile, and then only when the soil conditions are such as to allow of a nearly vertical percolation from the surface to the underdrain. The path taken by a drop of water in passing from the surface to the drain is illustrated in Fig. 1 The surplus moisture in the upper layers of soil, or upon the surface, moves as nearly directly downward as the soil formation will allow, until it reaches the level of the groundwater. It then moves downward and laterally in a curved path to the drain, entering it from the bottom. Its movement after reaching the groundwater level is somewhat uncertain, but Fig. 1 illustrates the general course of this movement.

In speaking of the relative efficiencies of different systems, it is often stated that the underdrains in one field "draw" better or farther than those in another field. Actually the drains do not draw at all, if by that it is meant the tile exert a pull tending to suck the water out of the soil pores and into the drain. The underdrains serve simply as collecting channels or outlets for the percolating water. If one field is drained farther back from the lines of the tile than is another, it signifies simply that the conditions of the soil are such as to cause a more ready movement of the groundwater to the tile in the one field than in the other and that the tile in the bettter drained field have ample capacity to remove the water as it reaches them.

Laterals spaced from 50 feet to 100 feet apart in ordinary Iowa soils will give adequate drainage for field crops. If the soil is unusually close, or if the drained area is to be used for truck crops, the laterals may need to be as close together as 33 feet. If the soil is unusually open, or if there is a large surface runoff from the area to be drained, the distance between the laterals may be increased to 150 feet, and in very rare cases to 200 feet. However, spacings larger than 100 feet or smaller than 50 feet are not now desirable for the average soils of Iowa.

In most Iowa soils, laterals laid at a depth of about four feet will give the best service. In a few cases where the sub-soil is very impervious up quite close to the surface, it may be desirable to use a less depth, but even in the closest clay it generally will be found advisable to use this depth and decrease the distance between the laterals. It is well known that underdrainage will show far greater results the second or third year than it does during the first year, and it is doubtful if there are any Iowa soils which will not drain satisfactorily after the first three years if the system is properly designed and constructed and the laterals laid four feet deep.

Relation to Efficiency and Cost. In any underdrainage system the separate parts must be correlated if the whole is to be efficient and its cost a minimum. Each part must be considered not only by itself, but in its relation to every other part. By such analysis it often appears advisable to change the tentative location of the main, either in alignment or in grade, so as to serve, to the best advantage, all the laterals of the system. It should also be borne constantly in mind in locating the various lines of the system that the most economical arrangement is usually that one having the least number of junctions. At each junction point the land is drained by both the joining lines, so that a few long laterals are rather to be desired than are a larger number of shorter ones. The above are general principles, not iron-clad rules; each system must be designed to meet the special needs of the area which it is to drain.

Relation to the Area to be Drained. In slough or swamp areas of irregular shape, it is usually advisable to run the main up the general course of the low area and drain the arms by laterals. For wider and more regular sloughs a main may follow up the center, with parallel laterals branching at approximately right angles on each side, or a number of long parallel laterals may be laid up the slough and all joined to a main at the lower end. Unless the slough is too wide or too long, the latter system will probably be the cheaper.

The seepy places at the bottom of a slope can best be drained by laying a tile so as to intercept the seep water at the foot of the slope. Such a drain should have a good grade and should follow the foot of the slope as closely as is practicable. Its depth should be determined by the depth of the porous stratum from which the water seeps.

The underdrainage of areas adjacent to a natural drainage channel or open ditch can usually be accomplished best by the construction of a number of small systems, each serving a small area. All the tile in these small systems may be of small size, thus reducing the total cost below that of one large system. However, this scheme can be followed only when the water course will furnish a good outlet for each of these small systems.

SURFACE DITCHES AND INLETS.

When the area to be drained receives considerable surface runoff from adjoining lands it is sometimes advisable to provide shallow surface ditches to care for this surface flow. Such ditches will usually follow the line of the lowest elevation. They should be very shallow, not more than one or two feet deep, but should be wide and should have very flat side slopes. Such a ditch will aid materially in caring for the surface flow in the spring and during heavy storms and will not interfere with the cultural operations. It is desirable to furnish outlet for these ditches through an inlet and a short line of tile, whether the outlet is a large tile, an open ditch or a natural watercourse. Such construction is very necessary if the flow in this shallow ditch is to empty into a county tile drain. If the ditch is to empty into an open channel some protection is necessary or a deep ditch will gradually be cut back into the field.

These shallow ditches should never be used except across flat fields. If the general surface slope is at all steep such ditches are not necessary and if constructed would soon wash out so as to become impassable with field implements.

It is often desirable to construct inlets for the quick removal of water which collects in the depressions or ponds. Such inlets should be of durable construction, and should be so designed and located as to readily admit the surface water to the drain and still prevent the admission of trash carried by the surface flow.

Probably the most inexpensive surface inlet can be constructed by filling in over a short section of the drain with crushed stone or coarse gravel. Such an inlet will be satisfactory as long as the amount of water to be carried to the drain is quite small. Some landowners favor the construction of such inlets wherever the dead-furrows cross a line of tile. In most cases where it is necessary to construct surface inlets the amount of water to be removed will be large enough to make it advisable to use some other type than the crushed stone inlet just described. Inlets may be constructed of brick in the same way as for sewers or of tile or sewer pipe. For farm drainage systems it is probable that the most economical, satisfactory inlet can be built by replacing one length of drain tile with a sewer pipe T and building the vertical leg to the surface with sewer pipe. The top of this vertical section should be fitted with a wire or cast iron grate.

UNDERDRAINGAGE OF UPLANDS AND SLOPES.

In addition to removing the surplus moisture, underdrainage is desirable and valuable for upland tracts as well as for level or swampy areas because of its action upon the character and formation of the soil. The supply of available moisture in upland soils, and especially in the slopes, is usually small. Underdrainage will so alter the physical character of these soils as to increase their capacity for that form of moisture which is valuable for plant use.

Upon the slopes of areas not underdrained much of the water from rainfall escapes as surface runoff before the soil has time to take it up. The moving water collects in the small depressions and forms into rivulets which flow down the slopes. These small streams carry away much of the surface soil and in time wash out large gullies. Upon the more gentle slopes much of this erosive action may be prevented by the construction of properly designed underdrainage systems. The action of the underdrains not only increases the reservoir capacity of the soil but also the rapidity with which the water will pass from the surface to the subsoil. Through these two agencies the amount of surface runoff is materially lessened and a corresponding reduction effected in the erosive action.

VERTICAL DRAINAGE.

"Vertical drainage" contemplates the use of wells as drainage outlets. One system of vertical drainage consists in constructing numerous comparatively small and shallow cased wells each of which is designed to serve as both laterals and outlet main of a small system. The surplus soil moisture is supposed to move through the soil pores to these wells and from them to some porous underground stratum through which it finds a final outlet. This system will probably be less costly than tile drainage but will be much less efficient and its use can not be recommended.

In the other, and more common system of "vertical drainage" wells are used as outlets for tile drains. This system has not proved uniformly successful, and so cannot be recommended for general use. In some cases an outlet for a farm drainage system can be secured economically in this way, but it is practically impossible to foretell the success of such outlets. Some wells which at first afford very satisfactory service fail later to care for the flow of water from the drains. In some localities one well will prove amply sufficient, while another, nearby, will be entirely inadequate. If no satisfactory outlet of one of the usual types can be secured, this means may be tried if, from the engineer's

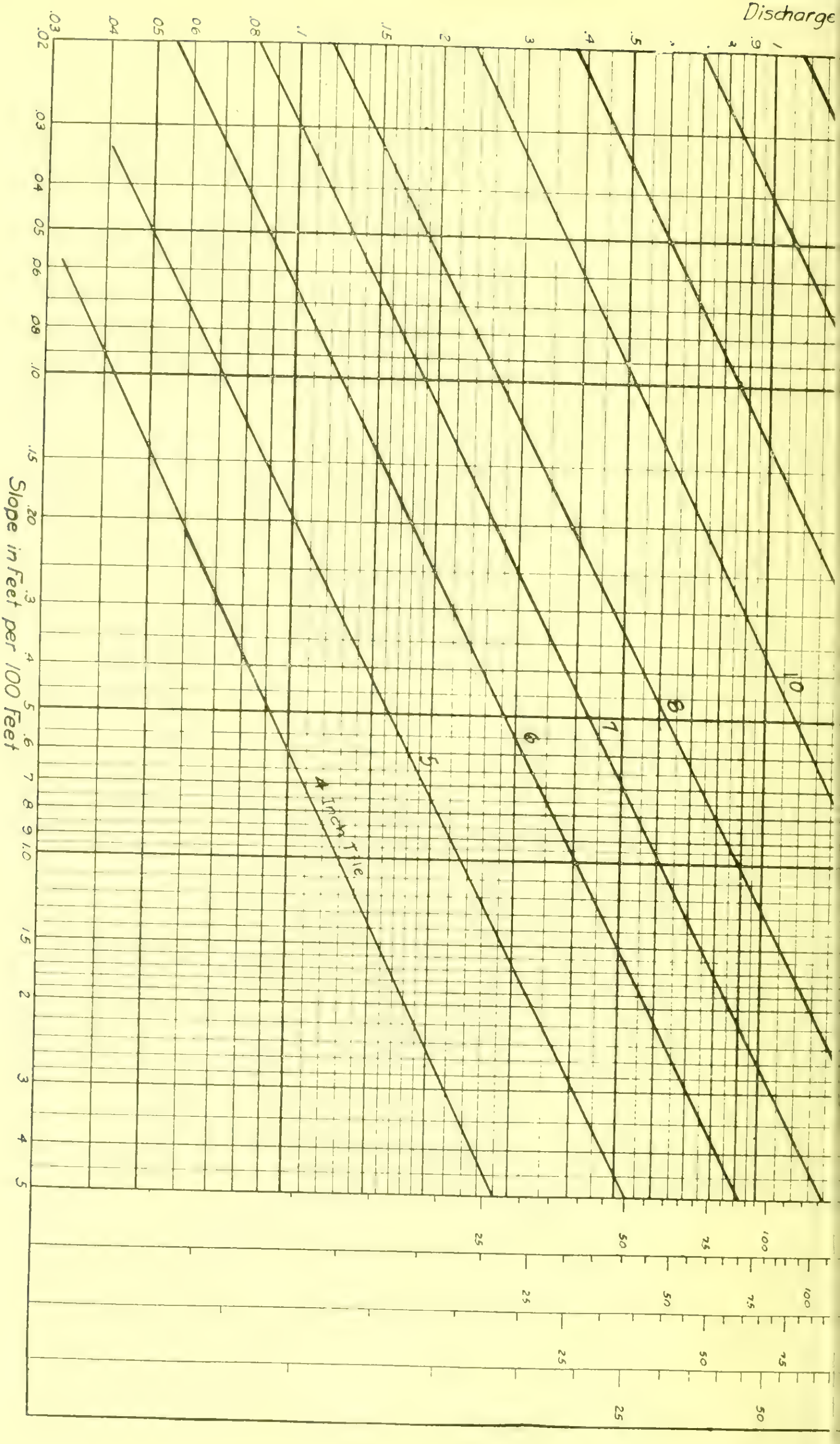
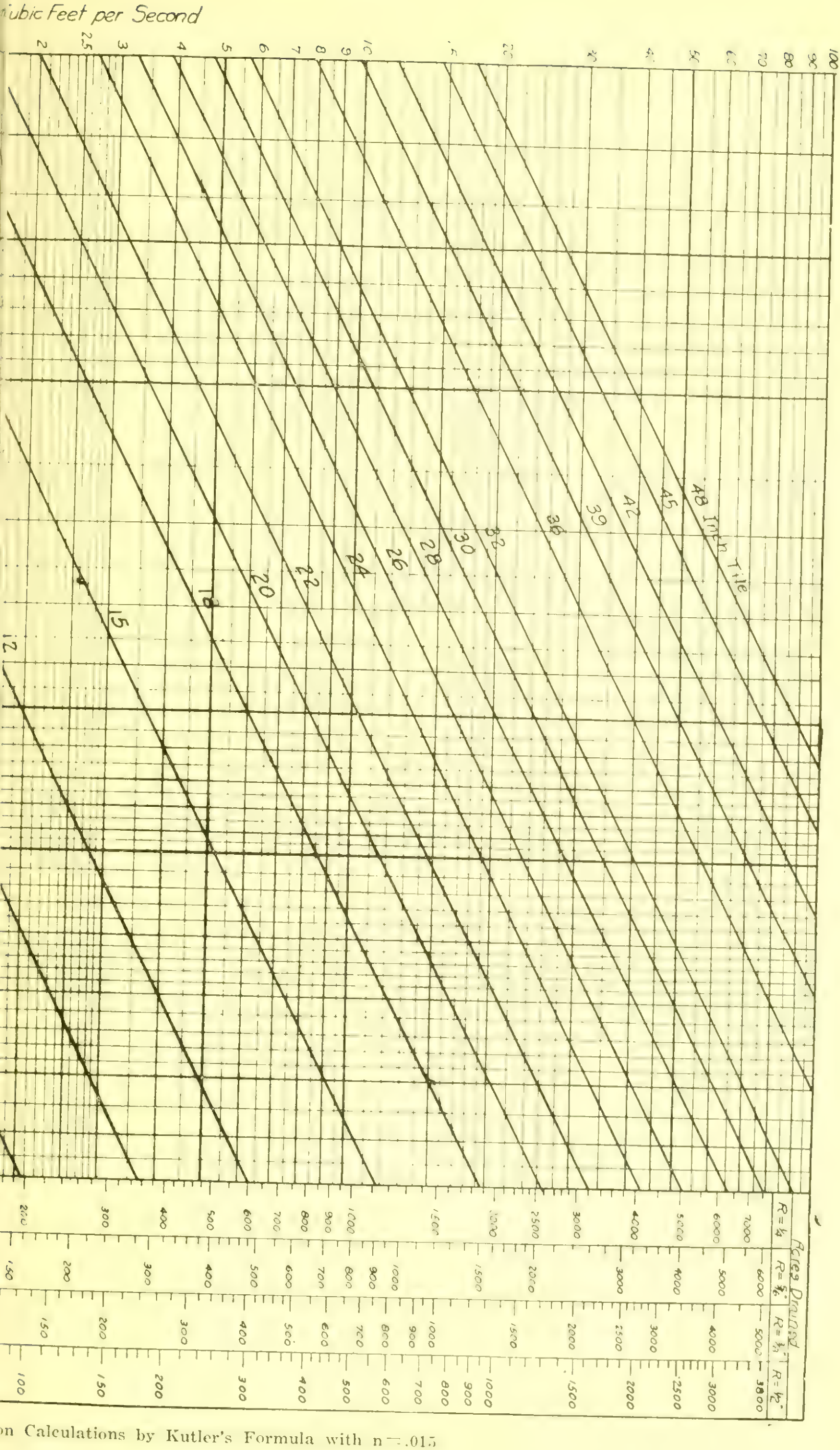


Fig. 2. The Capacities of Tile Drains b



on Calculations by Kutler's Formula with n = .015

knowledge of the district, it seems certain or probable that porous underground stata, of sufficient cross section to carry away the drainage water, can be reached within reasonable distance.

The cost of wells for drainage outlets will depend upon the size and depth of the wells and the nature of the material which must be excavated; it is, therefore, wise to determine quite definitely what is involved before deciding to construct such a system.

SIZE OF TILE.

The following discussion of runoff and the methods of calculating sizes of tile is intended particularly for the young drainage engineer. It will prove of value to the landowner also, by explaining how his system should be designed and by furnishing him with a means of understanding the decision of the engineer upon questions which may arise regarding the sizes of tile to be used.

Runoff. The runoff coefficient adopted will control in a large measure the cost of the system and the efficiency of its operation. It should provide a rate of runoff large enough to insure adequate drainage for heaviest storms to be expected year after year, tho perhaps it is not always necessary to provide sufficient capacity for the extreme maximum during those extraordinary storms which occur, say, once in ten or fifteen years.

The rate of runoff from underdrains will vary directly, tho not necessarily proportionally, with the amount and character of the rainfall. Localities subject to heavy rainfalls will have a rate of runoff larger than will other localities having less rainfall. The nature of the storms also, will have a marked effect upon the runoff from underdrains. For instance, a rain of one inch falling in a short time, as in summer thundershowers, will cause a much smaller total runoff from underdrains than one of an equal amount falling as a gentle rain for twelve or twenty-four hours. In the case of the heavy shower the water reaches the earth much faster than it can be taken up by the soil, and, of necessity, much of it must run away over the surface. However, the rainfall in Iowa is of sufficient uniformity that, so far as this factor is concerned, the runoff coefficient will be the same for all portions of the state.

The rate of runoff is markedly affected by the size, shape and slope of the watershed or drainage area. Other things being equal, the rate of runoff from a large area is somewhat smaller per acre than it is from a small one, and that from a long, narrow watershed is somewhat less per acre than from one more nearly circular. However, the size and slope of the watershed affect the rate of surface runoff more than they do the runoff thru underdrains. As a matter of fact, the rate at which the water moves thru the drains is so much greater than that at which it moves thru the soil to drain, that the affect of these factors is comparatively small.

In deciding upon the runoff coefficient, the relation of the size, shape and slopes of the untiled contributary watershed must be considered in connection with the area actually to be underdrained. If the untiled adjacent area is comparatively large and has fairly steep slopes, the surface and underground runoffs on to the flatter tiled area below are equivalent to so much additional rainfall, and must be taken into account in designing the drainage system for the flatter area.

The rate of runoff is considerably affected by the character of the soil. In close soils, such as clay, the water will not pass down to the drains as rapidly as it will in a more open soil such as loam. It is for this reason that tile in clay soils are laid with relatively close spacing, and generally should be kept at the top of any very impevious subsoil stratum.

The rate of runoff will vary with the seasons. A rain of a given character and amount in the early spring will cause a much larger rate of runoff than if it occurred in July or August. During the warm months, when the natural evaporation from the ground surface is large, and when the crops are growing rapidly and drawing large amounts of water from the soil, the groundwater is maintained at a comparatively low level, thus creating a large storage reservoir in the soil. Under these conditions the soil absorbs and holds what water is necessary for plant life, and accordingly decreases the rate of runoff thru the drains.

In Iowa a common practice has been to use a runoff coefficient which will provide for the removal of a 1-4 inch depth of water from the drainage area in 24 hours, though of late, there is a tendency among drainage engineers to provide for larger capacities in some instances. No one coefficient is truly applicable to all drainage systems in the state. This low value may be correct under some conditions, but is probably smaller than should be used for a great many systems. So if an average value is to be stated, it seems probable that 3-8 inch will be more satisfactory than 1-4 inch. In reality the maximum rate of actual underdrainage runoff will vary, under different conditions, from 1-4 inch to more than 1-2 inch. All the factors affecting the rate of runoff must be considered in deciding upon the correct value.

If the rate of runoff is equal to the removal of 1-4 inch depth of water per 24 hours, the flow will be 0.0105 cubic feet per second from each acre. The total flow from 100 acres would thus be 100 times 0.0105, or 1.05 cubic feet per second. When the rate of runoff is 5-16 inch, 3-8 inch or 1-2 inch, the rate of flow in cubic feet per second, from each acre will be 1 1-4, 1 1-2 or 2 times 0.0105, respectively.

Calculating Sizes of Drains. After the system is all planned as to location and probable grades of the tile lines, and the proper runoff

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A full discussion of the factors affecting runoff is given in Bulletin 50. There is also given in Bulletin 52 a description of some typcal underdrainage systems and runoff data for them. These are for those who wish to give these matters more thoro study than is possible here.

*See recommendations for values of runoff coefficient, Bulletin 52.

coefficient has been adopted, it is then necessary to determine the sizes of tile which will be required for each line. This involves calculating the capacities of different sizes of tile at the grade which is to be used, until the proper size is found to care for the runoff. The experience of the engineer will enable him to estimate so closely at first that he probably will need to calculate the capacities of but two or three sizes. Probably he will also save himself much labor by the use of thoroly reliable tables and diagrams. However, these should be used only by the engineer who understands them fully, and knows them to be accurate.

Most drainage engineers use either Poncelet's formula, Elliott's Modifications of Poncelet's formula or Kutter's formula with the value of the constant "n" determined by assumption from a study of experimental data, for calculationg the capacities of tile drains. Practically all hydraulic engineers who have investigated the flow of water thru pipe lines similar to tile drains, have adopted Kutter's formula as being the most accurate of all those in general use. Each of Elliott's formulas is Poncelet's formula with factors added to care for an assumption that the water in the main is flowing under pressure, or under a head greater than that due to the slope the line of tile. This increased head is provided for because of a belief that the water in the soil over the upper end of the main, and that flowing in the submains which have steeper slopes than the main, cause a larger flow in the main than that due to its grade.

The capacity of a line of eight inch tile is nearly one-third more according to Elliott's formula, as it is commonly used, than that given by Kutter's formula with the value of "n" taken as 0.015. This difference decreases as the size of the tile increases, the two formulas giving practically the same capacity for a line of 24 inch tile.

In his book, "Engineering for Land Drainage," Mr. Elliott gives several modifications and states that each is applicable to a certain condition. It has been common practice with many engineers to use one of these modifications, or a table prepared from one of them, for all tile lines, mains, submains and laterals. This practice is not fair to either the formula or to the landowner.

All engineers who have measured the discharge from tile mains know the discharge is sometimes larger than the calculated capacity. Investigations made by the Iowa Engineering Experiment Station have proven that tile systems in Iowa often discharge at a rate required to remove 1-2 inch, or more, in depth from the drainage area in 24 hours. This being the case, it is more reasonable to assume that the increased flow is due to the fact that the water reaches the laterals and submains more rapidly than the main can carry it away, thus backing the water up in the submains and increasing the hydraulic head upon the main, than to assume that the large discharge is due to a head caused by the water in the soil above the upper end of the main. As long as tile systems are designed for a runoff coefficient of 1-4 inch per 24 hours, which is known to be much less than the actual maximum rate of runoff, it seems needless to attempt to explain the large discharge in any other way than that it is due to an increased hydraulic head caused by the water reaching the submains faster than the main can carry it away when flowing under gravity head.

So long as the tile drains are large enough to carry away the water as fast as it reaches them, the water flowing through the soil has, in effect, a free outlet and cannot increase the hydraulic head or slope of the flow through the drains. On the other hand, if the water can pass thru the soil to the drain more rapidly than it can flow away through the drain, water is being held back because of the insufficient capacity of the drain and the condition in the drain is similar to that in the discharge pipe leading from an elevated water-tank. If the drains are large enough to carry away the water as fast as it reaches them, the assumption upon which Elliott's formulas are based can never be true. In one case where the measured discharge showed the runoff coefficient to be very large, and where the main was known to be surcharged (the water rose to the surface at the junction of the submains and the main and was backed up in the submaines), the coefficient of roughness ("n" in Kutter's formula) was computed using the slope from the surface at the junction of the submains and the main to the surface of the water at the outlet of the main. The value of the coefficient "n" in this case was just slightly less than 0.012, which is larger than has been found for some well laid drains when not flowing full. It is known that this particular line of tile was well laid, so it does not seem incorrect to assume that this large flow was due simply to the increased hydraulic grade.

It is believed that Kutter's formula is the most rational one for use in the design of tile drains and it seems certain that if it is in error that the error is in the right direction. Kutter's formula will require slightly larger tile for the farm system than will Elliott's formula, which fact alone is sufficient reason for its use. Larger sizes of tile are needed in Iowa drainage systems and are now economically feasible.

For the reasons just stated only Kutter's formula is given here. It is assumed that each drainage engineer will have access to books or publications giving any formula he may desire to use.

Kutter's formula:

$$v = \left\{ \frac{41.6 + \frac{.00281}{s} + \frac{1.811}{n}}{1 + \left\{ \frac{\left(41.6 + \frac{.00281}{s}\right)}{r} \right\} n} \right\} \sqrt{rs}$$

Where, s = the slope in feet per foot

r = the mean hydraulic radius in feet, or the area of the wet cross-section in square feet divided by the wet perimeter in feet.

n = the coefficient of roughness.

The discharge, then equals the product of the area of the wet cross-section and the velocity.

Coefficient of Roughness. From the results of actual drainage investigations it appears that for average Iowa drains the average value of the coefficient of roughness "n" in Kutters formula is 0.015. Some drains were found where this coefficient had a lower value, but it does not seem wise to use any lower value in designing the drainage system. Engineers have not infrequently used too low values for this coefficient in the past with the unfortunate result that they selected too small tile.

Use of Formula. In using Kutter's formula, the hydraulic grade should be carefully determined and the proper value of the coefficient of roughness decided upon. Kutter's formula may be easily expressed by use of diagram such as shown in Fig. 2, from which the capacity of any size of tile at any grade can readily be taken. In using this diagram it should be kept constantly in mind that the hydraulic slope or grade is to be used always and that this hydraulic slope may differ from the actual slope or grade of the constructed line. In the case of submerged outlets, for example, the hydraulic slope will often be much less than the grade of the tile.

Use of Diagrams. A diagram like that in Fig. 2 is prepared by computing the capacity of the different sizes of tile at different grades when flowing full, and then platting them in suitable arrangement on a logarithmic chart. The diagonal lines, marked with the size or diameter of tile, represent the capacity of the tile when flowing full. To find the capacity of any tile line, follow up the line representing its "Slope in Feet per 100 Feet" (grade) until it intersects the diagonal line representing that particular size of tile. From this intersection trace the horizontal line to the left and from the scale at the side of the diagram read the "Discharge in Cubic Feet per Second." At the same height on the right of the diagram will be found the number of acres drained, whether the runoff coefficient be 1-4 inch, 5-16 inch, 3-8 inch, or 1-2 inch.

To make this operation clear, take the following concrete example: Assume a line of 15-inch tile laid at a 0.10 per cent grade (a fall of 0.10 foot per 100 feet.) It is desired to determine how many acres this main will serve. By following up the vertical line representing a slope of 0.10 till it intersects the diagonal line maked, 15", and then following the horizontal line to the scale at the left, it is found that this tile has a capacity of 1.52 cubic feet per second. By following the same horizontal line to the scale at the right side of the diagram, it is found under "R=3-8 inch" that at this rate of runoff this drain would care for the flow from 101 acres. If the rate of runoff were 1-4 inch, this line of tile would care for the flow from 153 acres.

The landowner is especially warned against estimating the grade at which his tile may be laid and calculating the sizes required when using this estimated grade. It is impossible to correctly determine the grade for any line without survey notes. It will be seen from the diagram in Fig. 2 that the capacity of a tile changes very rapidly with any alteration in its grade.

THE CONSTRUCTION WORK.

It is not intended that the following recommendations for tile drainage construction shall serve as complete construction specifications. They will, however, give the landowner a general idea of the class of construction which he should have in his drainage system.

SPECIFICATIONS.

After the design of the system has been completed, the engineer should prepare a set of specifications which will set forth clearly how the work is to be done and what materials are to be used. For the latter purpose the adoption of the 1916 Standard Specifications for Drain Tile* of the American Society of Testing Materials is strongly recommended. They were adopted by a committee composed of able men representing the engineers and the manufacturers, and the committee's report was later adopted by the society. The engineer should specify that the drain tile used shall conform to the requirements of these specifications. In addition: (1) he should prescribe the class of tile; (2) unless shale and fire clay tile, surface clay tile and concrete tile are all acceptable, he must provide for excluding any raw materials to which he objects; (3) if he desires to hold the seller responsible for furnishing tile strong enough to obviate cracking in the ditch under reasonable treatment he must so prescribe, furnishing information as to width of ditch at the top of the tile and the depth and character of filling.

KIND OF TILE.

The engineer should so word his specifications that they will call for tile which will meet certain stated requirements; he should specify the quality of the tile rather than the methods or materials used in their manufacture. Good tile, whether they be made of clay or of concrete, should be required for each system. Poor tile of any kind are undesirable and in the long run will prove much more costly than those of a good grade.

Well-made concrete or clay tile can be purchased anywhere in the Mississippi Valley at present at reasonable prices . With standard specifications and the standard method of testing, engineers can now govern the quality of tile for any drainage project. There is, therefore, no excuse for using a poor product.

*A reprint of these specifications may be obtained upon request addressed to the Director, Engineering Station, Ames, Iowa.

DIGGING TRENCHES.

The trenches may be dug either by hand or by machinery, the most economical method depending upon the amount and location of the work. The tractor trenching machines have been perfected so that they will operate satisfactorily in nearly all soils and to any depth usually required for farm drainage work. However, with these machines it is usually necessary to finish the bottom of the trench with shovels or tile scoops, altho the smaller sizes of tile may be laid in the trench as it is dug by the machine, providing the bottom is true to grade and the depth of fill over the tile is not over six feet. For tile larger than 12 inches in diameter and where the cover over the tile is more than six feet it will be better to finish and shape the bottom of the trench by hand.

The trench should be dug from the outlet upstream and at a uniform distance to one side of the engineer's stakes. Care should be taken not to disturb the stakes, as they are for use in grading the bottom of the trench. When it is necessary to make a change in direction, this should be done in a regular curve and not as a sharp bend.

In digging deep trenches in some soils it is necessary to sheet and brace the sides to prevent caving of the banks. It is seldom, however, that trenches for farm drainage are deep enough to make this necessary. As soon as the tile are laid and blinded the sheeting may be pulled and used in other places.

The trench bottom should usually be shaped with a shovel or tile scoop so as accurately and uniformly to bed each tile for at least 60 degrees of the outer circumference and for its full length. A more careful bedding than this will not usually be required in any but County Drainage Districts. However, if a more careful bedding is required, the bottom of the trench should be shaped accurately to fit at least the lower 90 degrees of the outside of the pipe, using care to secure a firm bearing at the outer edges of the bearing area.

The engineer should specify not only the width of the trench for the different sizes of tile to be used, but also the shape of the trench bottom. The trench should be no wider than is necessary for economical digging and for pipe laying, usually six inches wider than the outside diameter of the tile.

LAYING TILE.

The tile laying should begin at the outlet and proceed upstream, care being used to keep the tile at all times true to the alignment and grade prescribed by the engineer. Adjoining tiles should be laid so that the crack between them will not be over $\frac{1}{4}$-inch wide. All cracks wider than this should be covered with pieces of broken tile.

As soon as the tile are firmly bedded in the correct position, earth should be placed around them to hold them in place. Where especially careful bedding is required the earth should be placed around and under the sides of the tile by hand, and tamped firmly in place.

When tile are laid in "running sands" they should be laid upon, and entirely surrounded and covered by a layer of good clay soil or loam. In some cases it may be necessary to use a more expensive type of construction, such as placing the tile on a layer of wild hay or upon planks, or to wrap each joint with a strip of light-weight roofing.

As soon as the pipe are laid and inspected, they should be blinded by placing top soil around them and over them to a depth of one foot. In cold weather this should be done as soon as the tile are laid, using sufficient earth to prevent freezing of the soil around the tile. Loam or clay (never sand) should always be used for this purpose.

BACK FILLING.

At least one foot of loose earth should be placed upon the blinding before any large stones or pieces of frozen earth are put in the ditch. After this one foot layer is in place, the remaining back filling may be done in any way desired. This is usually most economically accomplished with teams and some form of scrapers, altho with narrow and shallow trenches plows may be used quite satisfactorily. In any case the back filling should be heaped up over the drain so that when it has settled the trench may be full.

PROTECTION OF OUTLET.

The main will often discharge into an open ditch or natural water course, the banks of which are subject to erosion. Where the flow from an unprotected tile empties with a fall, even though only two or three feet, the pipe will be undermined and will drop down one by one until, in many cases, a large ditch or gully is washed back for some distance into the field.

It is well to construct the last 15 feet of the outlet main of bell and spigot sewer pipe and to cement the joints. In addition, a concrete or masonry headwall should be built around the end of the last tile. If such a headwall is carried down at least two or three feet into the ground, it will not be easily undermined, especially if a suitable apron or floor is provided to prevent erosion caused by the water falling from the drain. Such aprons or floors may be made of the same material as the headwall, or for small drains they may be made by filling in below the outlet tile with loose stones and boulders large enough to remain in place.

For small drains especially, it is sometimes advisable to cover the outlet with a grating of small bars to prevent the entrance of small ground animals.

COST DATA.

The unit prices for both the materials and the construction of drains vary so greatly from year to year, and in different localities, that it is impossible to accurately estimate the cost of the work of one job or one year at the unit prices of previous work. The data tabulated here are average values and are only sufficiently accurate for approximate estimates. The mere fact that the bid on any particular job varies from the prices given here should not be taken as evidence that either these prices or those of the bid are incorrect or unjust.

ESTIMATE OF TILE REQUIRED PER ACRE.

Table I shows the amount of tile required for the lateral system providing the laterals are laid at equal distances apart. This table and the cost data will make possible an approximate estimate of the probable cost of the laterals of the proposed system. To this must be added the estmiate of the cost of the main and the submains.

TABLE I.

TILE REQUIRED PER ACRE FOR LATERAL SYSTEM

Distance between Laterals—Feet	Linear Feet of Tile per acre.
20	2,178
25	1,742
30	1,452
33	1,320
40	1,089
50	872
66	660
80	545
100	436
150	291
200	218

COST OF DRAIN TILE.

Table II gives the average prices of drain tile in Iowa on Jan. 1st, 1917. The prices of clay drain tile are usually quoted on car-load lots delivered at points having an average freight rate. In general the landowners of Iowa are sufficiently close to clay tile factories to come within the zone of this average freight rate. The prices of concrete tile, on the other hand, are ordinarily quoted f. o. b. cars at the factory. The prices given are averaged from those of several factories. Hence in using this table for estimating, the cost of the concrete tile f. o. b. the factory must be increased by the amount of the freight from the factory to the point of usage. For purposes of comparison the price of concrete tile delivered has been computed by adding to the quoted price the charge for a 100 mile freight haul.

These prices are approximately correct average prices on January 1, 1917, but they will probably not agree exactly with those quoted at that

TABLE II

AVERAGE PRICES AND WEIGHTS OF DRAIN TILE IN IOWA (JAN. 1, 1917.)

Diam. of Tile Inches	Price per 1000 Feet			Weight, Lbs. per Foot		Cost of Hauling—Price per Ton.
	Clay tile delivered	Concrete tile f. o. b. factory	Concrete tile delivered	Clay tile	Concrete tile	
4	$ 20			6		First mile including loading and unloading, $0.50 to $1.00.
5	29	$ 28	$ 33	8	10	
6	39	37	43	10	13	
7	50	47	55	12	17	Each additional mile, $0.25 to $0.50.
8	62	58	68	15	22	
10	95	89	103	25	30	
12	135	115	137	32	45	
14	205	175	203	45	58	
15	265	200	233	30	68	
16	285	240	279	55	82	
18	395	325	375	70	105	
20	500	405	467	85	130	
22	600	480	554	95	155	
24	715	600	686	110	180	
26	875	690	793	135	215	
28	1025	800	922	165	255	
30	1250	900	1037	200	285	

Freight rates on drain tile in car-load lots, Jan. 1, 1917:
100 miles $.048 per 100 lb.
75 miles ..044 per 100 lb.
50 miles ..040 per 100 lb.

All prices, including freight charges, on Jan. 1, 1919, were about 25% higher than those given above.

time by any one factory.* The cost of production of all tile has increased materially during the past year. The coming season may see either an increase or a decrease in prices, and such changes must be taken into consideration in using the data in this table.

The prices given in this table will usually be too large for estimating cost of tile for a county drainage district. The large amount of work let in one contract in that case often secures somewhat lower prices.

The data as to cost of hauling tile are but approximately average. This cost will vary considerably with the methods used and the condition of the roads. However, this item is often of minor importance as the landowner can usually do the hauling with his own teams during the seasons when they are not needed for other work. The cost given in Table III are believed to be fairly average and valuable for preliminiary estimates.

COST OF DIGGING THE TRENCH. LAYING TILE AND BACK FILLING.

The prices for drainage construction given in Table III will vary considerably from the actual costs on any one system, the amount and direction of the variation depending upon the size and location of the system, the soil formation, and the methods by which the trenching and back filling are done. However, they are average values of sufficient accuracy for preliminary estimating.

TABLE III

AVERAGE PRICES FOR DIGGING TRENCH LAYING TILE AND BACK FILLING IN IOWA IN 1917

Diameter of Tile Inches	COST IN DOLLARS PER LINEAR FOOT FOR DEPTHS OF CUTS AT HEAD OF COLUMNS													
	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
4 to 6	.030	.040	.060	.11	.17	.25	.33	.45						
7 to 8	.042	.052	.078	.12	.18	.26	.33	.45	.56	.75				
9 to 10	.049	.062	.095	.15	.20	.26	.35	.46	.56	.75				
12	.061	.076	.115	.16	.21	.26	.35	.46	.57	.76	.98	1.15	1.45	1.67
14	.072	.090	.125	.17	.23	.28	.35	.47	.58	.78	1.00	1.20	1.50	1.70
16	.080	.100	.145	.19	.25	.32	.40	.51	.64	.83	1.07	1.32	1.65	1.80
18	.092	.115	.160	.21	.27	.43	.43	.54	.68	.90	1.10	1.37	1.68	1.89
20	-------	.127	.175	.23	.29	.36	.46	.57	.73	.98	1.21	1.56	1.93	2.14
22	-------	-------	.190	.25	.31	.39	.49	.65	.90	1.17	1.45	1.79	1.79	2.45
24	-------	-------	.210	.28	.35	.45	.59	.81	1.05	1.32	1.65	1.99	2.35	2.61
26	-------	-------	.240	.31	.40	.53	.74	.94	1.21	1.57	1.92	2.19	2.48	2.78
28	-------	-------	.260	.34	.47	.65	.86	1.12	1.40	1.76	2.03	2.31	2.61	2.93
30	-------	-------	.280	.40	.57	.87	.87	1.27	1.62	1.99	2.15	2.44	2.70	3.04

The costs for the three-foot depth are given for estimating the costs of construction of laterals in small ponds where a greater depth would require placing a considerable portion of the system at a greater depth and for mains and submains in narrow slougs or depressions where a greater depth of main is not needed to furnish outlet for laterals four feet deep.

he average prices on Jan. 1, 1919, were probably 25% higher than those given above.

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