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PRACTICAL
FARM DRAINAGE

A MANUAL
FOR FARMER AND STUDENT

BY

CHARLES GLEASON ELLIOTT, C.E.

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PREFACE

TWENTY-FIVE years ago "Practical Farm Drainage" was prepared by the author to meet an urgent demand for a simple manual upon the draining of farm lands. At that time the value of under-drainage was only beginning to be appreciated, but soon became recognized as an improvement of great importance in the development of agriculture. The book was cordially received, and the demand for it has been continuous. Now, after an added experience of twenty-five years, during which the author has been closely identified with many and varied drainage projects throughout the United States, he has entirely rewritten the book, bringing it up to date and adding much valuable matter. This new edition he herewith presents for the use of farmers and students. For a more complete discussion of drainage engineering and the larger problems connected with the subject, the reader is referred to the author's work on "Engineering for Land Drainage."

C. G. E.

WASHINGTON, D. C.
April, 1908.

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INTRODUCTION

THE subject of land drainage is attracting more widespread attention throughout the country at the present time than ever before. This interest is not confined, as formerly, to the owners of small farms, or to detached neighborhoods here and there, but farmers and land owners in many States, and in whole groups of States, are actively engaged in immense drainage projects, involving millions of acres.

State Legislatures, recognizing its importance, have enacted drainage laws which have made possible cooperative drainage work, and as a result, drainage districts covering from fifty thousand to seventy-five thousand acres of land have been incorporated in various parts of the country under the provisions of such legislation. These are now intersected by scores of miles of drainage canals carrying off the excess of water, and rendering the land, much of it before valueless, capable of producing large crops.

State Boards of Agriculture, in many instances, have fostered and stimulated interest in the subject by the offer of prizes for the best papers describing methods of successful drainage practice, and the benefits resulting to agriculture and health.

The National Government, through its department of agriculture, has provided for the active investigation of the various drainage problems presented in different localities, and the results of these investigations, in the form of reports embodying practical and scientific information along this line, have been widely circulated, and are obtainable on application by anyone interested.

The possibility of the reclamation of coast swamp lands, or salt marshes, which until recently have been considered worthless, is becoming appreciated, and many owners of such tracts are now engaged either in preliminary investigation or the actual construction of adequate drainage works.

The recognition of the fact that the complete extermination of the malarial mosquito can be accomplished only by the thorough drainage of its breeding-places has brought the subject prominently before our students of hygienic science, as well as enlisted the attention of both the summer boarder and his landlord, in mosquito-infested districts.

But perhaps the most surprising growth in drainage practice has been its extension to the irrigated lands of the arid west, it having been found to be an effectual, and indeed the only, remedy for the loss of lands through excess of alkali deposited by irrigating waters. Experience has proven that irrigation and under-drainage must go together in the reclamation and subsequent development of arid lands, if such reclamation is to be permanent.

The practice of drainage having thus increased in importance and widened in scope, the means by which it is effected have, of necessity, been greatly improved. The steam land dredge has been so perfected that the excavation of the immense canals now called for in large districts, through wooded as well as through prairie low-lands, has been greatly facilitated and the cost lessened, notwithstanding the increased price of labor, which is forty per cent above the rates prevalent ten years ago.

Much larger drain tile are in common use now than were formerly considered practicable or even possible. Then twelve-inch tile were the maximum size, while now stretches of many miles are laid with pipes from sixteen to thirty-six inches in diameter. Drain-tile factories, from their unpretentious beginnings a quarter of a century ago, have grown into large and flourishing plants, well equipped with the most improved machinery, and having a capacity sufficient to produce hundreds, and, in at least one instance, thousands of carloads of tile annually.

But while there has been such a remarkable progress in drainage, and great development and improvement of lands as a result, there still await reclamation by this means millions of acres of highly fertile swamp land, now worse than useless, but susceptible of drainage and consequent cultivation. And to these millions must be added other millions now occupied as farms and estates whose productiveness and value to the owners would be greatly increased by judicious drainage.

The immense drainage canals constructed, or in process of construction in many States, under the provision of the State laws, have opened up large areas, the drainage of which has hitherto been impossible for want of a proper outlet, and thousands of farms along the line of the big channels will in a few years be thoroughly drained.

Agriculture is assuming a prominence in this country hitherto unknown. Its real worth to the nation is becoming rightly appreciated. But in proportion as this is true the demands upon it have become more exacting. The highest degree in quality as well as in quantity is expected by the consumer and striven for by the producer. Our products seeking a market on distant shores must be able to compete successfully with those of other countries. All this has served to intensify farming. A fairly good yield no longer satisfies. It must be the best possible that the soil can produce under the most improved methods of cultivation. In the accomplishment of this, drainage has come to be recognized as one of the most valuable agents, and the results achieved along this line and now on record, have served to stimulate and encourage the efforts of others.

No improvement which the farmer can put upon his farm is so permanent as drainage. The large sizes of tile now procurable make it possible on many farms for open ditches to be done away with entirely. Where this is the case, the system of drains correctly located and accurately constructed requires no further attention. The drains laid by John Johnston, the father of tile drainage in this country, seventy years ago on his farm near Geneva, New York, are as effectively at work to-day as they were the first season they were in service. This permanency emphasizes the importance and value of having the work properly done, though the worth of the drains, even for one season's service, depends upon the wisdom of their arrangement and the accuracy of their construction. The farmer, therefore, should not be at the mercy of his employees, but have himself a thorough knowledge of the principles governing drainage, and of the methods and rules of practice.

It is the purpose of this little book to present for his use, in a clear and concise form, the established theories and most recent and best approved methods of practice in land drainage. While conditions in different parts of the country vary so strikingly that it is impossible in a treatise of this kind to provide for all the unusual contingencies that may arise in individual cases, it is apparent that a thorough study of the principles and their application under conditions ordinarily met are the best preparation for the successful solution of particular problems.

PRACTICAL FARM DRAINAGE

CHAPTER I

SOIL AS RELATED TO DRAINAGE

Soil as generally understood is the surface stratum of the earth which supports vegetable growth.

It is formed primarily from rocks which become disintegrated by the action of the weather, and probably by other agencies not yet fully understood, to which are subsequently added various kinds of organic matter. The whole story of this process, though one of deep interest, is not within the province of this book. The full discussion of soils, their formation, structure, characteristics, possibilities under cultivation, etc., forms a book of itself, and one well worthy of careful study by the practical agriculturist. Only such part of the subject is here considered as is necessary to make clear the action and effect of drainage in the various soils.

SOIL STRUCTURE

All soil is composed of minute particles of solid matter, irregular in shape and of varying size, which do not lie compactly together, but touch each other only at portions of their surfaces, leaving irregular spaces between them. These open into each other, forming connected, though tortuous, channels, through which air and water may freely circulate. The particles are of different sizes in different kinds of soil, varying from the largest in coarse sand, two to four hundredths of an inch in diameter, to the smallest, in fine clay, of infinitesimal proportions. They appear to the eye united in groups, forming what we know as grains of soil, which occupy the same relative position to each other as the particles, with similar intervening spaces. (Fig. 1.) These grains, in turn, usually unite to form masses, sometimes called compound grains, which are of various sizes and shapes, but related to each other in the same way as the grains and particles. (Figs. 2 and 3.)

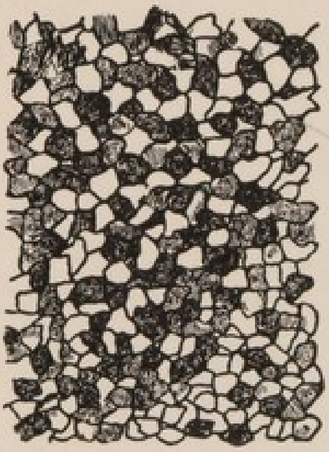

FIG. 1.—Relation of Soil Grains.

CLASSIFICATION OF SOILS

That soils vary greatly in color, texture, porosity, etc., is well known, but no satisfactory systematic classification of them has as yet been adopted. They are usually designated according to their composition. Thus **a clay soil** is understood to be one composed mainly of clay; **a sandy clay soil,** one in which sand and clay are somewhat equally combined. Other similar self-explanatory terms occur.

Loam is a soil composed of sand and clay, with or without organic matter, but with a peculiarity of structure which renders it friable. If one ingredient predominates slightly it is employed as a modifying term, as, **a sandy loam.**

Humus is a black or brown soil composed of decayed vegetable matter, and forming a component part of the soils of humid regions, their fertility depending largely upon the amount of humus.

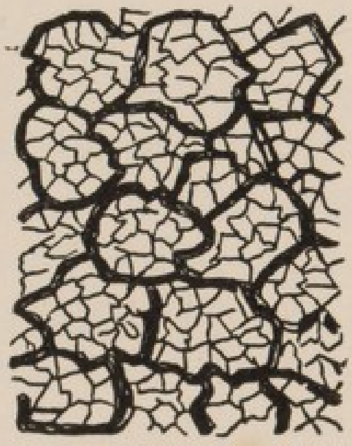

FIG. 2.—Compound Soil Grains, or Masses.

Muck is a heavy black swamp soil composed of decayed organic matter mixed with a small proportion of silt or clay.

Peat is a soil of peculiar structure, formed by the very slow decomposition of plants, usually wholly or in part under water.

Other descriptive terms are used locally which refer to the structure of the soil rather than to its composition, the arrangement or shape of the compound grains giving rise to such descriptive terms as "joint clay" (Fig. 3), "buckshot," "open loam," etc.

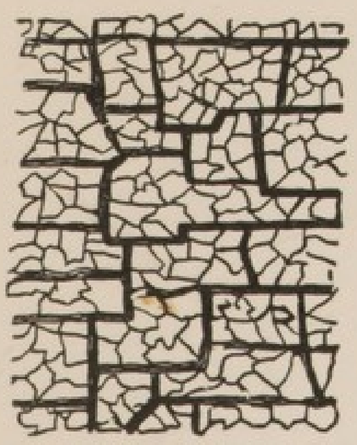

FIG. 3.—Joint Structure of Soils.

WATER IN THE SOIL

Practically speaking, water may be said to appear in the soil in two forms, hydrostatic and capillary. **Hydrostatic,** or **drainage water** comes either from *surface water*, that which flows over the ground, *seep water*, that which percolates through the soil from some stream or body of water at a distance, or *spring water*, that which issues from some spring and forms underground channels. It moves freely through the soil in obedience to the laws of gravity.

Capillary water is a thin film of water clinging to the particles and grains of solid matter, held there by what is known as surface tension. It is commonly spoken of as moisture, and is moved only by capillary attraction,* not being under the laws of gravity or affected by drains. It is this water alone that is used by the plants, the supply of it being replenished from the hydrostatic water. In an ideal soil, or a soil in ideal condition for plant growth, the capillary water will be found clinging to all the particles, grains and masses of solid matter, with the intervening spaces or channels filled with air. Hydrostatic water appears in such a soil only at intervals, soon passing off, not necessarily out of the ground, but into its lower strata, where it may remain, and is then known as **stationary hydrostatic water,** or **bottom water.**

If a soil becomes so thoroughly dried as to remove all the films of water, their places in that event being occupied by air, plant life will not thrive because deprived of all moisture. On the other hand, if a soil is saturated with water, that is, contains not only the proper capillary water, but has every space filled with hydrostatic water, more or less stationary, the air will be crowded out, and

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* Capillary attraction is the name given to the peculiar attraction which exists between a liquid and a solid partially immersed in it. It is most noticeable in small tubes, in which, upon their insertion vertically in water, the water is seen to rise as if no longer influenced by gravity, ascending highest in the smallest tube. By reason of this attraction, called also capillarity, oil ascends in lamp wicks and water creeps up in wood, cloth, or any porous material whose lower edge comes in contact with it.

vegetation cannot flourish, since oxygen is as necessary as moisture to the life of the plant, a fact which is often overlooked.

It becomes apparent that the keeping of a proper balance of air and water in the soil spaces is a matter of vital importance to the growth of the plant, and hence of utmost concern to the husbandman. It is equally apparent that the preservation of this equilibrium can be easily accomplished by providing for the timely removal of the surplus water by artificial drainage when necessary, since this can be done without lessening the capillary water, the needed moisture in the soil.

DRAINAGE PROPERTIES OF SOILS

The structure of soils has much to do in determining their drainage properties, their need of drainage and the ease with which it can be done. Those in which the particles are the most minute, and the spaces correspondingly small, have the greatest capacity for water, that is, will contain the largest amount when saturated. But such soils take in water more slowly and part with it by gravity less readily, than those having larger grains, popularly known as loose, or open soils.

On the other hand, soils made up of the coarsest particles and correspondingly large spaces, have the least capacity for water, that is, will reach a point of saturation by the application of the least water. These soils, however, absorb water much more readily, and gravity meets with much less resistance in drawing it off, than in finer soils. This fact has sometimes led to the error of thinking that they will contain the most water. But many actual experiments by students of soil physics have demonstrated that a cubic foot of clay soil is capable of holding more water than an equal volume of sand, and that the amount of water a given bulk of soil will hold is in inverse proportion to the size of the particles, the smaller the particles, the larger the amount of water.

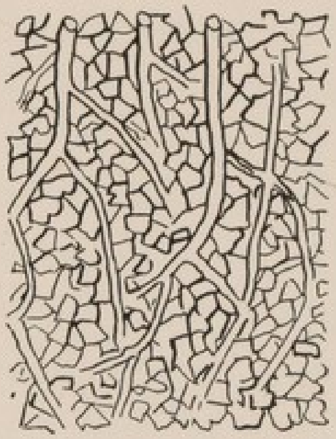

Fig. 4.—Soil Structure Modified by Roots.

These deductions hold good, in the main, in all grades of soil from the finest clay up through its coarser varieties and the different kinds of silt and sand to the coarsest sand found. There are, however, modifying factors which may affect the results. Thus the manner of massing the grains, which often differs in soils whose mechanical composition is practically the same, has a perceptible influence upon the drainage properties of such soils. For example, a fine clay soil with its grains massed in what is known as "joint structure" (Fig. 3) is more readily drained than one granular in structure (Fig. 1), even though the soil particles in the latter may be larger. The presence of pebbles and roots (Figs. 4 and 5) or the passageways left by the decay of the latter, also often modify soil structure materially, and affect its drainage properties.

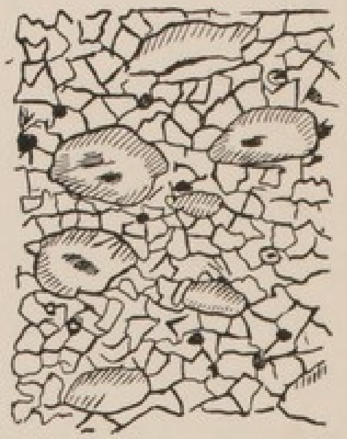

Fig. 5.—Soil Structure Modified by Pebbles.

A careful study of the soil to be drained is necessary to determine at what depth and distance apart the drains should be placed, when artificial drainage is determined upon.

NATURAL DRAINAGE

The removal of the surplus water from the soil is always undertaken by Nature, and often the contour and slope of the surface, the structure of the soil and its relation to the subsoil are such that perfect drainage is accomplished without aid from man. But many times gravity, Nature's agent in this work, is so impeded and restricted that partial or utter failure is the result, and where this occurs the land will not sustain vegetation. Thus we find ponds, or basins of water, in cultivated fields; low, wet spots, which differ from ponds only in degree, the water not covering the surface, but keeping the soil in a state of saturation, either all the time, or during unusual rainy seasons; sloughs, where the slope is insufficient, and the water moves too sluggishly to cut for itself a proper channel, but overflows its shallow banks and spreads out over the cultivated land; runs, or intermittent sloughs, which, in dry years, or at some seasons of every year, admit of cultivation, but in times of excessive rains become saturated, or even form channels filled with running water.

These various accumulations of water may be caused by lack of outlet, by insufficient slope of the surface or subsoil, by resistance to the movement of the water through the ground due to the fineness of soil particles, by the relation of soil to subsoil, or by a part or all of these causes combined.

Often wet places are found which cannot be accounted for by a superficial view of the contour of the surface. To understand these we must know the relation of the soil, the surface layer of the ground, to the subsoil, the stratum next below it. Except in arid regions, where the difference between these two strata is not marked, the subsoil differs materially from the soil in structure, composition and color. It is usually more impervious to water than the soil above it, so that water passing down through the ground meets resistance in the subsoil and moves laterally along its surface to some point of egress.

If the upper stratum of earth were of equal thickness, thus causing the surface of the subsoil to be parallel to that of the ground, it would be possible to judge more nearly from the contour of the land, the movements of

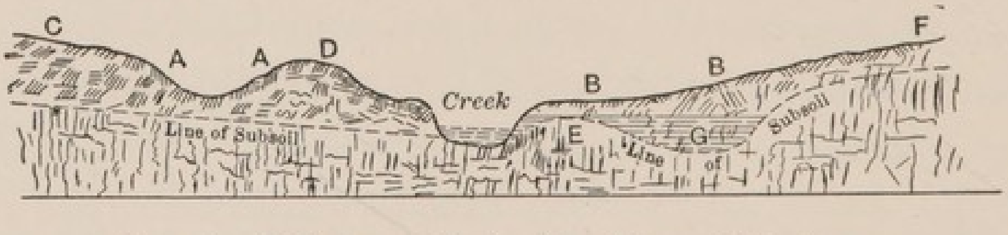

Fig. 6.—Relation of Subsoil to Natural Drainage.

ground water. But this is often not the case. Sometimes the relative positions assist drainage, in others retard it. This is illustrated in Fig. 6. At *A*, *A*, from the contour of the surface, we should expect to find an accumulation of water from the slope *C* checked in its course to the creek by the rise of *D*. The absence of it is explained by examination of the line of subsoil. It does not follow the rise in the surface, but slopes directly to the creek bed, thus affording perfect drainage to *A*, *A*.

On the contrary, no reason is apparent from a view of the surface for the saturated condition of the ground at

B, *B*. But here it is found that the line of subsoil is such as to retard the otherwise natural drainage. Water flows from the hill above *F* through the ground along the comparatively impervious subsoil and settles into the dip or basin at *G*, and cannot escape until deep enough to flow over the point *E*. Thus a perpetual underground pond, as it were, is formed at *G*, which causes the saturation of the soil at *B*, *B*. Such cases very frequently occur, and this relation of soil to subsoil should be taken into account in artificial drainage, whether facilitating or retarding it.*

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* Attention is called to the value of this illustration in showing the possible cause of seemingly inexplainable pollution of water or milk producing typhoid and other epidemics. Suppose a privy-vault or hog-pen to be located somewhere in *A*, *A*, with a well at some point between *D* and the creek, and a dairy farm so situated that the cows have access to the creek in this neighborhood. It will be seen that the germ-infested pollution from the vault or hog-pen may be carried along the line of subsoil, some of it entering the well in its passage, the remainder emptying into the creek where the cows are liable to drink in the disease germs, which may then be conveyed through the milk to human beings. The hill at *D* seems on a superficial examination to make any contamination between *D* and the creek impossible, especially when, as may happen, the surface at *A*, *A*, slopes to one side. But even then enough water filled with pollution may percolate through the ground to the line of subsoil to endanger the water in well or creek.

CHAPTER II

ARTIFICIAL DRAINAGE

THERE are two classes of drains employed where artificial drainage is found necessary. **Open drains** are simply ditches of varying dimensions, so located as to receive the surface water of the area to be drained. **Covered** or **under-drains** are constructed below the ground and entirely covered, not receiving surface water direct. The latter are more effective in accomplishing the work and benefiting the soil, but the former have their place.

ACTION OF OPEN DRAINS

Open drains receive water which flows over the surface and also that which percolates through the soil. Where slopes are considerable and the surface smooth, a large part of the rainfall passes directly into the ditches before the soil has time to absorb it. The same is true on more level lands when the rainfall is precipitous and large in quantity. If not provided with such ready facilities for removal, a considerable portion of the water which passes away through the ditches would and should be absorbed by the soil and become its reserve moisture for use when rainfall is deficient. Under such conditions, where open drains are the only ones provided, their location should be such that no considerable drainage water will pass off until the soil has been supplied with all of the capillary water it will contain. This may seem a theoretical condition impossible to obtain by means of open drains, yet by their skilful location with due regard to surface slopes and absorptive properties of the soil, this valuable result may be approximately secured.

When the rainfall is slow, even over considerable slopes, the soil will absorb it all until fully saturated, after which the entire volume of water passes over the ground to the ditch, while the surplus soil water begins to percolate through the soil in the direction of some relief channel below the surface, if such channel exists. If the land is moderately level and the soil absorptive, no water will pass to the ditches until the soil is completely saturated, except during times of heavy precipitation, or when the ground is frozen.

Water which enters open drains by percolation through the soil moves slowly or rapidly in proportion to the openness of the latter. Sand and gravel subsoil formations are favorable to the efficiency of open ditches, since they collect water from the upper stratum readily and permit its free percolation laterally into them. In clay and loam soils the percolation is very slow, especially where the ditches are frequently flushed by flood flows. At every flushing the sides of the ditch are more or less puddled and the soil spaces closed, which greatly impedes the passage of water into it, a condition favorable to the flow of water through the ditch, but unfavorable to its action as a drain for subsoil water.

ACTION OF COVERED DRAINS

The action of a covered drain of any kind is not retarded in this way. Whatever soil channels or spaces already exist in the soil, permitting the percolation of water, are in no way impaired, but rather increased in size, by the construction of the drain. The covered drain when running full is subject to the constant pressure of the soil water above it, which causes a more continuous and free flow than takes place when the trench is open. If well made it has a more perfect flow line, which, not being subject to change, gives a higher velocity than open drains having the same gradient. This accounts for the popular notion that a covered drain "draws" better than an open one.

In the explanation of the operation of under-drains which follows, the circular tile drain, now regarded as the most perfect form of covered drain, has been selected; and it may be well before taking up this subject to call attention to the custom of writers of using interchangeably the terms gravity, weight and downward pressure. Weight of water, or its downward pressure, is the measure of the force which gravity is exerting to draw it toward the earth's center. In this explanation, the term gravity alone will be used, in order to avoid confusion of ideas.

There is always to be found in the lower portion of the soil or in the subsoil, water filling all the spaces, called either **stationary hydrostatic water, bottom water** or **ground water,** held there by underlying rock or other impervious strata. Or, to state it another way, below a certain plane whose distance from the surface of the ground varies greatly in different localities and from time to time, the earth is full of water to the point of saturation. This plane is spoken of as **the plane of saturation,** or more often, **the water-table.** Its distance below the surface depends mainly upon the efficiency of the under-drainage, natural or artificial, and is easily ascertained by noting the height to which water will rise in an open pit dug in the locality under consideration. During a heavy rainfall the water-table is coincident with the surface of the ground, since at that time the entire body of the soil is completely saturated. Gravity, drawing the water down as rapidly as it can find outlet, gradually lowers the water-table. If the soil particles offered no resistance to gravity the water would pass down from all points at once, as through a sieve, and the water-table would be lowered equally at every point, thus remaining horizontal at all times. But the action of gravity is constantly resisted and impeded by the grains of solid matter. Thus a molecule of water, pulled downward by gravity, encounters a mass of soil particles, and like a boy in a crowd, who must slip and dodge hither and thither wherever an opening is found, yet always working toward his objective point, however circuitous the route, so the molecule of water, headed as it is for the center of the earth, finding its way obstructed at every turn by the crowd of earth grains, slips this way and that, diagonally, and even laterally when forced to, wherever it can find its way most easily downward.

When a line of tile is laid in the ground it provides an open channel through the resisting particles which are kept out by the walls of the tile. The drops of water in the soil nearest the drain, moving downward on their gravity-impelled way, finally slip into the crevices between the joints of the tile, and thence into the channel. They are followed by others next them, and these in turn by their neighbors, until there is a steady movement of water through the soil toward the drain, which gradually fills, and a flow is created.

It is apparent that the molecules farthest from the drain have the most resistance to overcome before they can reach it. Thus while at a point directly over the drain all the water has escaped, that farthest distant lags most behind and has made the least progress downward. Owing to the very gradual increase in resistance a line connecting these two points and passing through the upper molecule at each intermediate point would form a convex curve. (Fig. 23.) This is the line of the water-table, since below the plane in which this line lies every space is filled with water which has not yet found an exit. Its curvature, as we have seen, is caused by the resistance of the soil particles to the movement of the water, and in the absence of further rainfall this curve is slowly flattened as the water gradually finds its way into the drain, and possibly in a very long, dry season the water-table may become horizontal or nearly so, the soil above it at any stage retaining its proper moisture.

LAND REQUIRING ARTIFICIAL DRAINAGE

Much of the land insufficiently drained by Nature does not need pointing out, the water appearing on the surface being a sufficient indication, as in **ponds, sloughs,** etc.

Low spots in the field which are slow in drying out after heavy rains, and on which the crops are either an entire or a partial loss, are also well known to the owner, being a constant grievance.

That many soils not so easily recognized as needing drainage would be greatly benefited by such an improvement should be more generally understood. **Undulating fields** with abundant surface slope often require frequent drains because the soil is retentive throughout, or because the irregular arrangement of an impervious subsoil occasions "spouty" places, or even springs upon an otherwise arable hillside.

The **summits of knolls** covered with a friable loam are sometimes wet on account of the heavy clays which lie at various depths underneath the surface.

The **erosion of hillsides** with its injurious effects may often be wholly or in part prevented by intercepting the surface flow caused by precipitous rains, or distributing and regulating its volume by well-disposed terraces and drains.

Hill water may often be stopped by intercepting ditches and carried around a fertile level field, thereby greatly benefiting it through the protection thus afforded.

Level swamp lands which have little or no surface drainage require considerable skill to provide a sufficient amount of drains with uniform descent to remove surplus water.

River and creek bottom lands subject to overflow from the adjoining streams need careful draining after they have been protected by suitable levees.

Peat bogs and the various kinds of **muck lands** call for particular attention in their drainage if they are to be made productive.

Level lands in the humid sections which show indica-

tions of injurious alkali can be reclaimed only by careful drainage.

Irrigated lands in the arid west present a variety of conditions requiring the practice of drainage. The *cat-tail swamp* upon the lower levels, the *alkali bog*, the *hillside swale*, at times white with baneful alkali, all demand skilful drainage if all parts of the irrigated farm are to be alike productive.

Salt marshes, or coast lands subject to overflow by the tide, especially those near large cities, may be profitably drained by the use of ditches and simple structures, an old and well-established method of reclamation now attracting favorable notice in this country.

The removal of **stagnant water** from lands of any class destroys malarial and other breeds of mosquitoes, changing unsanitary locations into healthful ones, and the mosquito-breeding bog into the fruitful garden.

The extension of our agricultural lands by utilizing waste areas wherever farming is practiced, and the successful introduction of new crops, many of which call for special soil conditions, have widened the scope of drainage and emphasized its importance in agricultural economics.

EFFECTS OF DRAINAGE UPON THE SOIL

That drainage has a very marked effect upon soil conditions is admitted by all who have experimented even slightly along this line. One good effect is rapidly followed by another resulting from it, which in turn produces another.

As we have already seen, the first effect of the removal of the surplus water from the soil is **aeration,** or the admission of air into the spaces previously filled with water. It is through this free entrance of air and consequent aeration of the entire body of the ground above the drains that the other beneficial effects noted are brought about.

Of these, **greater depth of soil** is the first result seen. While the soil, technically speaking, extends to the subsoil, which may be several feet below the surface of the ground, only that in which air circulates can be used by plants. All the processes of plant life depend upon air, and in its absence the soil becomes inert. Its deeper penetration into the soil at once opens up the latter and makes it available to plant life to whatever depth the air reaches.

An **extended range of roots** is at once made possible by this increase in the depth of the soil. Only those who have given the matter attention realize the depth to which roots of grains and grasses, and even garden vegetables, will penetrate in an aerated soil. The popular idea of the depth to which such roots will go is from six to eighteen inches, two feet being considered an extreme depth. Interesting experiments have shown, however, that in favorable soils such roots extend from three to four feet quite commonly, and often much deeper. They also push their way much farther laterally in an aerated soil, all of which increase in roots in any direction means an added vigor of growth in the plant.

An **improvement in the texture of the soil** is soon noticed. The drying out of the water-logged particles and grains affects the massing of them in such a manner as to change the structure of the soil causing it to become more friable and easy of culture. It also retains its moisture better, owing to the breaking up and enlarging of the capillary tubes.

Another beneficial effect produced upon the soil is the **increase in temperature.** Water is very much more difficult to heat than the solid matter of the soil. To bring a certain volume of water to a desired temperature requires something like ten times the amount of heat necessary to raise an equal volume of soil particles to the same temperature. Hence the less water in the soil the more quickly it is warmed. Another cause of the increased temperature is the lessening in evaporation from a dry soil. This process, as is well known, has a cooling effect upon the surface. A difference in temperature of from six to ten degrees in undrained and drained soil is often noted, a very material aid to seed germination and all the processes of plant life.

It has been found that drainage **promotes the activity of nitro-bacteria.** The recent discoveries by soil investigators of the presence of bacteria in the soil, which play an important part in the preparation of plant food, throw added light on the effects produced by drainage, and explain more fully the remarkable results often obtained. Here again we touch upon a great subject, that of plant life, but shall enter into it only enough to aid us in our present study.

Briefly, then, soil bacteria are said to be of two kinds, *beneficial* and *injurious*, with many species of each. The former, which are greatly in the majority, assist in the several processes required to convert free nitrogen of the air, or as found in organic matter, into soluble nitrates, the only form in which it is available for plant food. Just what part they play has not been satisfactorily determined, but it has been quite clearly established that the processes cannot, or do not, go on in their absence. It has also been demonstrated that an abundance of air, a proper amount of moisture (neither excess nor deficiency), and a temperature between 70° F. and 105° F. are the environment most congenial to them, and in which they reach their greatest activity, resulting in a corresponding increased vigor of the plant. As we have just seen, these are the conditions of soil brought about by drainage, whose importance in the light of these discoveries assumes increased proportions. Much yet remains to be learned in regard to these bacteria, their methods of work, etc., but while the whole subject is in too early a stage of development to make any very positive statements entirely safe, the continued efforts of the scientists encourage us to expect within the next few years more definite and satisfactory conclusions. The importance of nitrogen in plant food, and its elusive nature, tend to make the process of nitrification of the greatest importance, and the full understanding of it essential to the agriculturist. In the meantime he should not fail to make use of the knowledge already gained that aeration, moisture and heat are beyond a doubt necessary soil conditions in the process.

One injurious effect of drainage must be mentioned, and that is **loss of nitrogen.** It is sometimes asserted that the beneficial effects of drainage do not compensate for the loss of soluble nitrates which unquestionably takes place. The Rothamsted Experiment Station, England, conducted exhaustive experiments, covering a period of nearly thirty years, to determine the truth in this regard. The soil experimented with contained ten thousand pounds of nitrates per acre, and the annual average loss of nitrogen was found to be 31.4 lbs. per acre, an inconsiderable amount, it would seem, compared with the total amount in the soil. A practical demonstration that drainage does not seriously deplete the supply of nitrogen is found in the fact that soils which have been artificially drained for sixty and seventy years give no evidence of lack of nitrifiable nitrogen.

PRACTICAL BENEFITS RESULTING FROM DRAINAGE

In addition to the consideration of the chemical and mechanical effects of drainage upon the soil, it is well to enumerate the practical benefits which the farmer who drains may expect to reap from his labors.

1. **Land is ready for seeding earlier.** As the ground thaws, the water is at once carried down to the drains, together with that from the melting snow and ice on the surface. The result naturally is that the soil is much more quickly dried out, with a corresponding increase in temperature, and it is found to be fit for cultivation from one to three weeks earlier than undrained land.

2. **Crops begin a healthy growth at once.** The right amount of moisture and heat germinate the seed promptly, the tiny rootlets find oxygen at hand, plant food prepared as they need it and an open soil into which they can push their way with little or no resistance.

3. **Fertilizers are not wasted by surface washing.** Fertilizing gases held in the air, or artificial fertilizers applied to the soil are carried by rains directly into the soil, instead of passing off over the surface.

4. **Crops are better able to withstand drought.** The greater depth of soil and the extended range of roots, together with the change in the texture of the soil, rendering it capable of retaining more moisture, are among the agents which assist a crop to pass through a period of drought safely.

5. **There is no loss of crops from heavy rains.** A sufficient number of drains of proper size, accurately laid, will carry off the heaviest rainfall so rapidly as to prevent any serious injury to the crop.

6. **Frost does less injury to crops.** Grass and fall grains will not be injured by freezing or by heaving of the soil. Much less harm also results from late spring or early fall frosts.

7. **Crops make a much more vigorous growth.** This is due to the fact that all the conditions for plant growth are most favorable: the right amount of air, moisture, and heat; extended root range; availability of fertile elements; increased activity of beneficial bacteria. All these so aid the plant that it makes a maximum growth.

8. **The profits from the land are greatly increased.** It makes hitherto waste lands highly productive. It doubles and sometimes triples the yield per acre. It lessens the expense of cultivation because young crops are no longer drowned out, necessitating replanting, and there is no waste of time and labor in cultivating irregular fields.

9. **Roads and walks are bettered.** The ground in lawns, walks, public and private roads is rendered more firm and sustains travel much better.

10. **Sanitary conditions of the farm are improved.** Removal of stagnant water by drainage lessens the

danger of malarial troubles and provides an efficient disinfectant of dry earth around the farm buildings.

11. **The attractiveness of farm premises is increased.** All plant life in the gardens and grounds makes a more vigorous growth, adding much to the beauty of the farm home.

12. **Disease among farm animals is decreased.** Sheep and other animals pastured on low, wet lands are much more subject to some forms of disease than those running on well-drained soil.

The foregoing facts, based as they are upon actual knowledge and demonstrated by wide experience, should be sufficient to convince the thinking farmer that the drainage of wet or heavy land in his possession will be a paying investment well worth undertaking, and the practical methods of accomplishing it which are presented in the following chapters should receive careful consideration.

CHAPTER III

KINDS OF DRAINS

MANY varieties of drains have been employed successfully, but some are limited in their usefulness by ground conditions or lack of durability in the material of which they are made.

OPEN DITCHES

These are in universal use, and are generally a necessary adjunct to any large system of drainage. They must also often serve as receiving channels for field and farm drains, though the large sizes of tile now made render it possible for a farm with good fall and convenient outlet to employ only covered drains. This is of great advantage, and should always be done where practicable, since open ditches take up valuable space, frequently divide fields into irregular and inconvenient shapes, and require periodical cleaning to keep them in repair and free from weeds and briers. They may vary greatly in form, depth and width, but a study of their behavior shows that certain essential factors enter into the economy of their construction, efficiency of operation and cost of maintenance.

The sides of ditches passing through firm loams and clay soils, and excavated by the natural washing of the streams, are nearly vertical. The scouring action of the stream is greatest when the channel is nearly full, so that at such times earth is cut from the sides, the greatest erosion taking place near the surface line of the water, and is carried away little by little. Small ditches are self-cleaning where the grade of the bottom is two and one-half inches per one hundred feet or more. Freezing of the earth causes instability of the sides of ditches, as it loosens the earth, inducing crumbling, sliding and caving of banks, and is a fruitful source of injury to all ditches in cold climates. In non-freezing localities, where this trouble is eliminated, the longer growing season and warmer climate cause more luxuriant growth

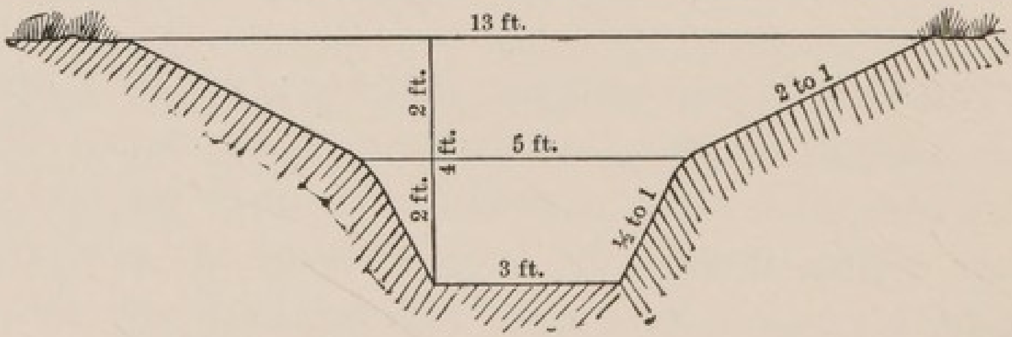

Fig. 7.—Ditch with Upper Half of Side Slopes less Steep.

of vegetation, necessitating more frequent removal of obstructions of this character than is required in cold climates.

Farm outlet drainage ditches should be constructed with due regard to the following particulars: First, the character of the earth through which they are made; second, the grade upon which they are constructed; third, the depth to which they must be excavated; fourth, ease and economy of maintenance.

Ditches as deep as four feet should ordinarily have side slopes of one foot horizontal to one foot vertical, and a bottom width of three feet. They can be made by teams with plows and drag scrapers by using runways for the teams when the bottom half of the ditch is excavated. A form requiring the removal of more earth, but one more easily kept in order, is that having slopes two to one for the upper two or two and a half feet of depth, and one-half to one for the lower part, as shown in Fig. 7. The flatter slope can be kept in grass and

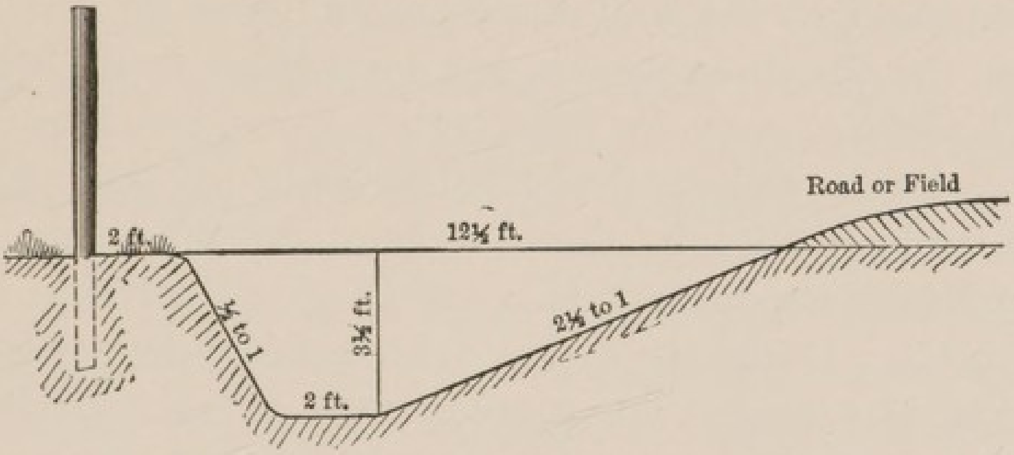

FIG. 8.—Fence Line Ditch. Excavations required 15⅓ cu. yds. to 1 rod.

mowed with little difficulty, while the lower portion can be cleaned by teams attached to drag scrapers by a chain eight feet long, and can be mowed by hand labor when necessary. A ditch by the side of a fence may have a steep slope on the fence side, and a three-to-one slope on the opposite, as shown in Fig. 8. The excavated earth must be deposited on the side with the flat slope. Such ditches can be kept free from an accumulation of vegetable growth by mowing the sloping bank with a machine. This form is adapted to highway ditches which serve as outlets for farm drains, and should be used in level areas where the road and farm outlet system may be profitably combined.

Another form of receiving drain well adapted to some conditions, and successfully used, is the combined overflow ditch and tile underdrain. This may be employed as an outlet to remove more than the usual rainfall from tracts where a system of tile drains takes care of the ordinary surplus water, but where it is either undesirable or difficult to maintain an open ditch as deep as required. The ditch should lie over the main of the tile system, be made broad and shallow, and carefully graded, its use being to relieve the land of a large volume of the rainfall after the tile drain system has been filled to its limit. Such ditches may be constructed along the lines of natural flow without depriving the owner of the use of the land occupied by them, while at the same time he may derive the benefits of a system of underdrains for his fields. Outlet tile drains eight inches to twenty-four inches in diameter are supplemented by such ditches, greatly to the advantage and convenience of owners of level lands.

A strip of grass not less than six feet wide should be maintained on each side of every ditch of any considerable size, except the broad and shallow overflow ditches, to prevent soil and other matter from being carried into it. Water brought to them by field ditches should be admitted to the main outlets through sluices made of pipes or lumber. These precautions will reduce to a minimum the amount of material which will be carried from the fields into the ditch. Vegetation should be removed from the bottom of all ditches each season before the plants mature their seed. Ditches should be made as straight as practicable, consistent with good service, and the excavated earth spread as evenly as possible. When thus made and cared for they are not unsightly improvements.

The best effects of drainage previously mentioned cannot be brought about by open ditches. Such drains are constructed to afford sufficient outlets for underdrains or on land having a stratum of sand or gravel which will serve the same purpose. We have seen that the natural drainage of many soils is slow and incomplete, and depends upon the nature of the soil and the relation of the contour of the subsoil to the surface. Open ditches are an aid to natural drainage, acting principally upon the upper six or eight inches of soil. During the spring season the soil below this depth is usually compact and tough, so that it is difficult to turn it to the surface with the plow, because of its adhesive and stubborn condition. Only a few inches of the surface soil which is acted upon by the sun and air become friable. Later in the summer, if the season is dry, the lower soil will be partially dry, but generally it is never found in a fit condition for cultivation or the growth of plants. Open ditches should be regarded only as necessary accessories to underdrains for receiving and carrying away the excess of soil water delivered to them by either natural or artificial underdrainage.

UNDERDRAINS

These have been made of stone, brush, plank and pipes, the latter either of clay or cement. While all have their use in places to which they are suited, the round, well-burned, clay drain tile is more generally adapted to underdrainage than any other form or material, with cement tile a close second.

Tile drains should consist of tiles laid at proper depths and intervals, of sizes sufficient to carry away all water coming to them from the soil, or from other drains, before the soil will be injured by saturation. Each line, to operate perfectly, should have a free outlet and be laid on an incline or series of inclines of regular grade. The tiles should be well burned and of uniform circular section, but may be made from a variety of quite ordinary clays. Two general classes are recognized, the *common clay* and the *vitrified pipe*. The former is made of clays which, when burned, show different shades of red or cream color, but which do not vitrify and produce what is commonly called stoneware. It is desirable that these clays contain sufficient silica to give the ware flinty and sharp corners when broken. The vitrified tile, either glazed or unglazed, are always good, but are no better for farm drainage than the common ware except where exposed to frost, as in the case of outlets. A convenient and sufficiently accurate test of the quality of any drain tile is the clearness of the ring which it gives when struck with a piece of steel after it has been outside the kiln long enough to absorb atmospheric moisture.

Porosity adds nothing to the efficiency of tile as drainage conduits, since water enters the drain only at the joints. The impression in the minds of many that water passes through the pores of the tile arises from the moist condition in which they are always found, unless the earth about them is very dry, which is rarely the case. The pores of clay ware absorb water readily until they become filled, but no appreciable quantity will pass through them unless under greater pressure than they are subjected to in the soil. This, however, may be said in favor of porous tile: by reason of their absorptive qualities they are cooler than non-porous varieties and condense more moisture from the air which enters the drain in time of drought, but this may not be of sufficient importance to merit serious consideration.

Cement tile have been successfully introduced in Iowa and Minnesota in competition with clay tile, with the prospect that their use will be extended into many sections where either the lack of suitable clay, or distance from a factory, precludes the use of clay pipes. Two methods of manufacture are employed. Sizes from four inches to sixteen inches may be molded by a machine more cheaply than by hand, while the material for the larger sizes is tamped in the molds by hand labor. They may be made in the field near the ditch in which they are to be placed, though the care required in keeping them properly wet while being cured makes this method more expensive and less satisfactory than when made in a properly equipped plant.

The mixture found most satisfactory is one part of Portland cement to four of sand for the smaller sizes, and one to three for the larger ones. It is quite essential that the pipes be well cured before they are handled. This requires at least two weeks, and a longer time is preferable. Cement tile fail under a less crushing test than well-burned clay tile; but the difference in strength is not sufficient to in any way discredit their use, as both exceed the requirements for ordinary depths. Tests of both kinds of tile indicate that neither resist crushing uniformly. A well-known characteristic of Portland cement is that it increases in strength with age, especially for the first six months, tests usually showing that the strength is twenty per cent greater at six months than at one month. The quality of cement tile can be judged with less certainty by inspection than the clay, yet when the cement is good and the material well mixed there can be but little, if any, doubt regarding the value and durability of cement drain tile.

Plank drains are of two patterns, and render good service while the material lasts. They are made either in the form of an inverted *V*, or the rectangular box, both usually open on the bottom.

The inverted *V* drain should not be larger than six inches on the sides, inside measurement, and two-inch plank should be used. One six-inch plank and one

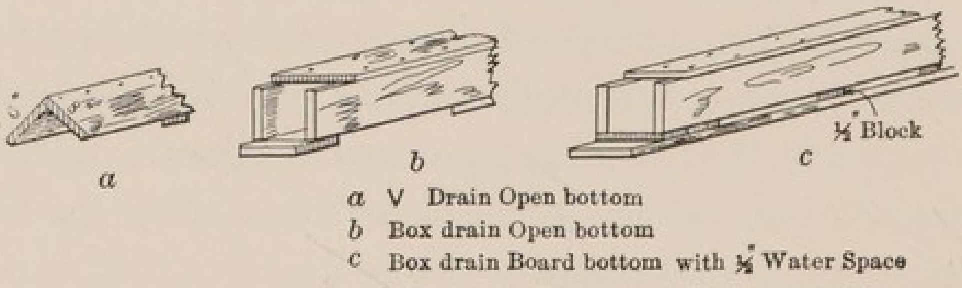

FIG. 9.—Plank Drains.

eight-inch tied across the bottom by cross pieces of inch board six inches wide, placed four feet apart, will make a very good field drain of the above size, having a sectional water-way of eighteen square inches.

The box form may be made any size desirable, but if larger than six inches by six inches inside, two-inch planks should be used in its construction. Box drains can be used in boggy, miry ground where it is impractical to keep tile in position. The boxes may be made of any convenient length, and can be kept in place and serve as drains in soft ground where tile cannot be used. They may serve temporarily and be replaced by tile after the ground becomes firm. The different forms of plank drains and the manner of joining the sections are shown in Fig. 9. It is not practicable to use drains with open bottoms where grades exceed six inches, or are less than three inches per hundred feet. In the first case the bottom soil cuts out by erosion, and in the second there is not sufficient velocity to prevent the accumulation of silt. Bottom boards may be used to obviate either difficulty.

Ordinarily, lumber should not be used in the construction of permanent drains where more durable material is available. There are many localities in the far West, however, where drain pipes cannot be obtained, but where lumber is at hand. In soil where the drains are alternately wet and dry, the material will not last longer than ten years, but where they remain constantly saturated, as in springy ground, they will last for an indefinite period.

Stone drains were once quite common on stony farms, and may still be used where no other material is convenient, or where the land to be drained contains surface stone which it is desirable to dispose of. Several methods of construction have been successfully employed, but the trenches should always have considerable grade, not less than six inches to one hundred feet. The bottom of the trench should be clay or other firm material. Selected flat stones may be so placed in the ditch as to form a rectangular opening called the throat, the bottom being smoothly graded earth. The cap-stone should be held in place by means of spalls, or fragments of stone, placed as wedges between it and the sides of the trench as shown by *a, a* in Fig. 10. Irregular-shaped stones are then placed upon the top of the drain if desired, or clay filling may be used for the entire depth.

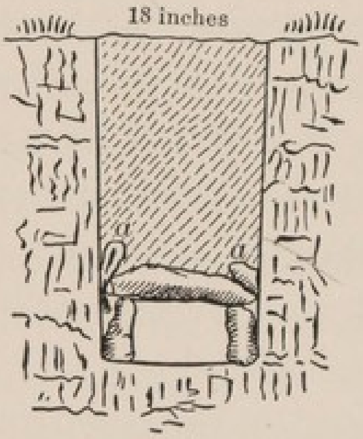

FIG. 10.—Drain Made with Thin Flat Stones.

Cobble-stones may be used in much the same way, but are more difficult to lay so as to make a permanent drain. (Fig. 11.) Where stones are abundant it is common practice partly to fill the trench with them, sometimes for the purpose of conveniently disposing of stones gathered from the field, and in others to add to the efficiency of the drain by providing a quicker entrance for surface water. Clay or hard earth forms the best covering for the stone. It should be compacted as firmly as possible, first by the feet of the workmen, and later by driving a horse in the trench as the filling is being completed with the plow.

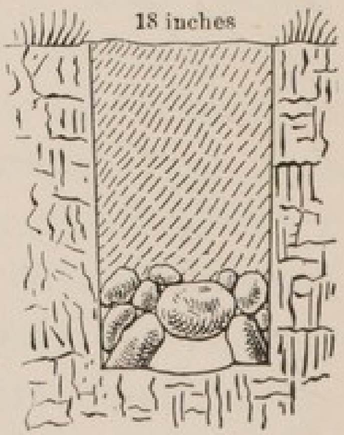

FIG. 11.—Cobble-stone Drain.

Considering the high price of labor and the availability of drain tile, it is doubtful if stone drains can be made as cheaply as tile drains even where stone is convenient and abundant. This, however, is a matter governed by local conditions.

Brush drains may serve as a temporary makeshift under conceivable conditions, where straight brush is at hand and labor cheap. Two methods of constructing them have been successfully used. The first and better one is to bind straight brush into bundles about five inches in diameter by means of willow withes or bands of grass, and lay them, butts up grade, in a ditch, which should be well graded and firm on the bottom. The trench should be ten inches wide and filled with the bundles as deeply as the drainage capacity required may suggest. Sometimes only one course of bundles across the bottom will be sufficient. The second method consists of the use of loose brush in the trench, cutting the twigs so that they will pack closely when covered with earth. The covering for brush drains should be turf or firm sods, which will prevent the earth from obstructing the spaces while it is loose and becoming settled in the trench. Straight poles about three inches in diameter are sometimes used in connection with the brush to prevent it from becoming too compact in the trench. The remainder of the trench should be filled with earth well firmed by tramping.

Brush drains are practicable only where good grade is possible, and where there will be a continuous flow of water. If the brush becomes dry any part of the year it forms a harbor for mice and other troublesome animals, and also decays rapidly. It is the least desirable of underdrains, yet it may serve an excellent purpose under some conditions and is at least better than no drain.

Mole drains were at one time used on the prairies of Illinois and Iowa with good results, where the kind of soil and the surface slopes were favorable to their construction and operation. The machine with which they were made was drawn by a cable and capstan, and consisted of a steel mole about fourteen inches long, conical in shape, and usually five inches in diameter at the base, attached to the end of a steel cutter or blade, the other end being inserted into a long beam of wood which lay upon the surface of the ground. The beam rested upon shoes and had a large screw at the rear end by means of which the depth of the ditch could be slightly regulated. It was forced through the clay and left a conduit with hard-pressed and smooth walls. Some of the moles were furnished with a ball attached to the rear end, which further pressed and perfected the walls of the drain. Such a drain, of necessity, lay parallel with the surface of the ground, in the main, and its durability depended largely upon the character of the clay through which it passed. It often gave good service from three to five, and sometimes eight years, where the subsoil was joint clay, free from sand, gravel, and roots, and where the slope of the surface was regular. Tile drains have practically superseded mole drains, since the former make a much more perfect and durable drain in every way.

SUBSOILING

Close soils, like "gumbo," "buckshot," and other stiff clays, are slow to respond to drains. Careful mechanical manipulation of the soil greatly assists in opening it for the entrance of air and the passage of water. The subsoil plow is an old and well-tried implement for this work, and is successfully used to better the drainage of soils, as well as to increase their depth and friability. A strong plow, with standard eighteen inches long, and small pointed shoe, drawn by a team of five horses, will leave a loose course fifteen inches beneath the surface which will serve as a reservoir for soil water, and at the same time break up and aerate the ground. Cotton-growers have secured excellent results by running the plow through every space between the rows as soon as the seed was planted, and as a means of making under-drains laid in stiff soils more effective, the plan is unsurpassed. Where lands are not underdrained the plow must be used every two years, but the effect is excellent in every way.

OBSTRUCTIONS IN UNDERDRAINS

To the oft-repeated question as to whether underdrains will become obstructed by roots of trees, shrubs and other plants, it may be replied that, ordinarily, in humid regions, they will not. There are, however, some conditions now fairly understood which are favorable to the entrance of roots into drains.

With reference to the record of experience upon this point it may be said that the drains first laid in this country by John Johnston on his farm in Seneca Co., N. Y., sixty and seventy years ago, are still unobstructed, though the lands have been in continuous cultivation, some in nursery and fruit trees, up to the present date. The extensive nursery and orchard lands in Wayne Co., N. Y., formerly owned and drained by Theron G. Yeomans, are the home of trees forty years old, yet no obstructions to drains by roots are recorded. The writer knows of farms in the Middle West where drains have been in successful operation for over twenty years without any injury, and requiring no repairs of any kind.

Ordinarily, drains are dry during a large part of the summer months, presenting no attraction as a source of water supply to roots. There are situations, however, where drains are subject to obstruction by roots of trees, and sometimes by other plants. When a drain passing through comparatively dry ground is supplied by a continuous stream from a spring, well, or similar source, roots of nearby trees persistently seek the supply when soil moisture is deficient, and entering the joints develop fine water roots very rapidly, often filling the bore of a six-inch pipe in a year or two. Under such conditions, trees like the maple, which ordinarily gives no trouble, may obstruct drains. In almost all cases, willows, water-elms and poplars, which are gross feeders and large water-users, are dangerous to drains, and should not be permitted to grow nearer to them than fifty feet.

Drains laid in irrigated land, in subtropical climates, planted to vines and trees, are particularly subject to stoppage by roots. It is there found necessary to construct silt-basins (see Chapter IX) along the lines, at intervals of four hundred or five hundred feet, so that the drains can be inspected and root obstructions removed. Roots are a peculiar menace to tile drains in irrigated soils of the west, and their behavior there will be found more fully discussed in Chapter XVII.

Obstructions from other causes rarely occur. Possibly some surface inlet is faulty and permits dirt and rubbish to enter the drain; or at some point where the line of tile passes through fine sand the grains sift through and fill the pipe; or perhaps, owing to unstable or miry conditions at the time of construction, the tiles have become displaced as the ground settled, and allowed soil to enter. If the outlet of the drain is unprotected, it occasionally happens that some small animal enters the drain, and, becoming fast, prevents the flow of water. The obstruction, whatever its cause, will make itself known by a wet spot in the field, or if the fall is considerable, the water will break through just above the obstruction, thus indicating where the trouble is.

CHAPTER IV

DRAINAGE SYSTEMS

If, as often happens, a single line of tiles laid through a flat basin or hollow of the field affords sufficient drainage, it is usually spoken of simply as "a string of tile." But in a more thorough or extended drainage system there is a main drain and branches. These branches are collecting drains, gathering the water from more distant parts of the field and discharging it into the main or receiving drain. In a large system it is often necessary to make receiving drains of some of the branches, in which case they are known as submains, and the collecting drains discharging into them are known as laterals. Branches and submains always discharge into the main, but laterals into the submain. This distinction is not always closely observed, the terms branch and lateral being often used interchangeably.

ARRANGEMENT OF DRAINS

While the location of drains must necessarily depend largely upon the contour of the field, there are certain recognized systems of arrangement which are more or less closely followed by drainage engineers. The **herring-bone system** (Fig. 12), or a modification of it, is well suited to ponds or basins which have a considerable slope toward the center by reason of which surface water sometimes accumulates rapidly in the lowest ground, and its removal is hastened by the action of the large number of drains there. The plan also meets the conditions where it is necessary to extend some of the branches farther than others to reach spots that should be drained.

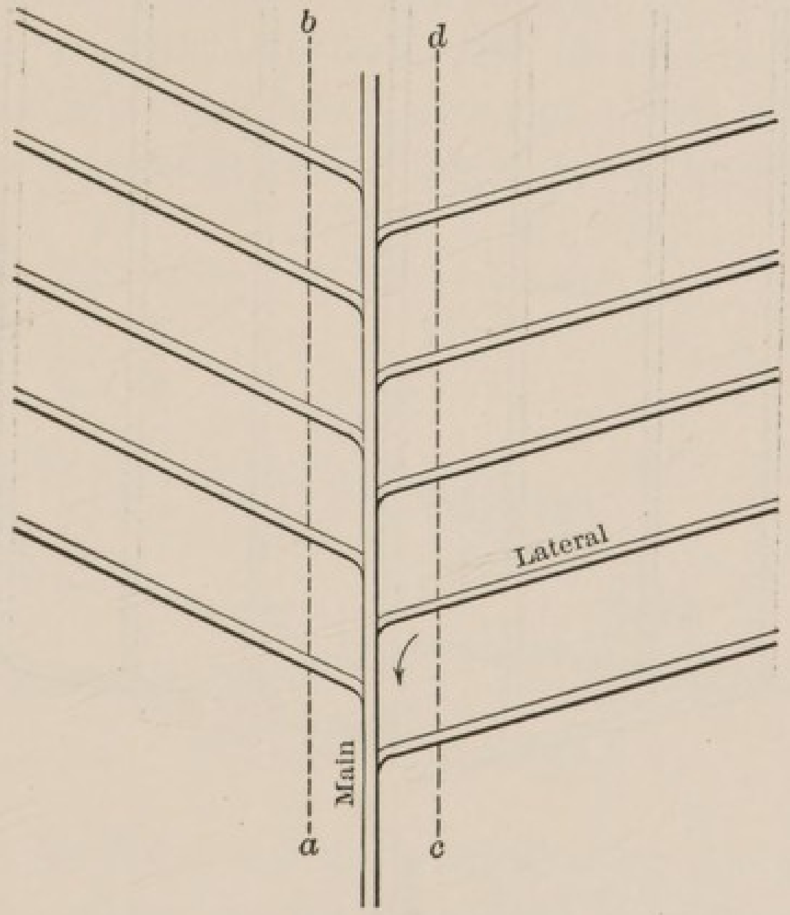

Fig. 12.—Herring-bone System.

While an efficient system, it is not an economical one except in the locations just mentioned, for the reason that the portion of the branch drains between *a–b* and *c–d* (Fig. 12) are unnecessary, that strip of land being drained by the main ditch.

The **gridiron system** (Fig. 13) is adapted to level land where there is no concentration of surface water, and where all of the soil within range of the lines appears to require equal drainage.

There are cases where a single intercepting line may be of more service than a system of many lines. From the office performed, this arrangement is called the **cut-off system** (Fig. 14), and is employed where it is

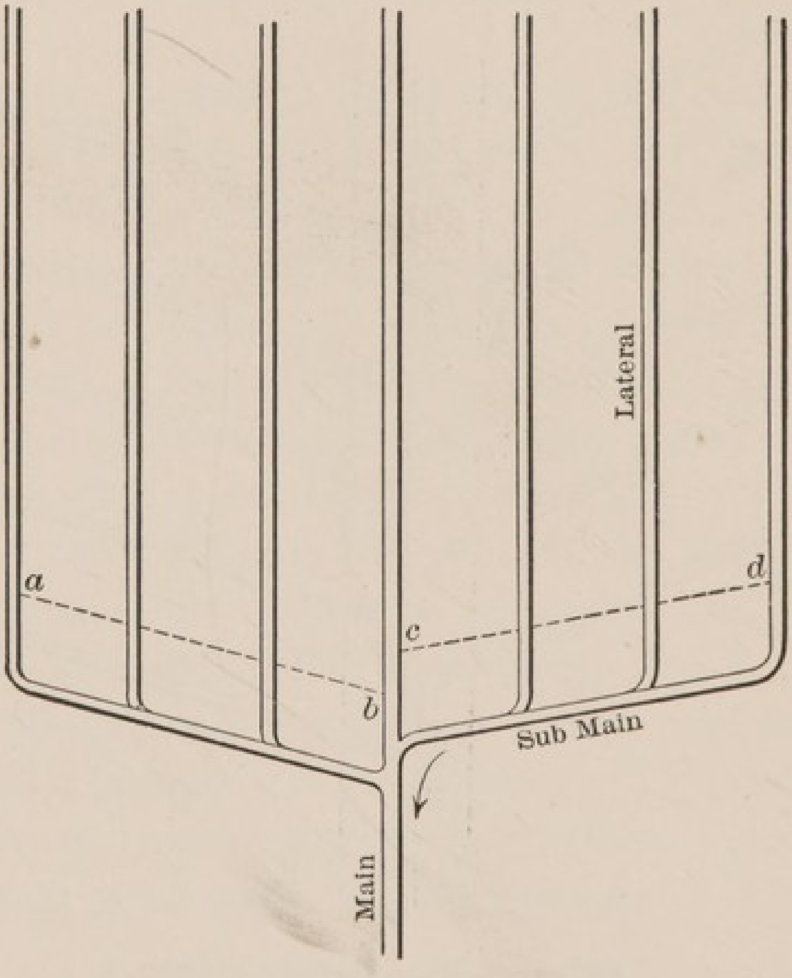

FIG. 13.—The Gridiron System.

necessary to protect a strip of land from saturation produced by water oozing from a slope or higher level. The depth of the drain in this system is an important consideration, for if it does not reach the plane of the water-bearing stratum, the water which produces the boggy or spouty condition will not be intercepted. It is used with good effect in draining lands under irrigation which have become saturated with the seepage from ditches, or from the waste from irrigated lands occupying a higher level. (See Chapter XVII.)

Across-the-slope system has come to have a recognized place. Slopes do not usually lie as a plain with only one definite inclination of the surface, but either upon the surface or in the subsoil they are broken by slight valleys which concentrate drainage water in a small measure, suggesting the running of drains down instead

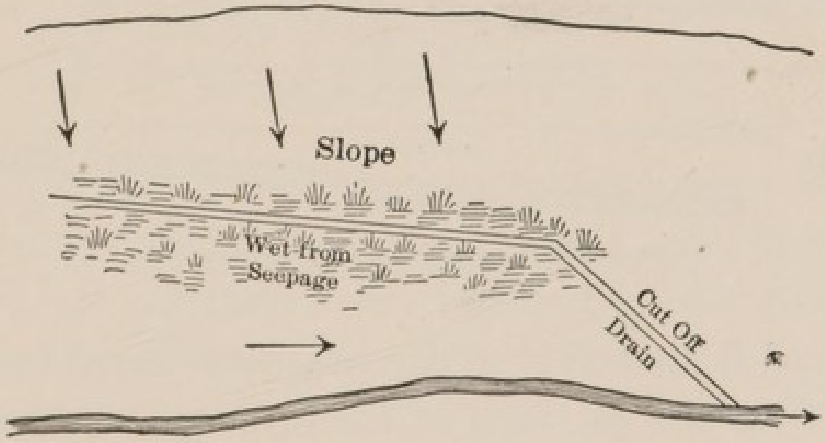

FIG. 14.—Cut-off System.

of across the slope, and this method is the one generally practiced. Close observation of old drainage systems, however, shows that in some instances this plan may be profitably modified by placing the lateral drains either diagonally to or nearly across the slope. (Fig. 15.) The occasion for the adoption of such a plan is furnished when the slope is a plain, devoid of the corrugations or draws before alluded to, to such an extent that water in its natural course will pass in straight lines directly down the slope instead of being deflected laterally into little valleys. M. Faure, a French drainage engineer, in his recent book upon this subject, urges that all lateral drains be laid across the slope. It is evident, however, that due regard should be given to both subsoil and surface conditions in the consideration of this matter, for the history of this system, known as the Keythorpe system, shows that though it has been attended with satisfactory results in some places in England, it has in others been replaced by drains laid down the slope.

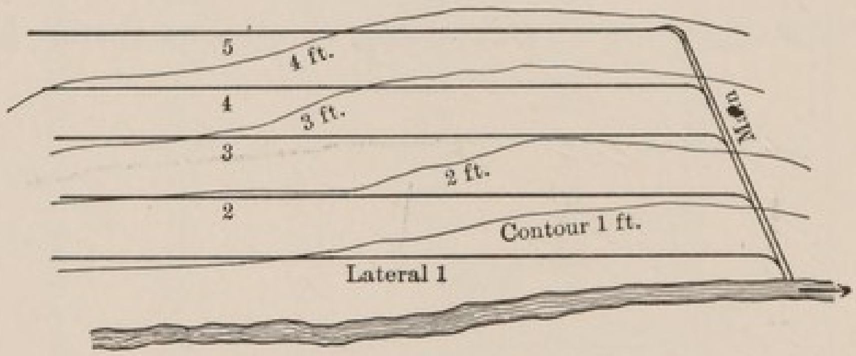

FIG. 15.—Across-the-Slope System.

Often it is advisable to use **two, or even more, systems** or modifications of them in the drainage scheme of one field or tract of land. Sometimes also in place of submains it is expedient to have **two or more mains** discharging into the outlet stream or ditch. It is, however, desirable to have as few such tile outlets as is consistent with the system or systems employed, as they must be protected and kept in order for all time. The plan of **a modified gridiron system,** shown in Fig. 16, reduces the number of exposed outlets to a minimum and requires no additional cost but that of the necessarily increased size of pipe for the main.

When long parallel lines can be employed, the cost of drainage of land directly affected is less than where short lines must be used. Natural conditions of soil and surface are, however, controlling factors in the arrangement of drains, in whose results efficiency holds first, and economy second place, and it will readily be seen that

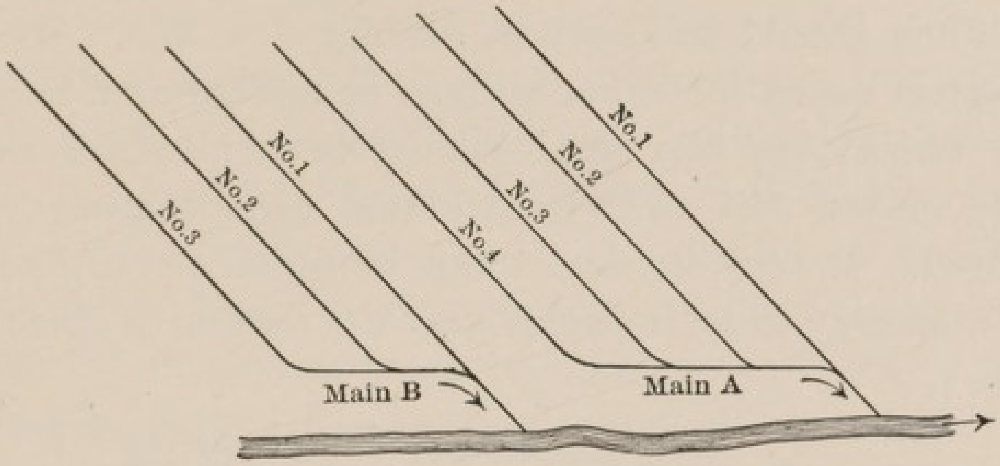

FIG. 16.—Modified Gridiron System.

the greater the familiarity of the landowner with the surface and peculiarities of his fields, the better able will he be to determine what method is best adapted to meet the requirements.

THE OUTLET

This is obviously the first and most important part of a drainage system. Whether open ditches or underdrains are employed, other things being equal, their efficiency will depend largely upon the completeness of the outlet provided. The lack of good natural outlets is many times the greatest difficulty that farmers meet in the drainage of level lands. To secure them it is often necessary to straighten and deepen natural water courses, dredge channels through level areas, and make ditches where mere depressions in the surface of the land suggest courses for them.

There are two points essential to an outlet. First, the ditch or channel should be of such capacity that it will not run full more than twenty-four successive hours. Second, the general plane of the drains discharging into the ditch should be above its average flow line. While a perfect outlet for either surface or underdrains is one into which they may discharge freely at all times with more or less fall, such a condition cannot always be secured. It may be, and often is, necessary to locate the discharge of underdrains near the bottom of ditches,

FIG. 17.—Effect of Submerged Outlet.

in which case they have **a submerged outlet** at every considerable rise of water. A tile outlet may, however, be submerged for a time without serious injury to the land it serves, but during such submergence the portion of the field lying between the outlet and the point where a line level with the outlet ditch intersects the grade line of the tile drain will not receive drainage deeper than this level. For example, in Fig. 17, the soil between the outlet and *C* can be fully drained only above the line *B-C*. If the earth in which the tile is laid is clay, or of such a character that but little silt or sand is carried in the flow, no injury to the drain by filling will occur, and only the lower section of the land will fail to receive drainage. Instances are known to the writer where drains have operated successfully under these conditions for years. If, however, a considerable volume of sediment is present in the water carried either by the outlet channel or by the field drain, the submerged part may become inoperative by reason of the deposit of silt or sand in the pipe. This will take place gradually, a layer of sediment being left at each submergence until the pipe is filled. If the gradient is not less than four inches to one hundred feet there is little risk of the clogging of the drain from this cause under any conditions usually found, while drains in clay soils may be laid upon any gradient if the drainage water is fairly free from heavy sediment. Free soils requiring drains of large capacity are injured less by a submerged outlet than close, compact soils where small tiles are used and there is less static head to force the outlet and keep it free from obstruction.

It may be questioned whether a permanently submerged outlet, operating without injury to the pipe system, furnishes ideal conditions to the land which is not affected by back water, because of the water-seal, which prevents the entrance of air at the discharging point of the system. Observations so far made indicate that the submergence affects only the saturated soil, since it is believed that soil aeration is accomplished by the atmosphere which permeates and fills it as the water of saturation disappears, rather than by the circulation of the air through the drains. If, however, silt basins and surface inlets (see Chapter IX) are a part of the system, a water-seal at the outlet would to some extent interfere with the circulation established with the atmosphere by these openings.

CHAPTER V

LOCATION OF DRAINS

THE observing farmer or cultivator who has acquainted himself with his fields during his labors upon them through successive seasons will have noted the location of parts on which an excess of water at certain times occasioned a partial or total failure of crops. He also will have marked the direction taken by surface water after the ground was saturated in a heavy rainfall, as well as the points at which overflow from low places, ponds and swales occurred. Knowledge of this nature is of first importance in the location of a system of drains that shall relieve his lands of all excess of water.

If in addition he has looked below the surface and observed whether the soil structure is characterized by parallel layers or is close and compact; if he has dug post holes or pits when the ground was wet, and has noted the freeness with which water oozed and trickled from the sides, and how quickly it filled the hole; if he has been still more observant and noticed whether the water spouted from little crevices or formed on the walls of the hole in an almost imperceptible film, and whether the walls began to slough off as the water increased or remained smooth and intact; if he has sunk the hole still deeper and ascertained whether there is sand, gravel, or hard clay at a depth of from five to seven feet;

if, in short, he has become familiar through his field operations with the composition, structure, texture, and drainage properties of the soil and subsoil of his land, he has acquired data of utmost value as a preliminary to the proper placing of his drains.

When about to begin actual work in this direction he must supplement this general knowledge, which has been accumulating year by year, with more exact information, gained by a detailed examination of the area under consideration, having the precise location of the drains definitely in view. Here he should bear in mind that what may seem commonplace and trivial matters are often important determinants in the establishment of a drainage system.

PRELIMINARY LEVELING

In this final study of the fields, a level, either in the hands of the farmer or of an engineer accompanying him, will always be of great assistance, and is often absolutely necessary. While occasionally the slopes are well marked and the best location of the lines quite apparent to the eye, thus making the use of the level at this stage seemingly superfluous, it is much more frequently the case, so deceptive are slopes and distances, that grave errors of eye or judgment are quite possible and should be avoided by taking accurate observations with the level. (See Chapter VI.) There should be a sufficient number of such levels taken to indicate the height of the principal depressions and elevations in the tract of land under surveillance, that by a comparison of these, the outlet point, the watershed, and the direction of main and important minor slopes may be ascertained.

In addition to keeping the necessary level notes during this part of the work, a preliminary level sketch should be made to accompany them. This should be constructed on the field by the proper notations at each station as the work progresses. It should show when completed the approximate location of the stations, with the elevation of each, the direction of the slopes, indicated by arrows, and the course of any natural water channel which may be made the outlet or any part of the drainage system.

LOCATING THE DRAINS

The engineer, or farmer, if the latter is undertaking the work alone, is now ready to locate his drains; to determine from the facts secured where the lines shall be laid most effectively and economically to do the work desired. At this point, in addition to the use of the knowledge acquired relative to the situation, the exercise of discretion and good judgment is imperative. Previous experience is, of course, a valuable aid here, but thought and painstaking in the application of the data secured will in a great measure compensate for its lack. Too much emphasis cannot, however, be placed upon the need of guarding against errors in location which shall either impair the efficiency of the drains or add unnecessarily to their cost. Though it may be the intention to construct at first only a part of the drains necessary for the thorough drainage of the field, the entire system should be decided upon at this time and recorded, so that to the work now done other portions can be added later, and when all are finished a complete, well-arranged drainage system will be in operation.

As the most practical method of offering helpful suggestions for this part of the work, the development of drainage plans for two fields, presenting different, but typical, problems, will be given as examples.

Example No. 1. The South Field. This consists of sixty-one acres which is seemingly quite nearly level. A small creek, three hundred feet distant from the field line, and on the land of a neighbor, is the only outlet available. Beginning at the point *o*, on the bank of the creek (Fig. 18), assume for it an elevation of 100. Find the elevation of the bottom of the creek, which latter point will control the location of the outlet for the field. Select points upon the field as shown on the sketch map (Fig. 18) and record their elevations in the notes. The level notes to accompany this sketch will appear as shown on page 53. The station numbers and accompanying elevations in the notes correspond with those upon the map. A small stake should be set at each point where a level is taken and numbered to agree with the station recorded in the notes. From the numbers in the column headed *Elev.* can be computed the height of all the points indicated, above the bottom of the creek. It will be noted that the circuit is made and the levels closed upon station No. 1 so as to prove the accuracy of the levels.

The sketch map places the facts which have a bearing upon the location before the eye in a collective form so that the topography of the entire field can be seen at a glance. If the knolls and slopes were more pronounced,

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the levels taken would be confined to the lower sections of the field. Having before him, then, this map, which is on a page of the level note-book and need not be copied unless it is desired to use it for some other purpose, the farmer or engineer can indicate the plan of draining

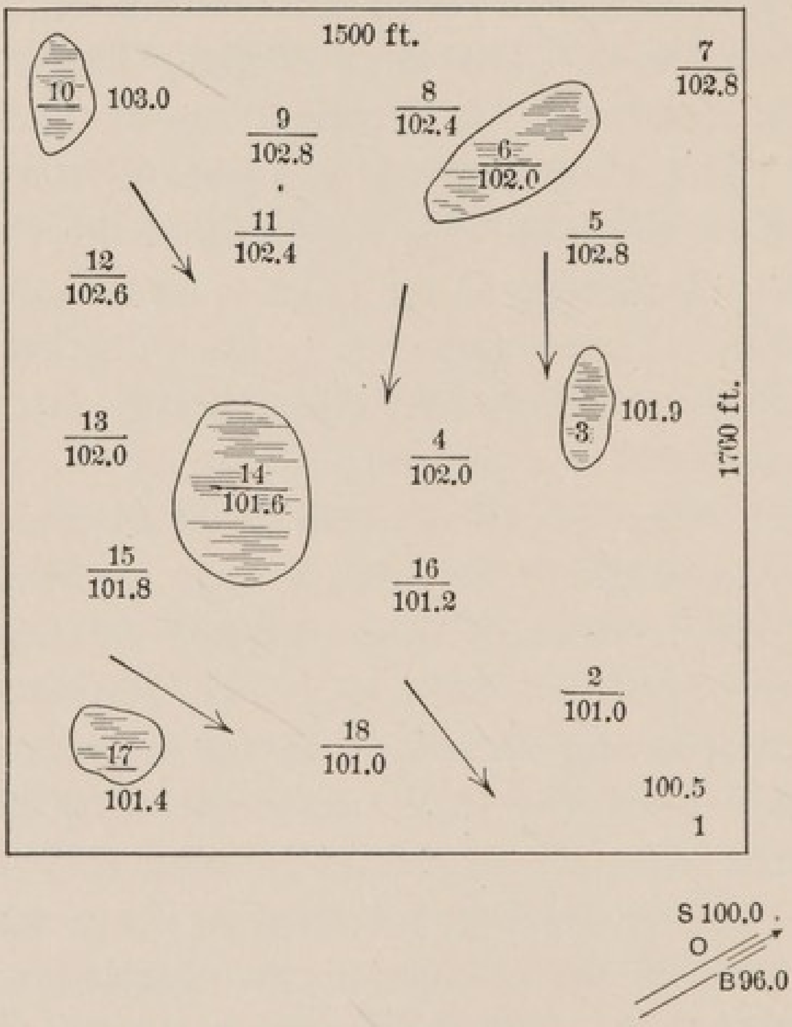

FIG. 18.—Sketch Map of South Field from Level Notes.

by sketching in the lines approximately, if he chooses, but the better method is to locate them upon the ground. Fig. 19 represents the plan which is made in accordance with the conditions ascertained by the survey. The creek is four feet deep, which will permit the outlet of the drain to be three or three and one-half feet below the surface of the bank. One of the principles of drainage is that in general mains should follow the lowest ground, and pass through the natural depressions. This principle should be applied here. There will be but one outlet. The main extends from the point o to point 14,

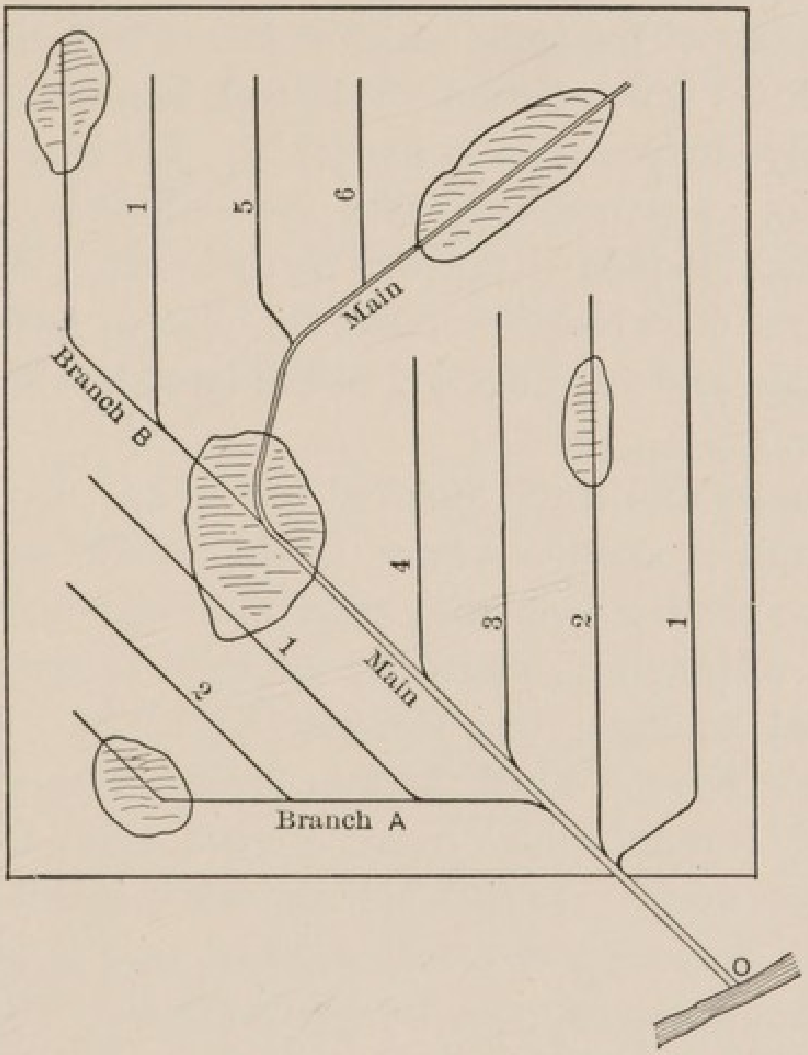

FIG. 19.—How to Locate the Drains on South Field.

and thence to point 6 (Fig. 18), all of these being lower than the surrounding land. There are other depressions shown, and the question arises whether it is now desirable to lay out a system which will secure uniform drainage, or place drains in the low lands only. In case the latter is decided upon, drains would be laid through points

3, 10, and 17 (Fig. 18), and drain No. 2 and Branches A and B (Fig. 19) would accomplish the purpose. The more complete system would consist of parallel lines as long as possible, running in the direction of the slope, as represented in Fig. 19. Branch No. 5 is joined to the main as shown, in order to shorten the line and lessen the acuteness of the angle which it makes with the main. The angles at which most of the laterals join the main are necessarily sharper than is desirable. The lines can be staked out as represented with the assurance that the fall on each, though slight, will be sufficient. Whatever the distance between the drains, the plan as to location of the main and the direction of the laterals will remain the same.

The outlet and three hundred feet of the main being on the land of another owner, it will become necessary for the respective owners to enter into some agreement mutually satisfactory, regarding the right of way for the drain, and its cost. (See Chapter XIII.)

Example No. 2. North Bottom Field. This is a part of a valley through which passes a creek, thirty feet wide and six feet deep. On each side there is valuable bottom land, but so level and poorly drained that it produces only coarse grass of poor forage qualities. The creek rarely overflows its banks, so that no dikes will be needed to protect the land.

Begin the preliminary level work as before by establishing an initial point at the bank of the creek marked 0 on the sketch map (Fig. 20), and assume the elevation as 100. Take a series of levels across the valley from the foot of one slope to the other as shown upon the map. The accompanying level notes are given on page 56.

PRELIMINARY LEVELS ON SOUTH FIELD

(See Sketch Map, Fig. 18)

Sta.	B. S.	H. I.	F. S.	Elev.	Remarks.
0	4.20	104.20		100.00	Bank of creek.
B	......	....	8.20	96.00	Bottom of creek.
1	......	....	3.70	100.50	
2	3.60	104.60	3.20	101.00	
3	......	....	2.70	101.90	Shallow pond.
4	5.23	107.23	2.60	102.00	
5	......	....	4.43	102.80	
6	5.42	107.42	5.23	102.00	Shallow pond.
7	......	....	4.62	102.80	
8	4.30	106.70	5.02	102.40	
9	......	....	3.90	102.87	
10	......	....	3.70	103.00	Pond.
11	......	....	4.30	102.40	
12	5.10	107.70	4.10	102.60	
13	......	....	5.70	102.00	
14	......	....	6.10	101.60	Flat pond.
15	4.80	106.60	5.90	101.80	
16	......	....	5.40	101.20	
17	......	....	5.20	101.40	Small flat.
18	5.10	106.10	5.60	101.00	
1	......	....	5.50	100.60	Check on Sta. 1. (Error .10 ft.)

While taking these levels, observe that at the foot of each slope, as *A* and *C*, there is a belt of seeped soil which evidently owes its boggy condition to percolation from the hillsides. The pond *D* is nearly level, and has no natural drainage. It is kept wet by the rain which falls upon it, and also by a portion of the flood

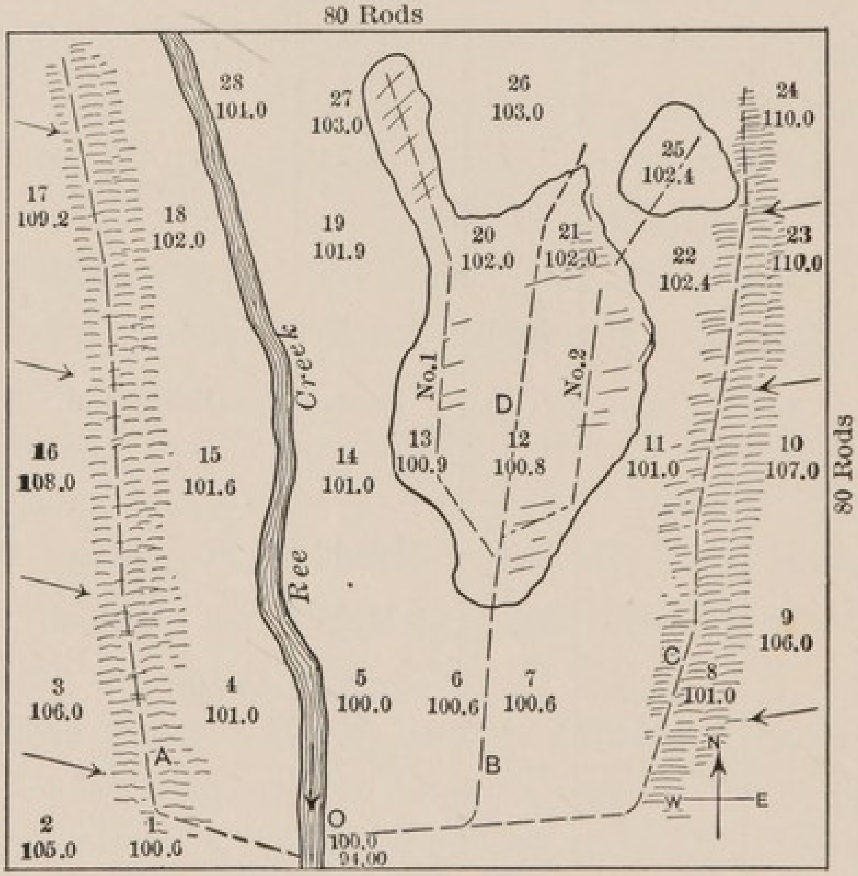

FIG. 20.—Preliminary Levels and Location of Drains on North Bottom Field.

run-off from the bordering hillside. The levels show that the direction of the slope of the valley is parallel with the course of the creek rather than laterally toward it. The soil is a friable loam containing a little sand, and easily cultivated when dry, while the subsoil is a joint clay.

Proceeding with the location, place intercepting drains *A* and *C* at the base of the slopes to remove the seepage which comes from the hillsides. Borings should be made, or pits dug, to ascertain the position of the clay, and the horizon from which the water comes, so that the depth of the drains can be correctly determined. The drain should be located on the upper side of the wet belt, a little below its upper edge, which it should approximately parallel. The grade must be so adjusted that the drains will lie in the stratum where the soil water accumulates. A minimum grade should be adopted (two inches per hundred feet, possibly less in firm soils). In keeping the drain in the stratum which furnishes the water one may frequently violate the rule that grades should be uniform where possible, but the best success in draining cannot always be secured by following either a plan or a gradient which looks well upon paper.

The marshy pond at *D* requires a drain through the middle, with a lateral on each side parallel to it. This plan is better adapted to the land than the herring-bone system (Fig. 12), since the drains may be made longer, and can be extended through the little arms at the upper part of the flat.

The question may be asked whether a better plan would not be to locate the main *B* so as to pass through the west side of the pond *D*, and extend laterals at regular intervals eastward to and through the wet belt at the base of the slope. This plan might give good results, but the combined length of the laterals would be greater than the length of the drain *C*, and it is questionable whether they would intercept the seep water as effectually as the single drain along the foot of the slope.

PRELIMINARY LEVELS ON NORTH BOTTOM FIELD

(See Sketch Map, Fig. 20)

Sta.	B. S.	H. I.	F. S.	Elev.	Remarks.
0	3.22	103.22	......	100.00	Bank of creek south end of field.
a	......	....	9.22	94.00	Bottom of creek.
1	6.20	106.80	2.62	100.60	
2	3.20	108.20	1.80	105.00	Hillside.
3	......	....	2.20	106.00	
4	......	....	7.20	101.00	
5	3.32	103.32	8.20	100.00	East bank of creek.
6	......	....	2.72	100.60	
7	2.30	102.90	2.72	100.60	
8	5.40	106.40	1.90	101.00	
9	4.20	110.20	0.40	106.00	Hillside.
10	......	....	3.20	107.00	
11	10.00	111.00	9.20	101.00	
12	......	....	10.20	100.80	Pond.
13	4.32	105.22	10.10	100.90	
14	......	....	4.22	101.00	
15	7.22	108.82	3.62	101.60	
16	4.62	112.62	0.82	108.00	Hillside.
17	......	....	3.42	109.20	
18	5.20	107.20	10.62	102.00	
19	......	....	5.30	101.90	
20	......	....	5.20	102.00	
21	......	....	5.20	102.00	
22	7.31	109.71	4.80	102.40	
—	6.41	111.92	4.20	105.51	
23	......	....	1.92	110.00	Hillside.
24	......	....	1.92	110.00	
25	3.61	106.01	9.52	102.40	Pond.
26	......	....	3.01	103.00	
27	......	....	3.01	103.00	
28	......	....	2.01	104.00	

In working out the plans upon the ground the course is walked over and guide-poles set at each important point as it is decided upon, as the outlet, changes of direction, entrance of branches, etc. This is equally necessary when the proposed system has first been outlined in pencil on the preliminary sketch, as some prefer to do. Actual canvass of the proposed course may suggest desirable changes in the plan as mentally determined upon, and in any event guide-poles must be set by which the staking of the drain shall be done later.

These examples by no means cover the great number of cases that will arise in practical work, but they serve to suggest the manner of solving the problems that enter into the location of drains.

CHAPTER VI

WORK WITH THE LEVEL

Believing that many times, where for any reason a professional engineer is not employed, an amateur with good judgment can do the necessary level work by following intelligently a few simple directions, the use of the level and the manner of taking levels is here treated in detail, for his benefit.

LEVELING INSTRUMENTS

There are many kinds of leveling instruments, varying from the simple water level to the accurate engineer's spirit level. A good carpenter's spirit level may be fitted with sights raised one inch above the edge of the bar and their accuracy tested by sighting over them at a given point and then reversing the bar and sighting the same point. If the sights are set correctly (the level bubble having been previously adjusted), the line of sight will strike the same point when turned about. If this is not the case, adjust the sights so that when the level bubble is in the center, and the instrument reversed, the line of sight will intersect the same mark on a rod set about two hundred feet distant from the instrument. The bar may be mounted upon a tripod and used as any other level. A man with a good eye can do fairly accurate work with an instrument of this kind, but only simple work on small fields should be attempted. The rod used with this level for measuring the height above the point whose elevation is to be determined should be ten feet long, and divided from the bottom upward into quarter inches, with the foot marks omitted and the inches numbered consecutively from 0 to 120, and read to the nearest $\frac{1}{8}$ inch. A piece of white cardboard, so adjusted as to be readily moved up and down the face of the rod, provides a sufficient target, the upper edge of the card to be brought into line with the sights on the level. Engineers use the decimal foot scale, which is more convenient, but amateurs usually prefer the inch, and its divisions into eighths. This simple device for obtaining the levels in a field may be used by the farmer if he wishes to do the work himself, provided he has fairly good fall and no difficult problems.

There are a number of cheap levels on the market intended to take the place of the more expensive engineer's levels. They are, as a rule, not to be recommended, because they are not sufficiently well made to take and hold their adjustments. The amateur is deluded by their show of accuracy, when in fact they may be giving him incorrect results. When one passes beyond the simplest and most easily understood leveling device, it will be best to use the drainage or builder's telescope level, costing about fifty dollars, accompanied by a graduated target rod, provided with a sliding target. This is convenient and reasonably accurate. The printed instructions furnished by the makers for adjusting such levels can be easily mastered by the novice. This kind is used by many drainage engineers having an extended local practice.

LEVELING

This can be done in various ways, but in whatever way it is done the principle remains the same. The level when in adjustment gives a horizontal line of sight. The rod is held by an assistant upon the point whose elevation is to be determined. The levelman, running his eye along the line of sight or through the telescope, notes where it intersects the rod, and signals the rodman to slide the target to that mark, where it is clamped, or in the case of the simple leveling outfit, firmly held at that point, and the rodman announces the feet and the fractions of a foot, which are at once recorded by the levelman in his note-book. This is called a rod reading. The rod is then moved to another point, and a reading is again taken. The difference between these readings is the difference in elevation between the two points upon which the rod was placed.

If we wish to take a system of levels, that is, find out how much higher or lower different points are than the starting point, the process becomes more complicated, for the reason that the instrument must be moved and the levels all referred to the same datum. The following method of operating, and of keeping the notes, is general, and will apply to whatever kind of instrument is used to obtain the horizontal line.

TAKING PRELIMINARY LEVELS

As we have seen in Chapter V, the first step in the design of a drainage plan is the taking of sufficient levels to indicate the proper placing of the lines. To make this preliminary level survey, begin at the place which seems to be the lowest point upon the farm or field, and assume the starting, or outlet, point at the surface of the ground to be one hundred feet above an imaginary plane below, called *the datum plane*, or *datum* (A in Fig. 21). The datum height 100 is used so that minus numbers will be avoided should the starting point not prove to be the lowest one. Place the instrument at some convenient point, the distance of which will depend upon the power and accuracy of the instru-

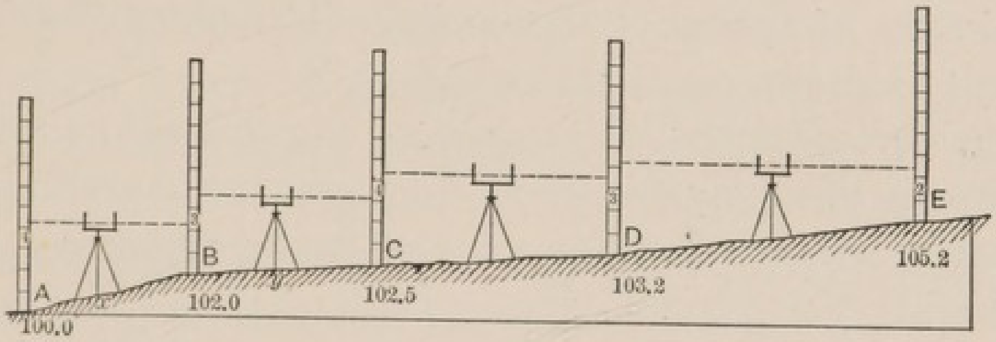

FIG. 21.—Leveling.

ment (x in Fig. 21), and take a reading from the rod held at the point A, called a back-sight reading, which we will assume, for illustration, to be 4.21 feet; add this to the assumed elevation of A, which gives 104.21 feet, for the height of the line of sight, or of the instrument, above datum. Now remove the rod to B, and with the instrument still at x, take a reading on B called a fore-sight, which we will assume to be 2.20 feet. Subtract this reading from the height of the instrument, which gives 102.01 as the elevation of the point B. Change the instrument to some place beyond B, as at y. With the rod still on B, take another reading, called a back-sight, which we will suppose is 3.62 feet. Add this to the elevation of *B* for the height of the instrument in its new position, which is 105.63 feet. Take a reading at *C*, which is 3.05 feet. The distance between the points should be measured or carefully estimated and recorded in the notes. Repeat these operations until the elevation of all points desired is found. Observe that at every change of the instrument a back-sight must always be taken upon the last point at which a reading was taken and its reading added to the elevation of that point for a new height of the instrument. Also subtract every fore-sight reading from the height of the instrument to obtain the elevation of that point. The notes should be kept as shown on pages 53 and 56.

As before noted, the foregoing is a description of the manner of taking the levels from which the preliminary sketch is made and the lines of drains planned. (See Chapter V.)

LEVEL WORK IN LAYING OUT DRAINS

Too much emphasis cannot be placed upon the need of care in all the details leading up to the actual construction of a system of drains. Unless inaccurate, and in the end costly, guesswork is to be depended upon, additional level work will be necessary to establish grades and prepare for the laying of the tile. There is often a failure to appreciate the need of accuracy and painstaking at every step of the work, with the inevitable result that serious mistakes are made. Drains are shallow where they should be deep, and vice versa; are laid in needlessly crooked lines, and on haphazard, irregular grades, thereby greatly impairing their efficiency; and so on through a long list of errors which might have been avoided by the use of data secured by the level. Many insist that water is the best guide in grading a drain, but this is not always the case. The quantity of water which accumulates in a ditch while it is being opened, the kind of earth forming the bottom, and the amount of sediment carried by the water as the digging progresses, so modify the flow as to deceive the most experienced workman. The additional expense of exact measurements and careful survey will be more than compensated for later in the saving of costly corrections and repairs necessitated by inaccurate work at this stage. Another advantage of such a course is that it makes possible the drawing of specifications for the work, which, if it is to be done by contract, is necessary in order that the workman may have a basis for his contract prices, and a guide in his labors, and the employer be in a position to secure accurate and high-grade work by insisting upon a compliance with the specifications.

Staking the line for the drain so that levels may be taken from which the grade can be computed, and along which line later the ditch shall be dug, constitutes the first division of this work. In preparing for this, provide a measuring chain or a tape graduated to feet, and two kinds of stakes, one called a grade peg, which should be ten or twelve inches long if intended for use in soft ground, but may be five or six inches if intended for use in hard ground; the other a guide stake, which may ordinarily be eighteen or twenty-four inches long. The first is driven flush with the ground surface and the top of it is the point from which measurements are made in grading the ditch. The guide stake is driven near the peg and carries the number which indicates the distance from the outlet, and perhaps, later, one giving the depth of the ditch at that point also. The stakes may be made of fence or plastering lath, or of heavier material, whichever is most convenient. The top end of the guide stake should be smooth enough to permit the use of a soft lead pencil for marking.

Starting at the outlet, drive a grade peg flush with the surface near the end of the drain; a few inches beyond it, in the direction of the first guide pole which was set

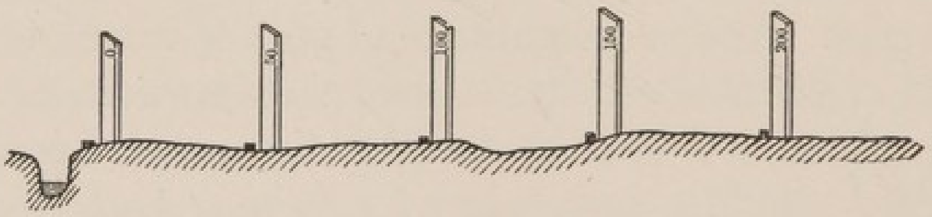

FIG. 22.—Stakes Set for Leveling.

in locating the drains, drive a guide stake, near the top of which mark 0. Measure a length of 50 feet from 0 stake, and with the eye over this stake, line in the second stake held by an assistant. Drive a peg and guide at this point as at 0, and number it 50. Proceed with third, fourth, and continue to the end, numbering the guides 0, 50, 100, 150, etc., each stake indicating the distance in feet from the outlet. (Fig. 22.) In changing direction at the poles, let the chain or tape follow in a curved line, and set a few intermediate stakes from which the ditch may be graded around the curve. The best possible drain curve can be marked by swinging a rope around the bend. Other intervals than fifty feet may be, and often are, used in setting stakes, but ordinarily fifty feet will be found the most convenient.

Where branches are to enter a main an intermediate stake with its distance number should be set, unless the branch enters at a regular station. In either case, the name or number should be marked on the stake in addition to the distance number, as Branch *A*, Branch *B*, etc., or Branch 1, Branch 2, etc., the letters being used to indicate submains and the numerals used for branches which have no laterals, and for laterals. The lettering is done in order from the outlet up. The guide stakes on each branch are numbered from its junction with the main in order to its upper end, the junction point being 0 of the branch line. The ditch, when dug, will not be nearer than 8 inches to the stakes, so in marking out the line it should be understood on which side of the stakes the ditch is to be dug.

Running a continuous level line is the next step in the work. Set up the level 200 or 300 feet from stake 0, up the line, but not necessarily on it. Take a rod reading with the rod upon the grade peg at 0. Assume the elevation of 0 stake to be 100 (this is for convenience and uniformity), add the rod reading to the assumed elevation for the height of the instrument, as directed in the instructions for general leveling. Take a rod reading at a point in the outlet ditch where the drain when laid can discharge freely, for the elevation of the grade line at stake 0. Take rod readings upon each peg in order, recording them in the notes until a stake up the line about the same distance from the instrument as stake 0 is reached. It is always desirable to have these distances as nearly equal as practicable. This will form the first turning point. Move the instrument up the line a convenient distance from the turning point and take a rod reading upon the turning point to determine the height of the instrument in its new position. This connects the two lines and enables one to compute and write the elevations of each stake without a break, and gives what is known as a continuous level line. Continue the readings upon each peg as before, to the next turning point, and so on. If the elevations of the grade pegs were joined by a line it would represent the surface of the ground along the course of the proposed drain. The advantages of having the grade pegs set flush with the surface are that the levels taken upon them thus represent the true surface, and depths of the drain measured from the tops of the pegs will be the actual depth of digging required. They will also remain undisturbed during the time the construction of the drains is going on, even though the guide stakes should be repeatedly knocked aside and replaced, as often happens.

Leveling on a branch should begin at its junction with the main, which is o for the branch, and the elevation of that stake, before determined, should be transferred to the notes as the elevation of that point. Then level the branch in the same manner as the main. If this is done with each branch, submain and lateral, the levels of the entire field will be connected, and the relative elevation of each stake in the entire field will be known.

The **keeping of the level notes** should be done with care. The accompanying forms, on pages 67 and 69, show how notes should be kept for a main and how a branch line should be started. Separate notes of each branch should be kept under its appropriate name. The columns with figures should be on the left-hand page of the book.

LEVEL NOTES OF MAIN DRAIN

Sta.	B. S.	H. I.	F. S.	Elev.	G. L.	Depth, Feet.	Depth, Ft., In.	Remarks.
0	6.45	106.45	....	100.00	97.25	2.75	2–9	Grade .40 to 100 or $4\frac{3}{4}$ in. to 100 ft. to stake 300.
a	....	....	9.20	97.25	....	....	....	Bottom of outlet ditch.
50	....	....	6.32	100.13	97.45	2.68	2–$8\frac{1}{8}$	
100	....	....	5.92	100.53	97.65	2.88	2–$10\frac{5}{8}$	
150	....	....	5.61	100.84	97.85	2.99	2–$11\frac{7}{8}$	
200	....	....	5.12	101.33	98.05	3.28	3–$3\frac{3}{8}$	Branch A from N.E.
250	7.10	108.94	4.61	101.84	98.25	3.59	3–$7\frac{1}{8}$	
300	....	....	6.72	102.22	98.45	3.77	3–$9\frac{1}{4}$	Grade .20 to 100 or $2\frac{1}{2}$ in. to 100 ft.
350	....	....	6.11	102.83	98.55	4.28	4–$3\frac{3}{8}$	
400	....	....	6.72	102.22	98.65	3.57	3–$6\frac{7}{8}$	
450	....	....	7.21	101.73	98.75	2.98	2–$11\frac{3}{4}$	
500	6.49	108.32	7.11	101.83	98.85	2.98	2–$11\frac{3}{4}$	
550	....	....	6.01	102.31	98.95	2.36	2–$4\frac{3}{8}$	Small pond, water 6 in deep.
575	....	....	6.03	102.29	99.00	3.29	3–$3\frac{1}{2}$	At field fence.

Remarks should be on the right-hand page, and should contain such explanatory notes as may be of service in conveying a full understanding of the work. The first five columns are filled in the field and constitute the field level notes. The elevation column may be filled after the levels in the field are all taken, but it is better to perform the subtractions required to obtain the elevations as the work proceeds. Especially should care be exercised at the turning points to have the new elevation and new height of instrument correct before proceeding.

This method of taking levels and keeping the notes may be applied to every kind of work where it is necessary to use a level. It is correct, simple, and easily learned, and the farmer or student using a level should become familiar with each step.

COMPUTING GRADE AND DEPTH

It will be noticed in the examples of *Level Notes* given that there are three columns of figures more than are found in the notes given in Chapter V. The column headed *Grade Line* is so called because it contains the elevation above datum of points on the line upon which it is proposed to lay the drain. These points are below and opposite every grade peg whose elevation has been found and recorded in the column of *Elevations*. When connected by a line they form the Grade Line, or line which determines the position of the drain with respect to its depth and slope.

The *Depth* columns contain the computed distances from the tops of the grade pegs to the bottom of

BRANCH A FROM STAKE 200

Sta.	B. S.	H. I.	F. S.	Elev.	G. L.	Depth, Feet.	Depth, Ft., In.	Remarks.
200	....	....	....	....	98.05	....	....	Grade .12 to 100 or $1\frac{1}{2}$ in. to 100 ft.
0	3.62	104.95	....	101.33	98.25	3.08	3–1	
50	....	....	3.50	101.45	98.31	3.14	$3–1\frac{5}{8}$	
100	....	....	3.60	101.35	98.37	2.98	$2–11\frac{3}{4}$	
150	....	....	3.75	101.20	98.43	2.77	$2–9\frac{1}{4}$	
200	2.93	104.16	3.72	101.23	98.49	2.74	$2–8\frac{7}{8}$	
250	....	....	2.04	102.12	98.55	3.57	$3–6\frac{7}{8}$	
300	....	....	1.90	102.26	98.61	3.65	$3–7\frac{3}{4}$	Dry ridge.
350	....	....	1.00	103.16	98.67	4.49	$4–5\frac{7}{8}$	
400	....	....	2.90	101.26	98.73	2.53	$2–6\frac{3}{8}$	Wet soil.
450	....	....	1.80	102.36	98.79	3.57	$3–6\frac{7}{8}$	Ends N.E. corner meadow.

the proposed drain, and are the only figures required by the workmen in preparing the ditch. The page for remarks is a useful part of the notes, and may be used in noting grades, soil and crops, and may also contain a sketch of the lines, and later a schedule of the tile used.

The method of obtaining the numbers in the added columns is as follows: The column of elevations should first be gone over carefully to see that there are no errors. The starting point of the grade line was ascertained when the lowest point at which the drain could be discharged was found, represented by "a" in the notes, the elevation of which is 97.25. This subtracted from 100, the elevation of 0 stake, gives 2.75, the depth of the drain at the outlet. It will be noticed that the grade used in this case, from stake 0 to stake 300, is .40 feet to 100 feet or .20 ft. to 50 ft. (The method of determining and adjusting grades will be discussed later on in this chapter.) Beginning with the initial grade elevation 97.25, add the increment .20 for each station of 50 ft. or a proportional part of it for less distances. At stake 300 the grade is changed to .20 ft. to 100 ft. or .10 ft. to 50 ft. .10 is the increment now added to each preceding grade elevation until another change in grade is made. The depth figures are obtained by subtracting each grade elevation from its corresponding grade stake elevation, that is, the numbers in *G. L.* column from those of the same station in *Elev.* column. In the forms here given, rod readings are in feet and tenths, and computations are made by continuing the use of the decimal scale. In the last column the decimal of a foot in the preceding column is changed to inches and the nearest $\frac{1}{8}$ inch for the convenience of the workman when he comes to grade the ditch. Should the rod used be graduated in feet and inches, instead of feet and tenths of a foot, all the records and computations are in that scale, and of course only the second depth column would appear.

Each branch is graded in the same manner. If possible a branch drain should join its main a little above the grade line of the latter, the amount depending upon the size of the main tile. That is, a branch drain should discharge into the main above the bottom of the latter as much as practicable, one-half the diameter of the main being about the proper distance. This constitutes what is known as a "drop," the amount being added to the grade elevation of the main at the junction point. For example, in the notes of Branch *A*, on page 69, the elevation of the main at station 200, the junction point, is 101.33, hence this elevation is recorded in the Branch notes as the elevation of 0 stake, since the points are identical. The grade elevation of Main 200 is 98.05 and the depth 3.28. A drop of .2 is decided upon, so .2 is added to the grade elevation of stake 200, which gives 98.25 for the grade elevation at 0, and a depth of 3.08 ft. for the discharging point of the branch.

The depths may be marked upon each stake, thus making a complete record of the work in the field, in which case each guide stake will carry two numbers, the upper one indicating the number of feet from the outlet, or, if a branch, from the point of junction with the main; the lower one the depth in feet and inches from the top of the grade stake to the grade line of the drain at that point. The depths, however, may be placed upon paper instead, under the names of each drain, and used as needed by the workman, and it is a wise precautionary measure for him to be provided with such a paper even when the depths are marked on the stakes, in case a stake becomes displaced or the figures erased.

After the levels have been taken, the grades may be determined and depths figured at once before leaving the field, or that important part of the work may be deferred until a more convenient time. The levels of each line may be represented in the form of a profile as is done in other engineering work, but this is not necessary, and is of use only in representing the grade lines so that one may see the general slope and depth, without going over the figures. The levelman may complete the work in the field and leave it ready for the workman without any delay if he so desires.

DETERMINING AND ADJUSTING GRADES

There are three elements which will control in the adjustment of grades: the minimum gradient which may be used, the general depth which it is desired to have, and points where gradients should change if more than one gradient on a line is used. The least grade allowable is measured largely by the accuracy with which the construction work will be done, since tile drains will operate successfully and be permanent, in clay or other firm soils, if accurately laid on a grade, however slight. Grades of .04 ft. or approximately ½ inch in 100 ft., are as light as can be made in practice. If the soil is soft, full of fine silt or sand which will enter the drains, more grade should be given the line, especially for the drains of smaller size, as a greater velocity of flow will be required to free them from silt which enters. A grade of

½ in. to 2½ in. to 100 ft. may be regarded as the minimum.

Where the ground does not have uniform slopes it is necessary to change grades at various points. Some practice is required before the amateur can do this with dispatch and precision. The subject of proper depth of drains, which will be considered later, enters into this matter. The surface elevations will indicate to the eye the profile of the ground. These figures may show a gradual rise for a distance and then drop back into a pond, or continue level for some rods. This condition will require that a deeper cut be made through the higher ground than at any other place, and it may be wise to change the grade just below the rise to avoid unnecessary cutting. As a trial, make the drain in the low ground the desired depth, obtaining the grade elevation at that point in the way before described; use a minimum grade of .10 ft., .12 ft. or .20 ft. per 100 ft., as may be best, run the grade toward the outlet by successive subtractions instead of additions, as before described, until the deep cut is passed and the depth desired has been reached. This will form the change point. Various trial change points may be used and moved about until a series of grades is obtained which will be satisfactory. In determining these points it is necessary to compute only a few indeterminates to ascertain the range of depths and grades that will result from the assumed points, after which the complete computations should be carefully made. An example of only one change of grade in a line is found in the *Notes of Main Drain* on page 67. A grade of .40 is used from stake 0 to 300, then a grade of .20 to the end, giving a maximum depth of 4.28 at stake 350, and a depth of 2.36 in the pond at 550. This may be regarded as a "3-foot" ditch. It is seen that a variety of adjustments could be made on this drain, any one of which might have given us an efficient drain. The depth of the pond at 550 might have been 6 inches more, which, if the same grade were used, would make the depth at 300, 4.78, and the change point be carried farther down and the grade from that point increased. Again, the depth in the pond might remain the same and the minimum grade be .10 to 100 feet. Then the depth at station 350 would be only 4.08.

It is frequently asserted that the grade of a drain should increase as the outlet is approached. This is desirable, but is impracticable in farm drainage, except where natural slopes make it permissible. We must make the best adjustment possible consistent with efficiency and economy. Lack of grade may sometimes be offset by additional size of drain in order that the relative efficiency of the different parts of the drain be maintained. It is desirable that a little additional grade be given at the bends, unless they are long. A careful arrangement of the grades of drains is of great value, and is one of the advantages to be derived from a survey, the best tile drain for the least digging being obtained. Definite points for securing accurate construction are also fixed, and it is known from the beginning how the drainage of the field can be best effected.

CHAPTER VII

DETAILS OF LOCATION

No questions pertaining to underdrainage have been more discussed than the depth of and distance between drains. Examples of successful and satisfactory drainage are cited in support of the claims of those who advocate their particular views and practice which vary widely from each other in these important details.

DIVERSITY OF PRACTICE

Col. George E. Waring fixed upon a depth of 4 feet for the drainage of Central Park, New York, and placed the drains 40 feet apart. Dr. W. I. Chamberlain drained his farm in Summit Co., Ohio, with lines of tile 2½ feet deep and 33 feet apart. John Johnston, the pioneer in tile drainage in this country, found 33 to 66 feet between drains laid 2 and 2½ feet deep about right for his farm near Geneva, N. Y. Many farms in Indiana and Illinois are drained to the satisfaction of their owners by tiles laid from 2½ to 4 feet deep and the lines 60 to 300 feet apart. Some use but a few drains of ample size to supplement the natural drainage of surface and soil.

This difference in practice leads to the conclusion, which is sustained by careful observation, that the depth at which drains should be placed, and the distance between them in ordinary practice, depends on the character and physical structure of the soil; the climate, in which the amount and manner of rainfall are important factors to consider; the kind of crops and system of agriculture to which the section is adapted; and the market value of the production.

DISTANCE BETWEEN DRAINS

Drainage by ridges and furrows suggests the principles which apply to the spacing of underdrains. The more nearly level the surface and retentive the soil, the more frequent it is necessary to make the parallel ridges and furrow drains. When underdrains are not used, these are laid off on land of heavy character from four to eight rods apart. The level rice fields are traversed by parallel furrows seventy-five to one hundred feet apart for drawing off flood water. Surface drains of this kind dry the ridges first, since they are the highest land. As soon as the water of the ditches becomes lower than the surface adjacent to them, the order is reversed and the land near the ditches dries more rapidly than the centers, because of the more rapid reduction of the water-table at the border of the ditches.

Underdrains begin to dry the land first near the drains as explained in Chapter II. All water must pass through the soil to the drains before it can pass away, the only force impelling it being gravity. This movement is retarded by the resistance of the soil, in proportion to the closeness of the latter, more if it is fine clay and less if it is largely gravel and sand. Assuming that the soil is saturated with water, gravity acts with the same force over the entire surface. The distance to the drains, the only points of relief, is least from the surface directly above them, so that the excess of water disappears from the line of soil above the drains first, the dry area extending gradually each side of the drain line as the water-table at the drain descends. (Fig. 23.) The successive lowering of the water-table is shown by the lines

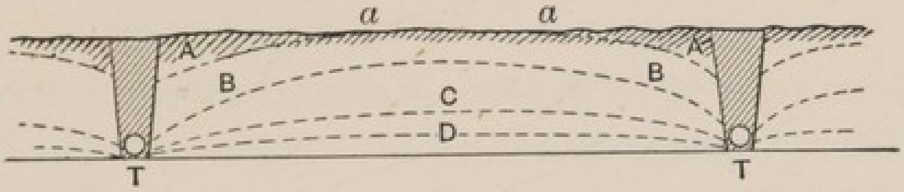

FIG. 23.—Effect of Drains on Position of Water-table.

A, *B*, and *C* in the illustration. In case the soil is retentive, the drains may not relieve the land of surplus water farther from them than to the points *a a*, in which case the drains should be placed nearer together. If the soil is of open character the water-table may descend very quickly to the line *C* and later to *D*. It is not infrequently stated that the distance to which a drain affects the soil is in direct proportion to its depth; that is, a drain four feet deep will affect the land to twice the distance of one two feet deep. This ratio does not hold good except in soils which are so open as to respond readily to drains in the deeper horizons, and then the application of the rule is quite limited.

DEPTH OF DRAINS

The first office of an underdrain, as has been shown, is to remove surplus water from the surface by downward percolation through the soil into the drains. The compact and retentive structure of some soils prevents water from reaching deep drains quickly enough to be of service to the upper soil. When resistance offered by the soil particles equals the force of gravity acting upon the free water in the ground, movement toward the drains ceases, and shallow drains are for this reason sometimes more effective than deep ones because of the shorter distance through which the water must move to reach them. Instances are known where drains placed four feet deep have proved useless, but when replaced by some two feet deep most gratifying results have been obtained. There are soils, however, that will not respond to underdrains laid at any depth until they have been broken and subsoiled. (See page 34.) Such soils, by reason of their peculiar characteristics, must be manipulated with more than usual care and skill. A combination of the ridge system with underdrains will often prove more efficient in draining tenacious clays than the level system with underdrains alone. The ridges need be but slight, six inches in fifty feet, to assist greatly in the drainage of such land.

The drainage properties of soils are often misjudged by those familiar with but few varieties of soil, or by those who make but a superficial examination. The variations found in the great range of soils having sufficient fertility for the use of agriculture, provided their moisture conditions can be properly adjusted, are too intricate to be described except by reference to specific examples.

In most cases the relation of soil to subsoil suggests the proper depth of the drains. Where a close and firm clay underlies an ordinarily permeable soil, lateral or collecting drains should be laid as nearly as practicable at the line between the clay and the more porous soil, provided this is not less than 2 feet from the surface. If the subsoil is a joint clay (Fig. 3), one of the most easily drained of all clays, the depth may be 4 feet, or even more, though the soil proper may be only 12 to 18 inches deep. Granular clays, either black, sometimes known as gumbo, or other varieties, yield their surplus water to drains placed 2½ to 3½ feet more readily than to those at greater depths, as before noted.

The structure of the grains of such soils changes with constant cultivation and consequent exposure to the air, so that the cultivated part will become finely comminuted and delightfully friable provided it is not cultivated when wet. This, in general, is the effect of drains upon clay soils, but to secure the greatest benefit the depth of the drains should be so adjusted that the lowering of the water-table will be gradual and continuous whenever the soil has become saturated.

The root habits of plants are worthy of consideration in connection with depth of drains. Different plants have habitats of root and stalk growth peculiar to themselves. Each plant requires a certain range of root space which, if greatly abridged, prevents its complete development. The root habit of grasses is more shallow than of grains. Vegetables of some kinds do not root deeply, while others grow more luxuriantly in soils which permit a wide range of root growth.

It is apparent that **the character of the crops to be grown** on a drained soil should govern to some extent the depth of drains. The depth to which the roots of farm crops extend into the soil was investigated in 1880 by Prof. W. O. Atwater, who, in discussing the subject at that time, made the following instructive statement: "I have often been interested in noting the ideas most people have as to how far and deep the roots of plants extend. The majority guess roots of grass to penetrate between five and ten inches, and are surprised to find that they reach several feet. I have some roots of timothy, clover, and other plants, dug from a very heavy clay soil—a good quality of brick clay, so compact and hard that a sharp knife in cutting it leaves a surface as smooth and shiny as it would cut on the end of a pine board. I have traced the roots of the timothy to the depth of two feet and four inches, and the clover three feet and two inches. A number of years ago a German scientist named Schubart made some interesting observations upon the roots of plants as they grow in the field. An excavation five or six feet deep or more was dug in the soil so as to leave a vertical wall. Against this wall a jet of water was played, washing away the earth and laying bare the roots of the plants growing therein. The roots thus exposed in a field of rye, in one of beans, and in a bed of garden peas, presented the appearance of a mat or felt of white fibers, extending to a depth of about four feet. Roots of wheat sown Sept. 26th and uncovered the 26th of April had penetrated three and a half feet, and six weeks later about four feet below the surface."

Plants will not reach their full development unless sufficient aerated soil space is available to meet the demand of their natural root habits. But while this is true, it is also observed that they go beyond their usual range if need be in order to adapt themselves to varying conditions of fertility and moisture. If sufficient moisture is not within their immediate range, the plants send "water roots" to lower depths for a supply, if the soil is penetrable. Thus a friable condition of soil enables plants better to withstand drouth. If the elements of fertility are exhausted in the soil within the natural reach of the plant, it will, if the nature of the soil permits, go some distance after them. Quoting again from Professor Atwater, "in one case, in a light subsoil, wheat roots were found as deep as seven feet. The roots of the wheat in April constituted forty per cent of the whole plant. Hon. John Stanton Gould, I believe it is, says that he has seen the roots of Indian corn extending seven feet downward, and Professor Johnson states that the roots of maize, which, in a rich and tenacious earth extend but two or three feet, have been traced to a length of ten, and even fifteen, feet, in a light and sandy soil. Roots of clover, when growing in a rich and mellow soil, extend both laterally and vertically. Professor Stockbridge washed out a root of common clover, one year old, growing in the alluvial soil near the Connecticut River, and found that it descended perpendicularly to the depth of eight feet. Lucern roots are said to reach a depth of twenty, and even thirty, feet."

Authentic examples of this character might be multiplied, but these will serve to show that the root habits of the crops to be grown on the drained land should be taken into account, and also to demonstrate the benefits of soil aeration brought about by drainage, in making possible a wider range of roots.

If the soil is fertile to a considerable depth, lateral drains may be laid as deep as four feet, since plants will easily avail themselves of fertility and moisture within that limit, and make a more vigorous growth because of the extended root range. On the score of practical economy, a greater general depth for laterals is not to be recommended, special cases and drains in irrigated lands excepted, and while a depth of four feet is frequently more effective than three, it is found that for field crops generally, taking cost into account, lateral drains placed at a depth of three feet more nearly meet all requirements than at any other that may be named. With the water-table at this depth, plants will in case of drouth extend their roots below it for needed moisture, and it will also furnish capillary water to the upper soil more readily than if deeper.

The depth of the main or receiving tile drains need not be governed by the same considerations as the lateral system, but should be regulated by the depth of the lateral drainage that it is desired to secure, being always a little deeper than the laterals, as has been before explained. (See page 71.)

SIZE OF DRAINS

Drains should be designed to relieve the land of surplus water during times of maximum rainfall, or seasons of continued precipitation which overcharges the soil beyond its capacity to provide for the excess by natural drainage. These seasons do not usually constitute more than one-tenth part of each year, yet if the drains fail to give adequate relief at such times, they do not serve the purpose for which they were made. They should, therefore, be constructed to meet maximum wet conditions which prevail in the locality, unusual, unfrequent, and abnormal storms excepted. Where the annual rainfall ranges from twenty-two to thirty-eight inches, the normal monthly rainfall is about three inches, the maximum precipitation during twenty-four hours not infrequently being from one to three inches. In providing for drainage adequate for agricultural lands under these varying conditions, we consider that the volume of water which must be removed by drains is regulated or limited by the reservoir capacity of the surface and soil, the evaporation of water from the surface and from the soil through growing plants, and the length of time which the soil may remain saturated without injuring it or the plants growing upon it. These three factors may vary widely in their effect upon the final run-off of water through drains, so that we must deduce from experience and observation a law that will meet the conditions within reasonable limits of precision. Figures or formulas to determine the volume of water which drains under certain conditions will discharge are of no value in solving questions relating to the size of main drains, unless the amount of water to be removed is fairly well determined. The mains and submains are the conduits for carrying away the excess of water from the soil, and their size should be proportioned to the rainfall, and the area and general slope of the land from which they receive drainage, without reference to the arrangement, number, or size of the laterals used in the system. Under standard conditions of climate, surface, and soil, main drains with a capacity to remove one-quarter inch in depth of water from the area from which drainage is received, each twenty-four hours, will meet the requirements of good

TABLE I

Acres Drained by Tile Mains

Computed with Discharge Due Only to Slope and with Tile Flowing Full. Drainage Coefficient ¼ Inch

Grade Per 100 Feet.		Diameter of Tile in Inches										
Ft.	Equiv. In.	6	7	8	9	10	12	16	18	24	30	36
.04	½	9	15	21	31	41	66	138	197	434	790	1279
.05	⅝	11	16	24	34	45	73	156	221	482	884	1427
.08	1	12	20	30	43	51	93	197	278	614	1122	1810
.10	1 3/16	15	23	33	48	64	104	219	318	685	1255	2019
.12	1½	16	25	36	53	70	114	241	338	751	1368	2208
.16	2	19	28	42	61	81	133	278	394	869	1583	2558
.20	2⅜	21	32	48	69	91	147	311	457	970	1775	2858
.25	3	23	35	53	78	102	165	347	492	1082	1987	3200
.30	3⅝	26	39	58	84	119	180	380	538	1187	2175	3400
.40	4¾	30	45	67	97	128	208	439	623	1370	2505	4038
.50	6	33	51	74	108	144	233	490	667	1530	2800	4520
.75	9	40	63	92	133	175	285	601	852	1872	3416	5530

TABLE I A

Acres Drained by Tile Mains

Computed with Discharge Due to Slope Plus Soilwater Head of 1.5 Feet. Tile Flowing Full. Drainage Coefficient ¼ inch

Grade per 100 Ft.		Diameter of Tile in Inches										
Ft.	Equiv. In.	6	7	8	9	10	12	16	18	24	30	36
.04	½	20	31	46	66	88	144	252	425	945	1730	2780
.05	⅝	21	32	48	69	91	147	311	442	970	1775	2858
.08	1	22	35	52	73	97	158	333	472	1042	1900	3065
.10	1 3/16	23	37	53	78	104	165	347	492	1113	1985	3195
.12	1½	24	38	55	80	105	171	360	512	1130	2080	3320
.16	2	26	40	59	85	113	183	386	548	1208	2202	3530
.20	2⅜	27	43	62	91	120	195	411	583	1280	2342	3780
.25	3	29	45	67	97	128	208	439	623	1370	2503	4038
.30	3⅝	32	47	71	103	136	221	467	660	1450	2658	4280
.40	4¾	34	52	79	114	150	244	516	730	1610	2940	4748
.50	6	38	56	86	123	163	265	556	794	1746	3197	5150
.75	9	44	69	101	145	192	312	658	934	2280	3759	6060

farm drainage where the annual rainfall is about thirty-five inches. This is called the "drainage coefficient" of the land, in which it is assumed that the lateral system is sufficient to collect the drainage and deliver it to the mains.

Tiles do not have the same effect in soils which vary in their physical make up. It has been observed that drains which are located in open soils, that is, those which permit the ready percolation of water through them, operate more quickly and discharge a greater volume of water in a unit of time than drains of the same size and laid on the same grade which are located in close soils, that is, those through which water percolates slowly. The former permits the soil water a ready access to the joints of the drains and by the pressure thus exerted, which obtains when the soil is saturated, a greater head is added to the drain, which accelerates the velocity of flow over and above that which is derived from grade alone. In the latter kind of soil, the closeness of the particles requires all of the soil-water head to overcome the resistance of the soil particles in its lateral and downward course, and reaching the tile without any appreciable head it passes through the drain with a velocity due to the inclination of the tile. Such land requires frequent lateral drains because the close soil absorbs the free water head in passing any considerable distance to reach a drain.

Tables I and IA have been prepared to meet the two conditions of soil above described. They have been computed by well tested and practical formulas. Table I may be used in designing the size of main drains for lands which have a fairly level surface with soils of a close texture such as clay, buckshot, gumbo, etc., which require frequent laterals to accomplish needed drainage. Table IA may be used in open loams, joint clays, soils, and sub-soils with sandy or gravelly structure, and in mucks and peats with their various phases.*

The rainfall is much greater in the Southern States than that for which the table has been prepared, and for which experience has proved it is well adapted. While it is not the amount of annual rainfall which taxes the capacity of the drains, but the amount which falls successively during twenty-four, forty-eight, or sixty hours, it is observed that heavy precipitation during short periods occurs in localities where the annual rainfall is large, though this is not always true. However, the amount of annual precipitation may be used as an approximate guide in determining the sizes of tiles that should be used for mains.

The number of acres given in the table for which the sizes of tile opposite will afford an outlet should be varied to meet the rainfall conditions of different sections by the use of the following factors:

Where the annual rainfall is 45 in. multiply acres in table by .7
" " " " " 55 " " " " " .6
" " " " " 60 " " " " " .5
" " " " " 30 " " " " " 1.2
" " " " " 25 " " " " " 1.4

The office of lateral drains we have seen is to collect the excess of water from the soil and deliver it to the mains. As before shown, it is necessary to place these at different distances apart and according to various plans, depending upon both surface and soil, to get the

* For a discussion of this subject in greater detail see "Engineering for Land Drainage."

desired result. The size of the tiles in the lateral system is governed in part by the grades upon which they are laid. To secure the best drainage, laterals should rarely be filled. Ample size will facilitate aeration of soil and render constant the conditions which favor activity of soil bacteria, those important agents in the development of soil fertility.

Where soil is retentive, requiring drains as frequent as forty to sixty feet, three-inch tile may be used. For greater distances, and more open soils, no smaller than four-inch are admissible, while five-inch and six-inch may be necessary under conditions where the laterals are practically submains to supplement natural drainage. In describing the size of tile, their inside diameter, measured in inches, is referred to, a six-inch tile being one whose inside diameter is six inches.

A schedule of the tile of the various sizes required for a system of drains should be made after the lines have been located and measured on the field and their gradients determined, which should show the number of tile of each size that the system calls for. The size and number for each line should be marked upon the sketch made in the field, and upon the page opposite the level notes of the respective drains. The order list should show the total number of feet of tile and the number of each size required. As a check to guard against mistakes, note that this total number, if correct, will agree with the sum of the lengths of the line as entered upon the level book. The list should also contain the number and kind of junction tiles needed. The order, "three 4 x 8 Y junctions," means three eight-inch tile with four-inch Y branches. Tile furnished by some factories are a little longer than one foot, so that ninety-six pieces will make one hundred feet of drain. About three per cent more than enough for the length of the lines should be ordered to allow for breakage in shipping and distributing upon the field. Material for any accessories, as outlet protectors, silt basins, etc., should also be estimated and listed, the same being noted in the field book.

It has been assumed, in the discussion of depth, frequency and size of drains in this chapter, that the water to be removed is that which falls directly upon the surface, or collects upon it in the natural course of flow from undulating fields. The necessity for drainage often arises from other causes, requiring more attention to be given to depth and location than to the distance between a series of drains, and governed by other conditions than those we have been considering. Bottom water, as it is appropriately called, and which was spoken of in Chapter II, often has its source quite remote from the land upon which it appears, and on a higher level. It fills the soil at some point, first appearing in the subsoil, and rising toward the surface in its effort to reach the level of its source. In this manner springs or seep water from the hillsides, irrigating canals and irrigated fields on a higher level, saturate the lands occupying lower levels, much to their injury. To protect them, drains must be located in a peculiar manner, and at such depths as shall intercept this underflow from higher levels before it permeates the soil of the lower land, or attempted drainage will prove futile. Problems of this nature are discussed in later chapters in their proper places. (See Chapters XVI and XVII.)

CHAPTER VIII

CONSTRUCTION OF UNDERDRAINS

While it is desirable that the construction of underdrains should be carried on at a time when it will least interfere with regular farm operations, this is not always practicable, since the condition of the ground is an even more important consideration, affecting as it does the amount of labor required, and thus the expense of the undertaking. The farmer will find it to his advantage to choose a season of the year for his drainage operations when digging can be most easily done, and to haul and distribute his tile when the roads and land are most favorable for such work. Swamp land is often more easily manipulated during some parts of the season than others, and land which is periodically wet may at times be too dry to be excavated at a reasonable cost.

The construction of underdrains consists of four distinct operations, not always undertaken by the same contractor. These are excavating the ditch, grading the bottom, laying the tile or other material used for the drain, and backfilling the ditch.

EXCAVATING THE DITCH

There are so many kinds of land which may be profitably drained that no one method of digging ditches will apply to all. Some soils contain roots, stones and tough clay; others are soft, mucky, and unstable; while others are free from all those properties so difficult for ditchers to contend with, being friable loams and clays which can be dug with ease and dispatch.

While various plows and machines are now put forward to take the place of hand labor, and in some instances are valuable aids, they are limited in usefulness by reason of the exceedingly variable conditions of land which requires drainage. While it is hoped and confidently expected that machines will materially assist in performing a large part of the trenching for drains, the skilful ditcher, with his simple tools, will always be in demand, and the excellent manner in which he performs the work will never cease to be the criterion in the making of farm drains.

The long-winged ditching plow is successfully used by some to start the ditch, and to loosen and partially remove the top fifteen inches of earth. This will lessen the cost, especially where unskilled labor is employed. It is not possible, however, to get a neat line at the bottom of the ditch where the plow is used, because the furrow will lack the straightness which is secured by the hand-made ditch when dug by a line.

The tools required in hand work are two steel ditching spades, with blades 18 and 20 inches long respectively, the blades being slightly concave, 6½ inches wide at the point and 5½ inches wide at the shoulder; two round-pointed shovels with long handles; a drain scoop for preparing the bottom; two lines, 100 feet long, one a ¼-inch rope for lining the trench, and the other a small cord for a grading line; a gage with arm; a pocket rule;

a small hatchet; and a tile hammer. If the land is gravelly, stony, or has hard clay, a mattock and steel handbar should be added to the outfit.

Assuming that the land to be drained is free from stones and sufficiently soft to permit the use of the spade, and that the lines for the drains have been staked out, proceed as follows: Start at stake 0, stretch the guide line on the ground at one side of the stakes, making deviations from a straight line where needed by swinging the rope until it takes an easy curve. Mark the line on the ground by cutting the turf about six inches deep with the spade. It is important that this be done neatly, as it is the dress line of the ditch. Begin by removing the earth with the shorter spade, making the ditch twelve inches wide on top when the ditch is to be three feet deep, and fourteen inches wide when it is to be four feet deep. The former depth can be reached at two spadings. Where the ditch will be deeper, it is best to remove sufficient depth of earth from the top to permit finishing the ditch at two full drafts of the spade. The spade should be thrust into the ground a little quartering, instead of square across the ditch, so that the sides will be partially cut instead of being wholly broken. The curve in the blade of the spade facilitates this, the skill of the workman being shown by the small amount of loose earth he leaves after each spading. The line side of the ditch should be kept dressed by a light side cut of the spade as the work proceeds, and the top earth be dropped on one side of the ditch, and the second spading on the other, so that the soil can be readily replaced when the ditch is filled. The first spading is followed by the shovel, which removes the loose earth and leaves the ditch clear. This is the base from which the workman operates to complete the ditch ready for the tiles.

GRADING THE BOTTOM

Place the grading line in position as shown in Fig. 24, setting it at a convenient height above the surface, and at a constant distance above the bottom of the proposed grade line, being certain that at each stake the distance measured above the hub to the line, added to the depth of ditch at that point, equals the distance at which the line is set above the bottom of the ditch, which in the illustration is five feet, the arm of the gage rod being set at the same distance. Various devices are used for

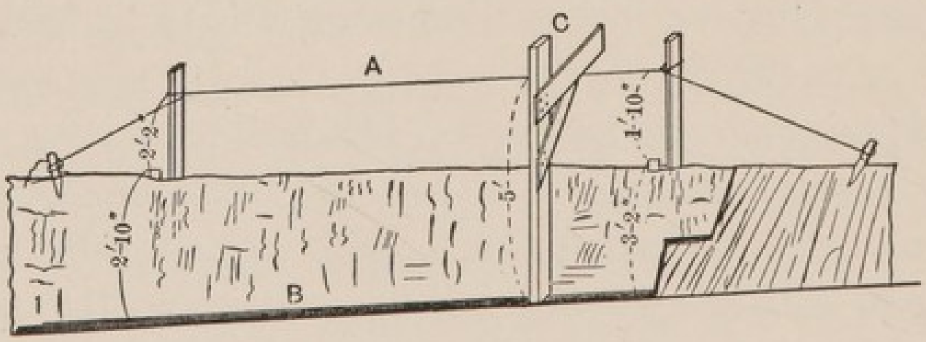

Fig. 24.—Grading by Line and Gage.

obtaining the grade indicated by the survey. In some cases the line is set high above the center of the ditch; in others crossbars are set for testing the grade by line of sight; but in all methods the principle is the same. While all are correct, and have their advocates, it has been found that the line and gage method is well adapted to farm use, and can be employed by workmen who do not succeed in using some of the others.

The workman now takes out the bottom draft, or "spading" as it is commonly called, taking care to leave as little loose earth in the bottom as possible, and not to cut deeper than the grade line of the ditch. When a stretch of about four feet has been dug, the workman, without moving from his position, removes the loose earth, or crumbs, with the drain scoop, and proceeds to cut the bottom to a smooth grade just wide enough to receive the tile it is proposed to lay. He tests the accuracy of the grade by means of the gage, the arm of which should touch the cord which has been previously set at the side of the ditch and drawn tight. This

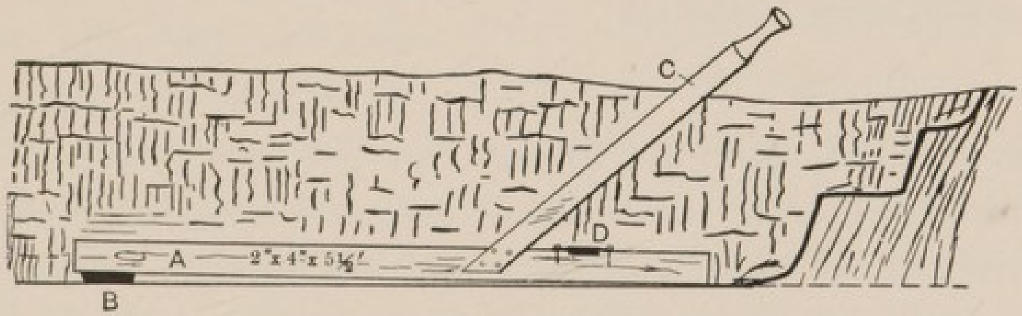

FIG. 25.—Grading by Drag Level.

stretch of the ditch should not be passed until it has been dressed down to the correct grade. If the earth is free from pebbles, the bottom can be easily made as true as the line parallel to it by which it is tested. Ditches for tile eight inches in diameter, and under, can be made in this manner. Larger ones, as well as board, brush, and stone drains, will require a wider ditch, which must be finished on the bottom with the shovel, the workman walking in the bottom of the finished trench. The method of testing the grade remains the same.

It may be that the line has not been marked by continuous levels, but sufficient measurements and levels have been taken to determine the rate of fall upon which the drain may be laid between certain points, as, for instance, two, three, or six inches per hundred feet, or the grade per rod, as the case may be. The bottom may then be graded by a drag level, shown in Fig. 25, which consists of a wooden bar (*A* in the Fig.) of the dimensions shown, upon which a small spirit level, *D*, is mounted, and to which a handle, *C*, five feet long, is attached. The fall per rod, or for one hundred feet, having been ascertained, compute the fall for five and one-half feet (one-third of a rod), and attach a block, *B*, equal in thickness to the fall in the length of the bar. Place the bar upon a plank or floor previously made level, and adjust the small level, *D*, so that the bubble will stand in the center. The bottom of the ditch is tested by the workman, who pulls the bar along as he completes the ditch, the bubble indicating the accuracy of the bottom. A little water in the soil and ditch is always desirable, as it lessens the labor of digging, and facilitates the grading of the bottom. Inexperienced ditchers make the trenches needlessly wide, and fail in that dexterous handling of the spade and draining scoop which distinguishes the professional workman from the common laborer.

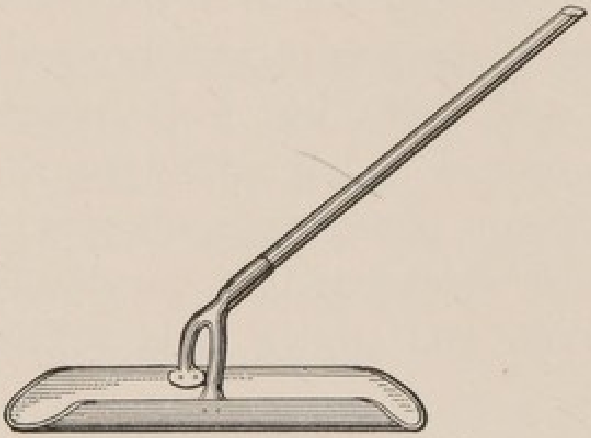

Fig. 26.—Drain Scoop.

The drain scoop, a most useful tool, shown in Fig. 26 (some forms of which are patented), is made with blades varying from three to seven inches wide. It may be purchased with a handle adjustable at the shank by means of a ratchet and bolt, or with a stationary handle. The latter is usually more satisfactory. Similar scoops of larger size or with greater strength in some of the parts, may be made by a blacksmith if needed, for scooping mud from a ditch, for which they are admirably suited.

LAYING THE TILE

If the bottom of the ditch has been perfectly prepared, the tiles can be easily and rapidly put in place. Sizes up to eight-inch can be more readily laid with a tile hook, the workman standing on the bank and putting the pieces in place from the outlet up grade, turning each tile until the ends fit closely on top. If the bottom has been poorly prepared, the workman should stand in the ditch and, taking the tile which have been strung along the bank within convenient reach, lay them in place, backing up the ditch as he proceeds. Any rough places in the bottom which prevent the tile from lying firmly, and joining properly, may be removed with a hand-trowel or with the drain scoop, a work which he cannot conveniently do when standing upon the surface using the hook. All large tile and box-drains should be laid in the same manner. Ordinarily the ends should be joined closely, but when the tiles are surrounded by stiff clay, it is better to join the several pieces quite loosely to facilitate the entrance of soil water, especially in lateral drains. No injury to the drain in such soil need be feared from the entrance of silt.

In case the curves in the line are too short to permit the use of straight tile without leaving wide gaps between the ends, they should be fitted by chipping with the tile hammer, as illustrated in *a*, Fig. 27. A hammer of this pattern, made of tool steel, the dimensions being shown in the cut *b*, is a most serviceable tool, and should be in the equipment of every tile-layer. With it tile may be cut in two, and junctions fitted in a work-

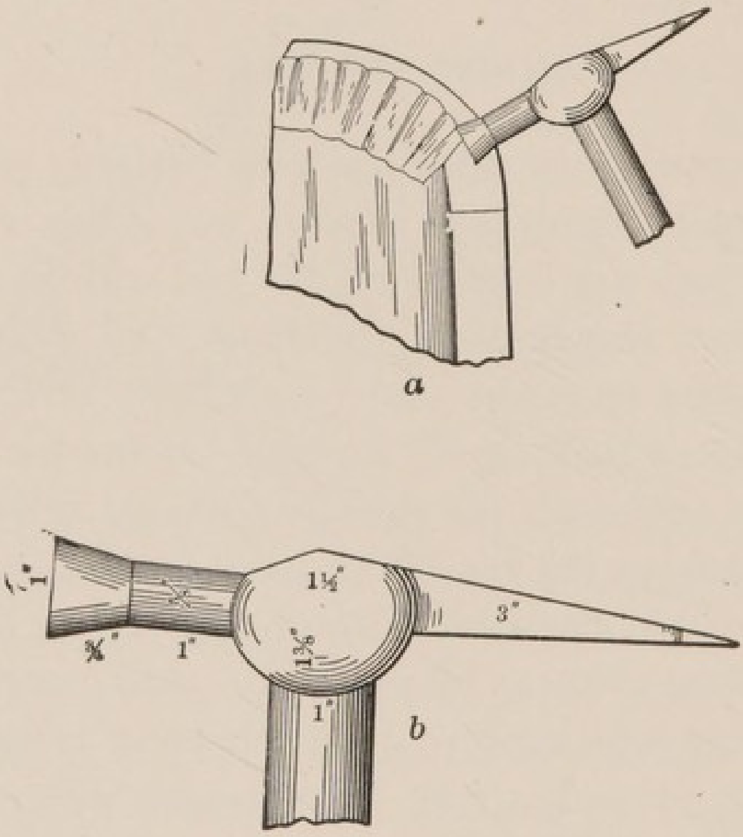

FIG. 27.—Tile Hammer.

manlike manner. Pieces of tile called bats should cover joints where tiles do not join closely.

Junctions of branch or lateral drains with their main should be made by the use of junction tile, which should be put in place when the main is laid. Not all manufacturers make junction tile, or junctions, as they are called. Some only make a hole in the side of a straight pipe, the drainer being obliged to make the junction by fitting the lateral to it, while others do not make even this helpful provision. Properly shaped "Y" and "T" junctions are made at many factories, and should be secured when possible. A badly made junction will greatly impair the efficiency of both lateral and main to which it is joined. The angle between the lateral and main should be about thirty degrees as shown at *a* in Fig. 28, which is known as a "Y" in distinction from a

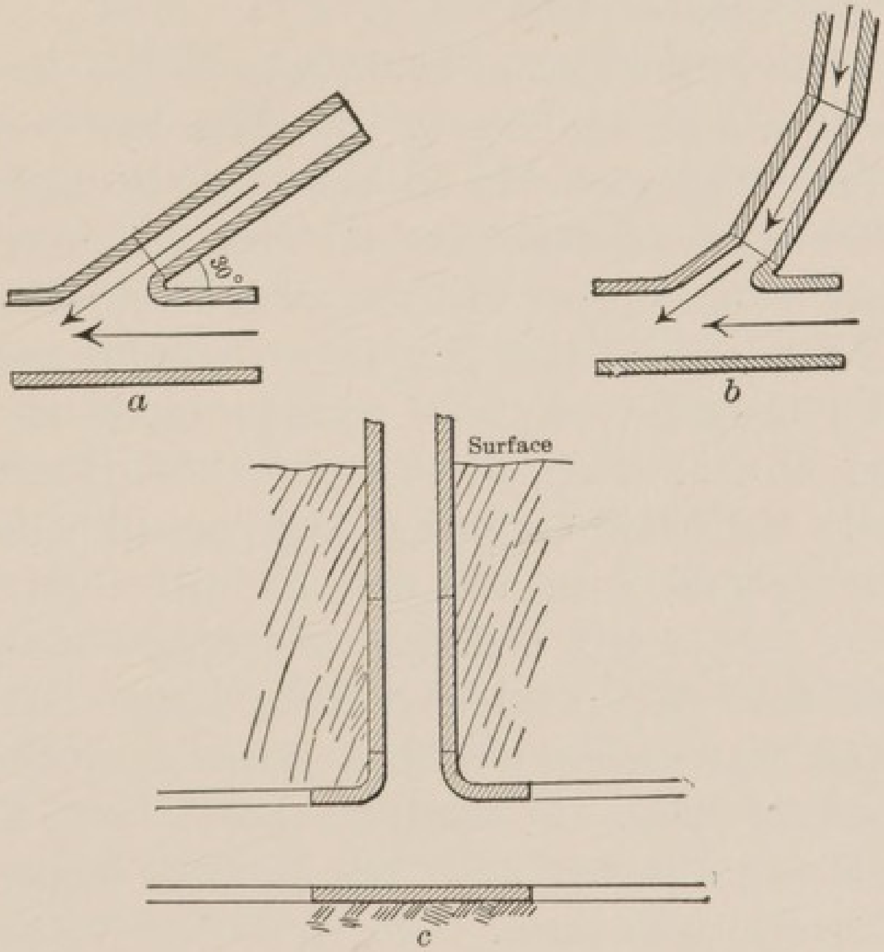

FIG. 28.—Horizontal and Vertical Junctions.

"T," in which the angle between the two is a right angle. In the former, the currents from the two pipes unite with the least possible resistance, so that the flow of neither is materially checked. It is frequently necessary to have the general direction of the laterals at right angles with the main, but the joinings can be made with

Y junctions in the manner shown at *b* in Fig. 28. "T" junctions are used on the larger mains in making stand pipes from the main to the surface, for inspection purposes, or for making surface inlets for admitting free water to the drain. This is shown at *c* in Fig. 28. All junctions, and the tiles which connect with them, should have the earth carefully tamped about them so that they cannot be displaced.

Inspection of the drains should take place as soon as the tiles are laid, and before any earth has been put over them. This should be critically done by the farmer himself, if he has not supervised the work as it proceeded. If he has reason to fear that the grade is imperfect, he may stretch the grading line in its original position, and with the gage rod placed upon the top of the tiles, test each one, allowing, of course, for the diameter of the tiles. He should see that they do not tilt when the spade is pressed upon one end, as that shows that there is a pebble or a high spot under the middle. If any bats have been used in covering large cracks, he should see that sufficient earth is placed upon them to hold them in place. In short, he should see to it that the drain is as perfect as it can be made before it is finally covered with earth.

Blinding is fixing the tile in place by chipping moist earth from the side of the ditch so that it will distribute itself about the tile. This earth should be carefully but lightly tamped about the tile so as to hold them firmly in place, after which sufficient earth should be sliced off the side of the ditch to cover them six inches deep.

This entire process of placing the tile in the trench properly, fixing them firmly in position, and, after inspection, covering them in the manner indicated, constitutes laying the tile.

FILLING THE DITCH

The drain having been properly blinded, the balance of the back-filling can be done in the most convenient manner. Earth can be moved more easily if moderately dry, and the filling may occasionally be deferred until the excavated earth becomes sufficiently dry to handle. But large mains located in low ground, and liable to flooding before the drainage system has been completed, should be filled with as little delay as possible. The plow is commonly used to fill ditches on cultivated land, but should not be used on meadow and pasture land, as it plays havoc with the sod. An "A"-shaped winged scraper, with the wide end behind, drawn by two teams of horses, one walking on each side of the ditch, is efficient, leaves the sod intact, and ridges the earth nicely upon the trench, an important matter in ditch-filling. The earth-moving wing of the scraper is held in position by a guide plank which extends into the trench, and prevents the wing from sliding away from the bank of earth to be moved.

DIFFICULTIES IN CONSTRUCTION

The difficulties encountered in draining some lands are frequently perplexing and costly to overcome. Among the most troublesome are soft and miry ditch bottoms, quicksand formations, and unstable earth which caves into the trench before the drain can be completed. Sometimes such contingencies can be met by opening but a few feet of the trench in advance of the tile-laying. At others just the opposite course should be pursued, that is, the ditches should be opened as far as practicable and in such a manner as to tap all the water-bearing strata possible, then wait for these drains to accomplish their work of partially drying the earth, after which proceed with the original work. This may occasion a delay of several weeks, but it is the most effectual way of contending against such conditions. No little skill on the part of the workmen is required in handling soft ground.

If the drain bottom is of a quicksand nature, through which water presses up from below so as to cause a bulging of the ground, place a line of boards on the bottom and lay the tile upon them, but do not cover the drain until the water pressure ceases and the earth assumes a firmer condition, then test the tile, and relay if necessary. In this way drains may be laid in treacherous ground, and when once correctly established rarely fail to remain where placed.

Where fine or sandy material is used for filling the trench, the immediate covering of the tile should be turf, clay, straw or hay, to prevent the fine material from entering the drains while the earth is becoming settled over them. It is also best to compact the earth as much as practicable during the process of filling.

LETTING CONTRACTS

The farmer will often find it more profitable to contract the digging of the ditches and laying of the tile to competent workmen instead of doing the work with his farm force. When the field has been made ready for the construction work, the contract for the trenching and tile-laying may be let to a professional ditcher for a specified amount per lineal rod or per hundred feet. He should agree to furnish his own tools and do the work accurately according to the survey, subject to inspection and approval by the owner, or by some one whom the latter may appoint. The matter of board will enter into the agreement. If the contractor boards himself and men, the price is usually about twenty per cent higher than when the farmer furnishes board. Except on small jobs, and where the owner gives personal supervision to the work, a written agreement, more or less formal, should be signed by both parties.

CHAPTER IX

ACCESSORIES TO UNDERDRAINS

In the solution of the perplexing problems which are met in the installation of a system of drains, frequent use is made of various methods and devices to overcome the difficulties or bring about desired results in special cases. Among these are silt basins, surface inlets, catch-basins, etc., which are of sufficient importance and worth to merit description.

THE SILT BASIN

This is a small well into which one or more drains discharge, and which is provided with an outlet for the escape of the inflowing water. It is one of those accessories to drainage which is quite essential in some localities, and of no value in others. Systems draining thousands of acres in the more level areas of the Middle West, where the soil yields no silt, and where grades are universally small, are in successful operation with no basins. Silt basins retard the velocity of flow by breaking the current, since additional head is required to overcome the entrance friction offered by the outlet pipe in each case. Hence it is the more common practice, where grades are small, to connect all drains by means of close junctions, giving to each branch a drop where possible to do so. By this means a greater efficiency, so far as velocity and discharge are concerned, is secured than if silt basins were interspersed throughout the system.

They are, however, useful and in some instances essential to the most effectual operation and maintenance of a system of drains. Where the soil is light loam con-

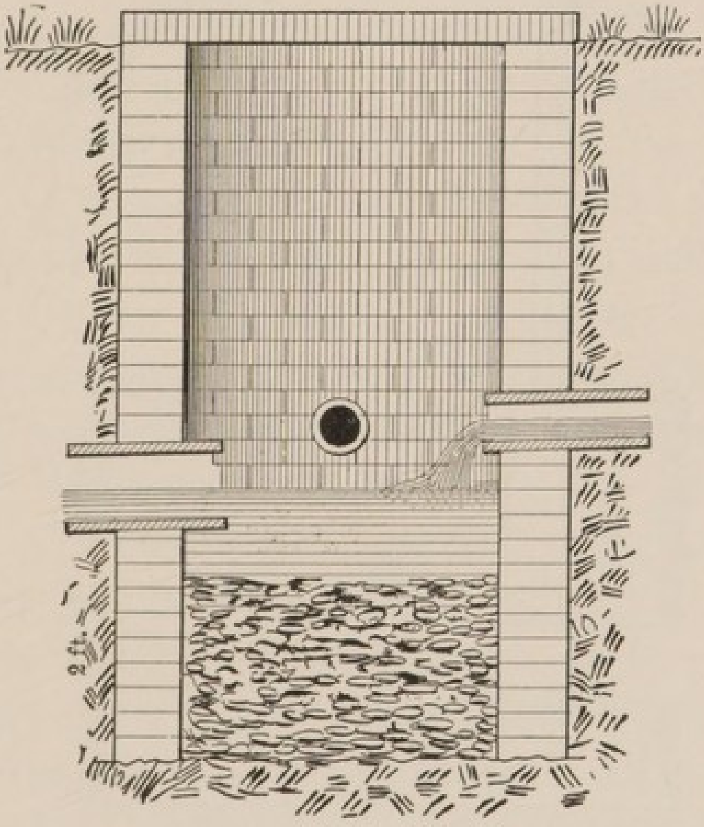

FIG. 29.—Brick Silt Basin.

taining much fine sand, and where the grades are six inches or more in one hundred feet, and it is impracticable to secure a uniform grade, the silt basin may be placed in the flatter portion of the grade to collect the silt from the steeper grades or from a series of drains whose discharge is received at some selected point. They afford a means of reducing grades which are too steep, by steps, and may also be used with proper precaution as surface inlets.

It is often wise to place a silt basin in a drain below a stretch of pipes laid through a treacherous sand spot from which it is probable that silt will gather for a time. It is also sometimes practical to gather several lateral drains into a basin and deliver their discharge from it

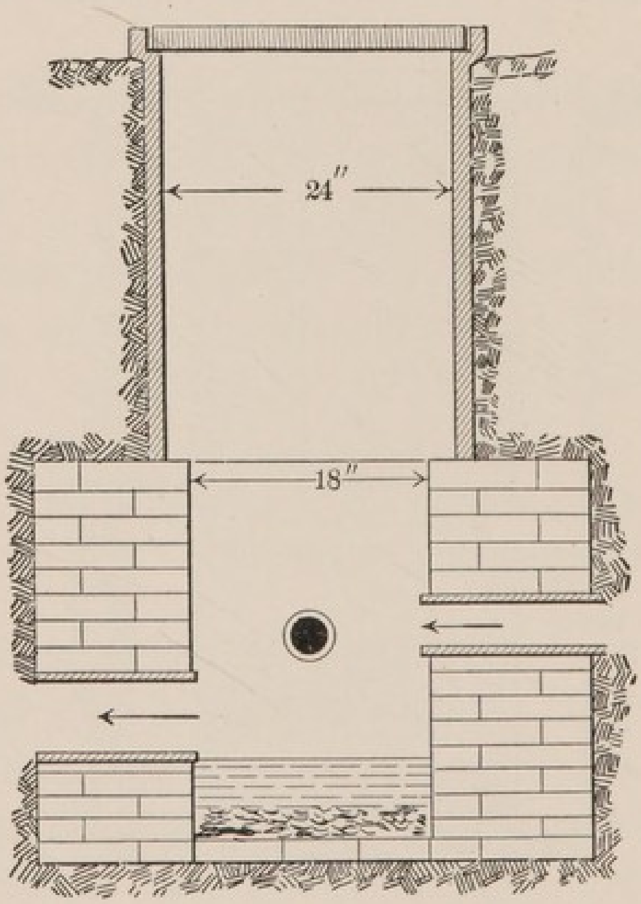

FIG. 30.—Silt Basin with Sewer-pipe Top.

into a common main. Basins are at all times useful as points where the operation of drains can be observed and studied.

Three kinds of basins are in common use. The one shown in Fig. 29 is two feet in diameter and made of brick, the walls being eight inches thick, laid in cement mortar. The base of the wall should be two feet below the outlet pipe, and the tiles placed in position as it is built. The basin may be made larger if desired, but the silt is usually removed by dip buckets, so that it is not necessary for a workman to enter the basin.

The one shown in Fig. 30 has a brick base as high as the tiles enter and a sewer-pipe top, which with the socket to receive the cover, makes a neat combination.

The third kind of basin is the wooden box, made of planks either one or two inches thick with two-by-four inch corner pieces. The box is first made the required size, and usually without a bottom, and the pit for it is then dug. From careful measurements the holes for the tiles are made in the sides of the box, and it is then lowered into place and the tiles accurately fitted. Such basins are used on drain lines in irrigated lands where fine silt is troublesome, and also where the drains require cleaning. When intended for the latter purpose, they should be made four feet long and three feet wide, so that a man can work in them.

All kinds of basins should have a depth of from one to two feet below the lowest drain, and should have fitted covers. They need not extend above the surface more than enough to indicate their position in the field.

SURFACE INLETS

The theory of the underdrain is that all water supplying it should enter by percolation through the soil; that the soil particles should first absorb needed capillary water from the supply, after which the surplus should pass to the drains. As noted in previous chapters, soils differ greatly in their porosity and the rapidity with which they permit percolation. Heavy rainfalls frequently cause an accumulation of water in surface depressions notwithstanding the fact that the soil may be well provided with drains, or the accumulation may be the inflow from outside territory. Under such circumstances the speedy removal of the water from the surface would greatly facilitate the drying of the land. It has been found feasible and safe to do this through underdrains, provided precautions are taken to prevent earth and débris from entering them. Drains are not charged with soil water until several hours after saturation ensues, so that surface relief may be readily afforded by the tile before they are called upon to carry soil water to their full capacity. Some soils become puddled upon the surface by the beating of the rain during extended precipitation, so that while the soil underneath the surface remains in its normal condition the surface is in a measure impervious. When this water is drawn off with little delay, the sun and air aided by a little cultivation soon restore the texture of the soil.

Various successful devices for admitting water from the surface direct to the drain are used. Only when improperly made are they a source of risk to the permanence of the drain. They all consist of some filtering material, as broken stone, gravel, bricks or brush, interposed between the surface and the drain in such a manner as to give a nearly free water head, and at the same time preclude the entrance of foreign matter. Fig. 31 illustrates one of the most simple, and as effective, perhaps, as any. A pit three feet square, and as deep as the drain, is filled with broken stones or brick, and rounded over the top so that débris will not lodge upon it easily. It should be located at a low point in the field where surface water gathers, but not where it will be walked upon by live stock, or run over by wagons, for its utility will depend upon the filling remaining loose and open. It is necessary occasionally to remove rubbish from the top, where it accumulates, and to loosen the material if it becomes partially filled with silt. It

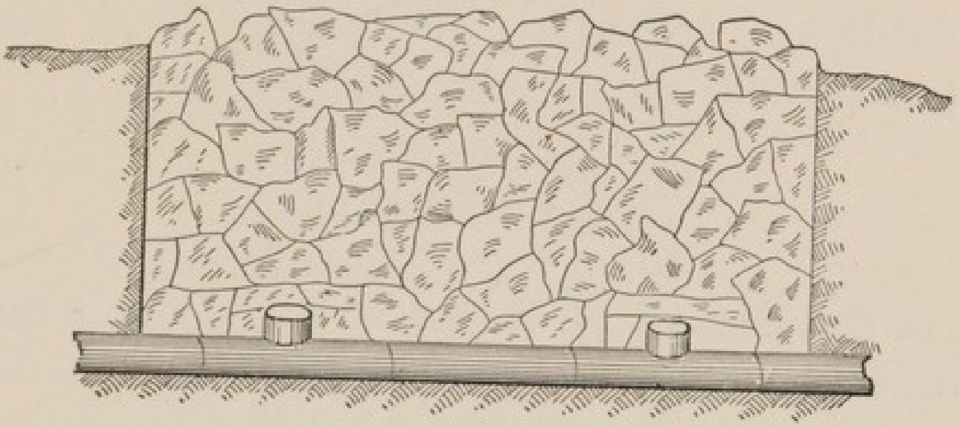

FIG. 31.—Surface Inlet to Tile Drain.

may be well to line the pit with brick or curb it with boards, if the soil is sandy or caves badly.

It is suggested by an experiment in North Dakota that it is not safe in such a climate to admit water in this way to drains during the winter or early spring because, the ground being frozen from the surface to below the drain, the water is congealed in the tiles and any further use of them is thus prevented until the ground thaws in early summer. It is also safe to infer that under those conditions the tiles will be injured. Surface inlets are used at all seasons of the year as far north as southern Minnesota, with no record, so far, of unsatisfactory results.

Direct inlets are a form of surface inlets in which no filtering material is employed, it having been found that, with care, it is wholly practicable under certain conditions to admit surface water to drains direct through an upright T-pipe extending from the drain to the surface. (Fig. 28.) The top must be protected by a screen which prevents all débris from entering. Numerous examples where water is admitted direct to a drain through a screened pipe show that, with a thorough knowledge of the conditions, and with proper precautions, it may be done successfully.

CATCH-BASINS

A catch-basin is a silt basin with an inlet near the top for receiving surface water. Like the silt basin, it should have a space at the bottom two feet in depth below the outlet to receive earth which is carried by water into the basin. The outlet should not be less than six inches in diameter. The inlet should be at the side near the surface of the ground, and be screened by rods placed vertically two inches apart so that no coarse material can enter. The most simple device is a box three feet square, which is placed in position, and the outlet pipe secured in place as is done in silt basins, and the inlet made and protected so that water will flow into it freely. Brick will make a more substantial basin (Fig. 32), but wood is as serviceable while it lasts.

The basin is useful where it is desirable to remove water from small ponds in a field or pools in a yard, or where the earth is so hard and firm that water cannot readily enter the soil. It will serve an excellent purpose where rainfall is extremely precipitous and where there is not ample provision for relief through surface ditches. It is a useful accessory to tile drainage systems in the South, where clay lands do not permit rapid percolation, and where the rainfall is heavy. Precautions should be taken to locate catch-basins in such a way that the

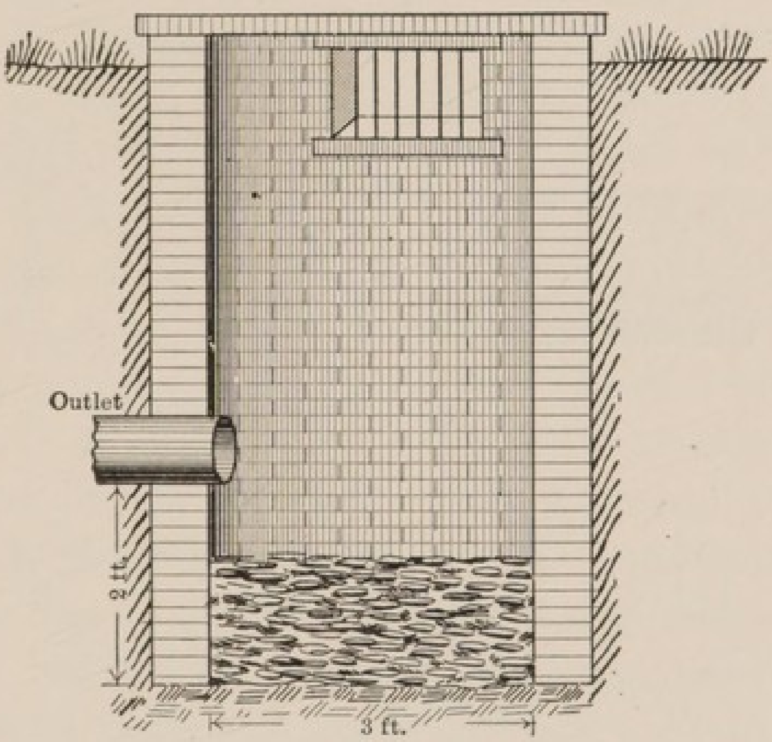

FIG. 32.—Brick Catch-Basin.

current of water entering them will not carry large quantities of earth into them. The closed, or filter, form of surface inlet is safer in this respect, as there is no risk from filling the outlet drain with earth under any circumstances.

PROTECTION OF DRAIN OUTLETS

Devices for the protection of outlets are required to meet two different conditions. The first is to prevent water from flowing back into drained land when the discharging level of the outlet is below high tide when near the coast, or below the periodical flood height of receiving streams inland. Such cases require automatic swinging gates which, when closed, are watertight, but when the pressure of the water in front is removed, open by the pressure of drainage water behind. Fig. 33 illustrates a ten-inch outlet pipe fitted with a swinging gate. The pipe is cast iron, cut at an angle of sixty degrees

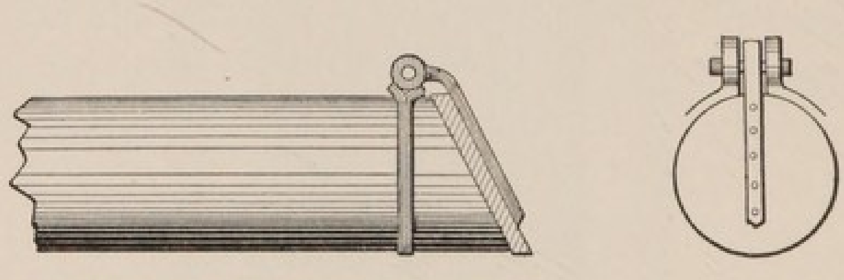

Fig. 33.—Automatic Outlet Gate.

with the horizontal across the end, planed smooth and true at the shop. The gate or valve is made of two thicknesses of one-inch boards, thoroughly creosoted. These are fastened together by rivets and covered with good rubber packing where it comes in contact with the pipe. The hinge is fastened to the pipe by a band shrunken to it and the gate hung as shown in the figure. A check should be put upon the gate so that it will not rise above a horizontal position. The pipe need not be longer than five feet, as the joint with the drain at that distance can be securely protected in the bank.

Well-made plank boxes may be fitted with hinged gates in such a manner as to serve the same purpose, but it is difficult to prevent them from warping out of shape.

The second condition which demands a protected outlet is where drains which have constantly exposed outlets are dry, as they frequently are, in summer. At such times they are in danger from the entrance of small animals which often get fast in the pipes and cause a stoppage, difficult and expensive to locate. The necessary protection against such accidents is very simple, whatever form of outlet is used. It consists of one-quarter-inch iron rods placed two and a half inches apart across the outlet, being fastened in differently, according to the style of outlet. Several plans for keeping the outlet tile in place are in use, a common one being a wooden box with the iron rods inserted in the outlet end. The box is ten feet long, made of plank two inches thick, and of a diameter sufficient to permit the tile to be inserted. The earth filling about the box, as well as about the tile where it enters the box, should be tamped thoroughly so as to prevent the water from passing under

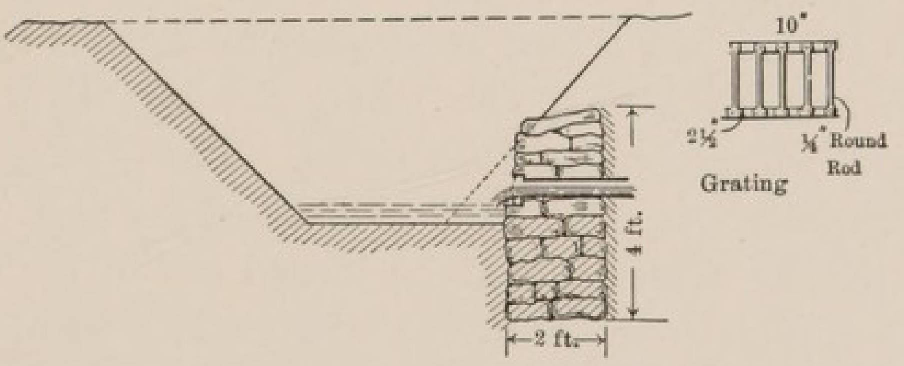

Fig. 34.—Outlet Protection.

instead of through the box, as it will do unless this precaution is observed. This plan is popular because it does not require that the bank of the stream or ditch should be protected, and yet secures the tile fairly well.

A more permanent work, in the form of a bulkhead made of stone, brick, or concrete, is desirable. Its base should be two feet below the bottom of the receiving ditch and of the dimensions shown in Fig. 34. It need not be carried far above the top of the drain, two feet usually being sufficient, but it is important that the foundation be secure. The material should be laid in cement mortar made of one part Portland cement, and four parts sand, mixed dry, and then wet into mortar as needed, not longer than twenty minutes before using. Where sand and gravel are convenient, the bulkhead may be made of concrete, composed of one part Portland cement to seven parts sand and gravel, which as before should be mixed dry, and wet just before being put in place. A "form" will be required to hold the material in place. With materials equally convenient, there is little difference in the cost of stone, brick, and concrete bulkheads.

Vitrified pipes should be used at the outlet of drains in northern climates, as the action of frost and water disintegrate ordinary red clay tile under these conditions. These should be guarded as in other forms by a grating, which any blacksmith can make, the iron bars being fastened to head-pieces with rivets. The grating is set in the wall about two inches in front of the pipe.

Outlets of drains should be turned out of the course of the surface overflow and discharge at a point a few feet farther down stream, so that the surface flow will not endanger the tile drain.

As before stated, the drainage system should be so planned that the outlet points will be reduced to the smallest number practicable, and these should be marked and guarded in a substantial manner. They are monuments which mark the drainage system, and should therefore be as effective and permanent as possible. They give a finished and workmanlike appearance to the discharging points of the drains and to the bank of the receiving ditch.

CHAPTER X

RECORDS OF DRAINAGE WORK

THE farmer is naturally more concerned with the construction of the drains, their efficiency and permanence, than with their record upon paper. The necessity for, or value of, a map with accompanying data which shall show the location, size, length and depth of the whole system of drains is not properly appreciated until later, when the details of the work having passed from mind, it is desired to add a needed branch, perhaps, or to explain the system to some friend seeking information, or to transfer the farm to other hands. In the latter instance, the necessity for a record of the underground improvements to accompany the deed of conveyance is at once apparent, since otherwise the new owner has no means of locating them when repairs or additions are needed.

MAP OF DRAINS

The progressive farmer has come to regard a working map of the farm, showing its division into fields, meadows, etc., with all surface diversities, and the location of buildings and other improvements, an essential part of his equipment. It is of even greater importance that all lines of underground drains should be recorded upon this or a duplicate map made upon the same scale.

Such a map need not be finely drawn to be useful. A correct representation of the lines and their relation to each other, with measurements recorded for greater precision, will meet the essential requirements. Should a well-drawn and artistic map be desired, a copy can be made by a professional draughtsman. If an engineer is employed to lay out the drains, he can make a plat of the lines from measurements and angles taken with an instrument, which is, of course, the most accurate and

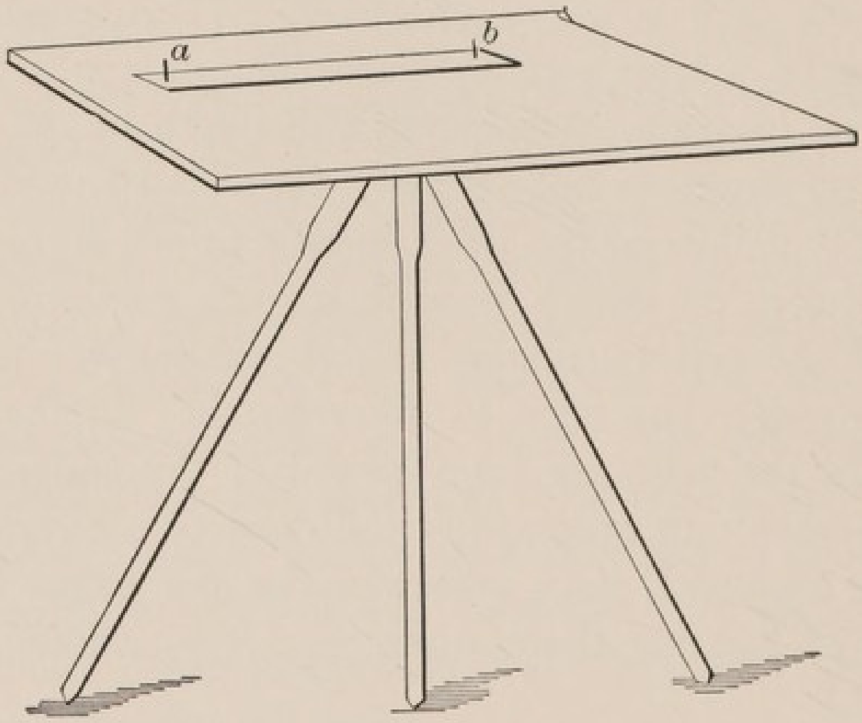

FIG. 35.—Plane-Table for Farm Mapping.

expeditious method. It is not the only way, however, of securing a good map. If the suggestions previously given have been observed, the lines have all been measured, and the number of the tiles and their sizes on each line have been specified. The work has been laid out upon the ground, may even have been completed, but the only records of it are the notes in the level book and the preliminary level sketch. These, however, with the panorama of ditch lines upon the ground, furnish sufficient data from which to construct the map.

The **plane-table method** of surveying is admirably adapted to this work and is easily learned. A plane-table (Fig. 35) is a smooth board twenty inches square, mounted upon a tripod in such a way that it may turn horizontally upon a spindle and be clamped in any desired position. A straight-edge in which are placed two sighting pins (*a*, *b* in Fig. 35), and a movable scale complete the simple outfit.

The tripod for the plane-table may be cheaply made in the following manner: A block of hard wood two inches thick and eight inches in diameter is used for a head. Three legs made of material three-quarters of an inch thick, two and one-half inches wide at the top, and tapering to one inch at the point, are attached to the under side of the head by means of small strap-hinges placed at equal distances around the center of the head. A bolt one-half inch in diameter is put through the center of the board, the head countersunk so that it will not project above the surface. This should be driven so tightly that it cannot turn in the board, and a hole made through the center of the head to receive it. It should be provided with a thumb-nut, by means of which the board can be clamped at any desired position. When in use the board is made level at any convenient working height by moving the legs upon the ground, and the board resting upon the tripod head may be revolved horizontally upon the spindle and fastened in any desired position by turning the thumbscrew underneath the head.

The straight-edge, or ruler, used upon the board for drawing the lines should be eighteen inches long and three inches wide, made of hard wood one-quarter inch thick, and bevelled upon one edge like a common school ruler. The sighting pins should be placed near each end at equal distances from the face edge and extend vertically about three inches above the top of the ruler. Stiff brass wires about the size of the lead in a pencil are best for this purpose.

To illustrate the manner of using the plane-table, we will assume that the drains of the field represented

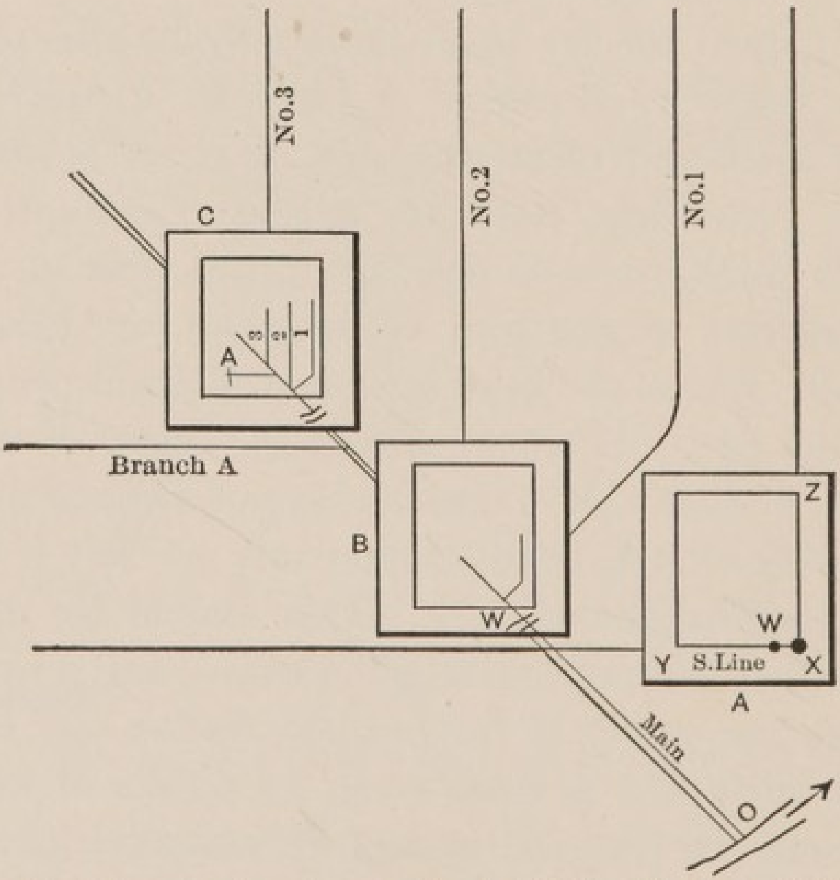

FIG. 36.—Mapping Drains on South Field with Plane-Table.

in Fig. 19 have been staked out, or constructed, perhaps. In the latter case stakes of sufficient size to be easily seen should be set over the drains at angle points, that is, at bends in the line. Decide upon the scale to which the map shall be drawn, as one inch to three hundred feet.

Tack a sheet of good drawing paper upon the board, and fix a point to represent the corner of the field, as *X*. Set the table at the corner of the field as represented at *A*, Fig. 36, with the point on the map over the point on the ground which it represents, and clamp the board firmly. Holding one edge of the straight-edge at the point *X*, turn the straight-edge until the two sighting pins are in line with the south side of the field, then beginning at *X* draw a pencil line along the straight-edge to represent on the map this side of the field. With the scale, now measure off upon this line from the point *X* the proper distance to represent this side of the field (fifteen hundred feet) on the scale adopted, which fixes the corner *Y* on the map. This process is known as scaling. Being careful to keep the board securely clamped in its first position, turn the straight-edge so as to repeat this operation for the east side of the field, *X*, *Z*.

Now scale off on the south line of the map from the point *X* two hundred and fifty feet to the main drain, and indicate this point on the map. Move the plane table so that this point on the map, *W* in the illustration, shall be directly over the point on the field which it represents, and turn the board until the line *X*,*Y* is exactly over and in line with the southern boundary of the field which it represents, clamping it in this position. With the edge of the straight-edge at the point *W*, turn it until the sighting pins are in line with the main drain and draw a line extending beyond *W* each way. Scale the distance on this line to the outlet and sketch the bank of the creek and outlet point; also scale the distance in the opposite direction, from *W* to the point where Branch No. 1 enters. Move the plane-table to this point (position *B* in Fig. 36), and place the line last drawn over its corresponding line on the ground, and draw in Branch No. 1, scaling it to correspond with the distance recorded in the level notes, as was done for the main line.

Proceed in the same way with successive points, as junction of Branch 2 with Main, of Branch A, of No. 3 (position *C* in Fig. 36), and so on, moving the table, drawing in the lines, and scaling them to correspond with their actual length upon the ground.

Where there are parallel lines like Nos. 2, 3, and 4, Fig. 37, the work may be greatly shortened after the first line has been drawn with the aid of the plane-table as directed, by simply drawing in the remaining lines, scaled to represent their actual measurements and distance apart, parallel to the first line.

This use of the plane-table is a departure from its usual one in the hands of engineers, its only office here being to secure the angles, the measured distances being taken from the note-book.

When completed, the map will appear as represented in Fig. 37. The number and sizes of tile should be marked upon each line, and any desired features of the surface, such as buildings and fences, may be represented.

In one important respect a map made in this manner is of more value than one made in the usual way by an engineer. By reversing the process the lines can be located upon the ground from the map as accurately as they were drawn on the map from the ground. With the outlet known, if any one point on the main below its first bend is known, or can be found by digging, the entire system of drains can be located on the ground. Or if the junction point or upper end of any straight branch line and a point anywhere on that line are known or can be found, the same may be done. In short, any two points on any straight line of drains, one of which is known to correspond to a point on the map whose distance from the discharging point is known,

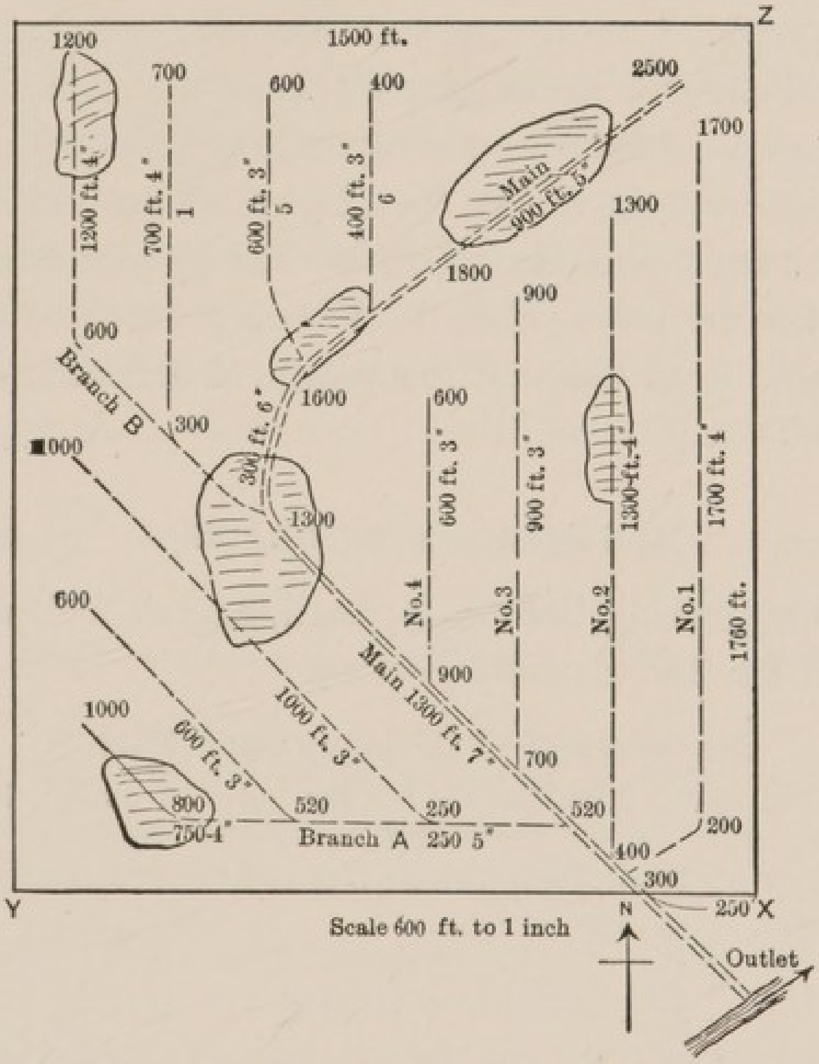

FIG. 37.—Map of Drains on South Field, 1908.

are sufficient to locate the system, or any desired part of it, by a very simple process. Take the plane-table with the map replaced upon the board to the field, and set it up at the point whose location on the map is known, having marked the other point by a pole set in the ground. By the use of the sights on the straight-edge turn the board until the line between the plane-table and the pole on the ground is directly under and in line with the line representing it on the map. The direction of the line on the ground being thus established, measure off upon the ground the actual distance as recorded on the map to the first bend in the line, or to its junction with its main, and set another pole. Remove the plane-table to that point, and again placing it so that the line just found shall be under its corresponding line on the map, the next line sought will be found under its corresponding line on the map, and can be established by measurements, and marked by poles, the process being repeated at each angle point until the entire system, if desired, can be located.

MEMORANDUM OF DRAINS

The map having been completed, attach to it a memorandum similar to the following:

Memorandum of Drains on South Field

Drains laid in 1908. Hard-burned red tile made by Smiley Bros. used throughout.

Cost of Tile (Delivered on cars at Lenox Station)

1,300 ft. 7-in. at $40 per 1,000	$52.00	
300 " 6-in. " $32 " "	9.60	
1,150 " 5-in. " $24 " "	27.60	
5,650 " 4-in. " $17 " "	96.05	
4,100 " 3-in. " $14 " "	57.40	
12,500		$242.65
Hauling and distributing		$ 56.00
Digging ditch and laying tile		262.00
Filling trenches		12.50
Outlet protection		5.00
Laying out and mapping the drains		20.00
Total		$598.15

Drains located as shown upon the map, and laid from 32 to 40 inches deep. Field contains 61 acres.

George Smith, Owner.

CHAPTER XI

COST OF DRAINAGE

THE great variation in the amount of labor required to construct drains, depending upon the kind and condition of the soil, together with the inequality in prices of labor and material in different part of the country, preclude a statement of cost which shall cover all cases. A fairly reliable estimate can be made for any locality when one is familiar with conditions and current prices there.

Drainage work naturally divides itself into several classes, which should be considered separately when estimates of cost are to be made. These divisions are as follows:

Open ditches and improvement of existing channels on the farm, as distinguished from those made at public cost and assessed against the land benefited under provisions of State Drainage Laws.

Cost of drain tile upon the field.

Digging ditches and laying tile or other material for covered drains.

Filling trenches.

Silt basins, outlet protection guards, automatic gates, surface inlets, etc.

The current prices of labor and material in each locality should be the basis of estimates, though the farmer may be able to accomplish a part of the work at less cost to himself by using his regular help at times when they are not required in the usual farm operations. He can also take advantage of periods favorable for doing the work economically, the benefits of which, as previously noted, are of considerable importance.

A preliminary estimate of the amount and kind of work which is contemplated should be made, to which the cost units may be applied. Later, when complete plans and measurements of distances have been made, a more accurate estimate may be secured by using the same cost units.

COST OF OPEN DITCHES

Consideration should first be given to the open channels which are to receive the discharge from the field drains. These should be as few as practicable, the tendency in practice now being to substitute tile for open ditches, sixteen to twenty-inch tile being used in ordinary farm drainage, while pipes of diameters up to thirty-six inches are employed in large drainage districts. Though the first cost considerably exceeds that of a ditch serving the same purpose, such a drain occupies no valuable land and requires no annual repairs.

The basis of an estimate for open ditch work is the cost of removing a cubic yard of earth, which will depend upon the kind of material, depth, and width of the ditch. This work is usually done by team and hand labor, the price of which varies in different localities. The price units which follow are based upon the best class of labor at $4 a day for team and driver, and $2 a day for men.

Prices in the South are lower than these, but it is doubtful if the ultimate cost of drainage work there will be materially lower because of the less efficient quality of the labor usually procurable.

Ditches in solid earth which can be readily turned with the plow, not deeper than three and a half feet, should cost ten cents, and those five feet deep thirteen cents per cubic yard. If the ground is sticky or somewhat soft, add ten per cent to these figures. The form of ditch will have much to do with its cost, both with respect to the yard unit and the linear unit.

Table II, this page, shows the amount of excavation in cubic yards in one hundred feet of ditch with bottom width of three feet and different side slopes and depths, from which the cost of different types described may be computed, when the price per cubic yard for the several forms of ditch has been ascertained for any locality.

TABLE II

CUBIC YARDS IN 100 FEET OF DITCH WITH BOTTOM 3 FEET WIDE

Side Slopes.	Depth in Feet.			
	2	3	4	5
½ to 1	29.6	50.0	74.0	101.8
1 to 1	37.0	66.6	103.7	148.1
1½ to 1	44.4	83.3	133.3	194.4
2 to 1	51.8	100.0	162.9	240.7
2½ to 1	59.2	116.6	192.5	287.0
3 to 1	66.6	133.3	222.2	333.3
½ to 1 on one side; 3 to 1 on the other	48.1	91.6	148.1	217.6

It will be well to compare the amount of excavation required to construct the different types before deciding upon the section to be used, though, of course, other considerations should be given their proper weight.

The deepening, straightening, or cleaning of old or natural channels are nearly always a necessary part of the execution of a drainage plan. Such dressing and cleaning out will cost twenty-five cents per cubic yard, and often more. Work of this kind, however, is usually estimated at a price per lineal rod, yet the basis of fixing the price is the cost of moving a cubic yard of the material.

Brush-cutting, grubbing, or removing stumps is estimated by the lineal rod or one hundred feet, based upon the time required to do the work at current day wages. Such a great variety of conditions may be encountered that it is impossible to name prices that will cover such work without giving it a critical examination, a thing which should always be done by a workman before undertaking any job which involves the moving of earth.

COST OF DRAIN TILE

The cost of clay drain tile, delivered upon the field, will vary, of course, with the price asked at the factory, the cost of hauling from factory or railroad station to field, and the freight charges when shipped by rail or water. Factory prices necessarily vary widely for several reasons. Labor and fuel, and especially the care required in the preparation of the clay in the manufacture of the tile are by no means uniform, so that there are sufficient reasons for the quotations of different prices by tile makers. Table III, page 125, gives representative prices for clay tile in the states named, delivered on the cars or in wagons at the factory. They are not the highest, but under average conditions seem to be remunerative to the manufacturer.

Table III

FACTORY PRICES FOR CLAY DRAIN TILE PER 1,000 FEET

Size in Inches.	Iowa.	Illinois.	California.	Indiana.	Mississippi.	Oregon.
3	$12.00	....	$20.00	....	....	$12.50
4	16.00	$16.00	25.00	$15.00	$17.00	17.50
5	22.00	21.00	40.00	21.00	24.00	25.00
6	29.00	28.00	50.00	27.00	30.00	35.00
7	37.00	37.00	....	36.00	40.00	45.00
8	48.00	48.00	70.00	48.00	55.00	55.00
10	85.00	68.00	....	66.00	75.00	85.00
12	105.00	95.00	....	95.00	110.00	150.00
14	....	....	....	150.00	175.00	....
16	....	....	....	190.00	220.00	....
18	....	....	....	265.00	300.00	....
20	....	....	....	335.00	385.00	....
22	....	....	....	400.00	460.00	....
24	....	....	....	450.00	520.00	....

The price of cement tile up to twelve-inch is not far different from that of clay, where both are obtainable, but the large sizes used in public work cost less.

Comparing the present prices of drain tile with those in the early days of drainage in New York State, it is of interest to note that in 1850, 4-in. tile were quoted in Albany at $40, 3-in. at $18, and 2-in. at $12 per 1,000. With these as prevailing prices, John Johnston, writing in 1851 of his experience, says: "No excuse now exists for wet fields, or grain being destroyed by freezing out." The tiles first used by Mr. Johnston were hand-made, and the 2-in. size cost him $24 per 1,000. They were used for laterals, and 4-in. (sometimes two lines in the same trench) for mains. Even at this cost Mr. Johnston found draining highly profitable. It should be added, perhaps, that the land drained was undulating to such a degree that abundant fall was obtained, 2 or 3 feet per 100 feet being a grade not uncommon for laterals.

Table IV

WEIGHT OF CLAY DRAIN TILE

Size in Inches.	Weight Per Foot in Pounds.	Average Carload in Feet.	No. of Feet Per Ton.
3	5	7,500	400
4	6	6,500	334
5	8	5,000	250
6	11	4,000	182
7	14	3,000	143
8	18	2,400	111
10	25	1,600	80
12	33	1,000	60
14	43	800	56
16	53	500	38
18	70	400	27
20	83	332	24
22	100	320	20
24	112	300	18

Freight charges on tile shipped by rail 50 to 100 miles will amount to 12 or 15 per cent of the factory price on sizes up to 10-in. and 20 to 30 per cent on larger sizes. These figures are only approximately correct. The land drainer should not only obtain quotations from the factories convenient to him, but also the freight rate from the transportation company. By using Table IV, page 126, which gives weights and the numbers which may be shipped in a car, he can estimate the cost quite closely.

Tiles of the same size from different factories differ in weight from ½ lb. to 2 lbs. per foot. The number of tiles in a carload as ordinarily shipped is also quite variable.

The cost of hauling tile is so largely governed by the condition of the roads and the field where the tiles are to be distributed that any cost figures here named are liable to fluctuate, but the following may be given as a fair estimate where road conditions are good and wages of team and driver $3.50 per day:

Hauling one mile	$0.65	per ton
" two miles	0.80	" "
" three "	1.15	" "
" four "	1.35	" "
" five "	1.60	" "

Strong racks should be provided for hauling all but the smaller sizes of tile, both for convenience in loading and unloading and to get the required weight of the larger sizes upon a wagon. The approximate number of tile required to weigh one ton is given in Table IV, page 126.

COST OF TRENCHING

The cost of labor required in making ditches by hand is about forty per cent greater at this writing (1908) than fifteen years ago. The work belongs to the class of skilled manual labor. This is apparent when the professional ditcher is employed by the side of the inexperienced workman. The former will in the same time execute one-third more work than the latter, and, what is of even greater importance, do it more perfectly. Such workmen prefer to dig farm drains by contract, since it gives them the opportunity to profit by the skill they have acquired.

There are in general three classes of ditching: "spade work," "bottom-pick work," and "all-pick work." In the first the earth is cut and removed by the spade and shovel; in the second, the bottom six or twelve inches must be loosened by the pick or mattock, the balance being readily handled with the spade or shovel; in the third, the earth for the entire trench must be loosened by the pick before the spade or shovel can be used.

The first constitutes the larger part of farm ditching, and properly forms the basis of estimates for trenching. While the soft, turfy, wet, or sticky condition of the earth modifies the facility with which it may be handled with the spade and shovel, the cost is at once materially increased wherever it is necessary to use the pick or mattock. Many clay soils that need draining, and which yield readily to the spade when wet, become exceedingly hard during the dry part of the season, suggesting the wisdom of constructing needed drains when moisture conditions are favorable.

There are trenching machines which operate successfully, but their use is limited by conditions of soil and kind of work to be done. They are not available for many classes of work, so that the cost of hand labor usually determines the price of farm ditching. Power machines are operated by contractors whose price to the farmer is made in competition with hand labor, and as yet does not materially lessen the cost of ditching to him. It is probable that these conditions will change as machines are perfected and come into more common use, but it is quite certain that hand labor will always play an important part in the cost of underdrains.

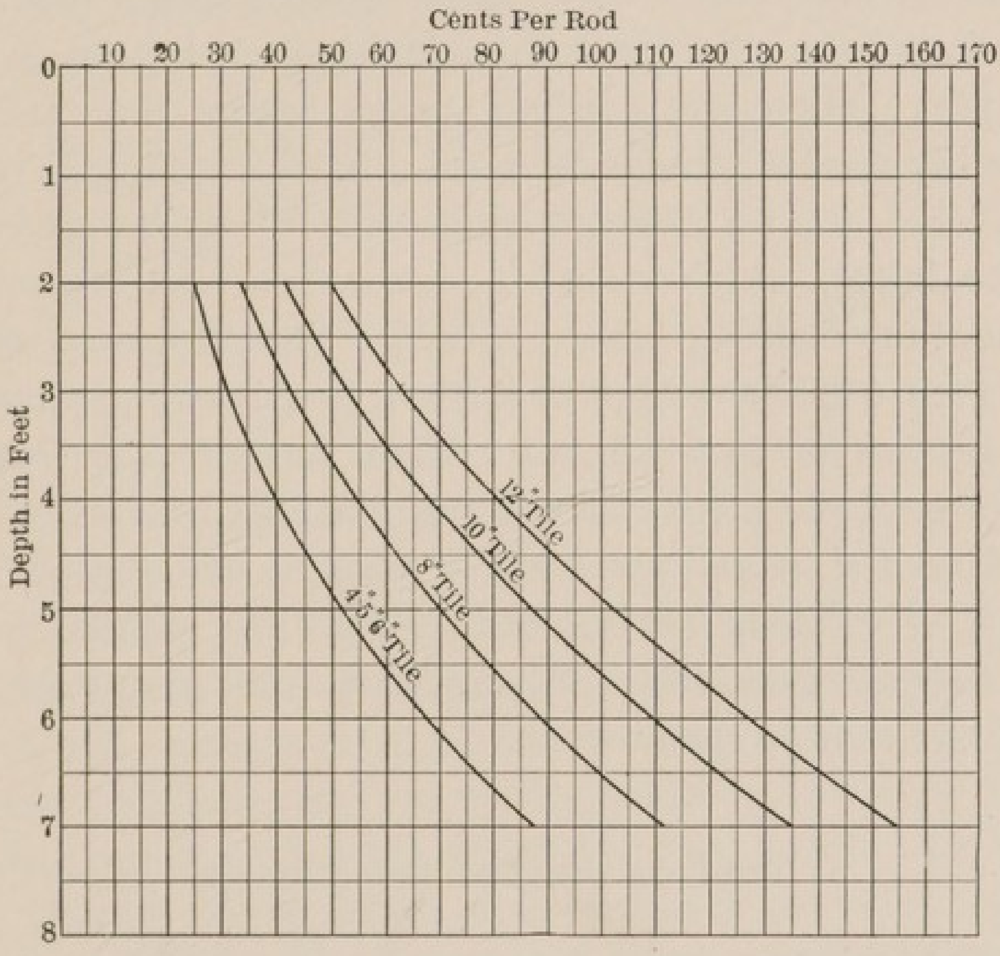

FIG. 38.—Diagram Showing Prices in Cents per Rod for Digging Trench and Laying Drain Tile.

The unit usually adopted as a basis for estimates is a ditch one rod long, three feet deep, and wide enough on the bottom to receive tiles up to and including six inches in diameter, the price to include opening the ditch, grading the bottom, laying the tiles, and blinding.

Fig. 38 is a diagram from which the cost of hand trenching for tiles from four inches to twelve inches in diameter, and depths from two to seven feet can be quickly ascertained. To use this diagram, observe where the curved line denoting the size of tile under consideration crosses the horizontal line indicating the contemplated depth. Follow the perpendicular nearest to this intersecting point to the top of the diagram, where will be found the price per rod for laying that size tile at that depth. These are contract prices where the earth is readily spaded, wages for good diggers twenty-five cents an hour, and for expert ditchers thirty-five cents an hour. The latter, which includes superintendence, represents about one-half the labor required. Should it be possible to secure efficient labor at a lower price, a corresponding reduction in cost will, of course, follow. The curves represent the ratio of labor required in constructing the different sizes and depths of ditches as indicated by the bids of ditching contractors. Where the pick and bar are required to loosen the earth, the cost may easily be double that of spade work.

COST OF FILLING THE TRENCH

Field ditches 3 feet deep can be filled for 3 cents per rod, or 18 cents per 100 feet, when done with a plow or with a filler made for the purpose, and by hand labor for 6 cents per rod, or 36 cents per 100 feet. Deeper ditches, and those for tiles larger than 6 inch, will cost proportionately more to fill; that is, the cost of a ditch 6 feet deep for 12-in. tile will be about four times that of a ditch 3 feet deep for 6-in. tile.

COST OF ACCESSORIES

The cost of the various accessories, one or more of which are used in almost every system of drains of any considerable extent, can readily be estimated when the material which shall be used has been decided upon.

The cost of brick silt basins, two feet in diameter inside, six feet deep, with walls the thickness of one lengh of brick, may be estimated as follows:

690 bricks on the ground at $10 per thousand....	$6.90
Excavating..	.50
Laying brick without mortar....................	2.00
Plank cover...	.75
Total..	$10.15

A silt basin made of plank will cost about one-third less.

For cost of catch-basins, add $1.00 for the inlet, to the cost of a silt basin of the same style.

Outlet boxes eight feet long, made of planks two inches thick, will cost approximately as follows: 6-in. outlet, $2.00; 8-in. outlet, $2.50; 12-in. outlet, $3.00.

Hard-burned sewer pipe with sockets suitable for silt basins or connecting the down spouts of buildings with drains, made in lengths of two or two and a half feet are about twice the price of drain tile of the same diameter and for the same length. A length or joint of sewer pipe with a Y or a T is double the price of the straight pipe.

These prices and estimates are only approximate, and are given for the purpose of representing the comparative cost and the manner of estimating, rather than to give exact figures, since prices of labor and material fluctuate, and thus vary the total cost.

CHAPTER XII

ESTIMATING THE PROFIT

THE inevitable question, Will it pay? to which the farmer desires an answer when any new improvement is brought to his attention is not indicative of a miserly or parsimonious nature, but is an eminently proper query, and one which arises in every sensible, practical mind. The capitalist or business man decides it with pencil and paper, figuring out in dollars and cents the whole proposition. The farmer is too apt to trust to mental processes of a general nature, and jumps to a final conclusion, rather than arrives at it by accurate calculation. One, and perhaps the chief, reason for this lies in the fact that farm operations are so complex, so intermixed in their gains and losses, so difficult to estimate because of their far-reaching effects that the farmer is discouraged in his attempts to figure out definitely the cost or the profit of any undertaking. Drainage, however, is an improvement of such a nature that its benefit to the farm, and its money value to the owner, can be very closely estimated before entering upon the work.

There are two distinct classes of farm lands that are subject to drainage. First, those which are under cultivation or in use, and to a greater or less degree productive; second, those so wet and swampy that no effort is made to use them, and they are considered wholly waste land.

PROFIT IN DRAINING LAND ALREADY UNDER CULTIVATION

When properly drained, such land, suffering from an excess of water, becomes at once more productive, with no increase in the cost of cultivation, seed, or management. The only expense incurred is in the installation of the drainage system. The profits will manifestly be the difference between this cost and the value of the increased yield as long as the drains continue in operation, and can be approximately estimated in dollars and cents before beginning the improvement. It is quite possible for the farmer to ascertain the prices paid for the different classes of labor in the construction of drains in his locality. He can tell by observation, supplemented if necessary by a few measurements, the probable number of rods or miles of drains he will need. From these data he can easily compute in dollars and cents what his drainage work is likely to cost him per acre.

Then from returns on his neighbor's farm, or the record of results on farms similar to his in soil and crops, he can know the amount of increase in yield he may reasonably expect; and, being familiar with prices of crops from year to year, he can soon figure out the money value per acre of the increase in production. To be on the absolutely safe side, he should in his calculations use cost prices above the average, and the yield per acre and the market price per bushel below the average. There are always unlooked-for contingencies which must be met in handling land propositions, so that it is wise to allow liberal margins between estimated cost and probable net returns. The cost of drainage of ordinary farm lands varies from $5 to $30 per acre, according to the locality, character of soil, the amount needed, etc. The increase in production also varies similarly from fifteen to forty bushels of corn per acre, and other crops in proportion.

For illustration, let us suppose that a farmer has 100 acres under cultivation which can be improved by drainage. He finds upon inquiries and computations that the cost of such drainage cannot exceed $20 an acre. It may be less, but certainly not more, making a total of $2,000 cost. The experience of others teaches him that he may confidently count on an increase of at least fifteen bushels of corn per acre annually, probably more. A low price for corn would be 25 cents per bushel (in the South 50 cents), or $3.75 per acre, making a total value of increase of yield from the entire farm of $375 per year. Now, if he has the $2,000 cash on hand, he may either consider it an investment on which he will get $375 a year, or 18¾ per cent annual interest, as long as the drains are in operation and he owns the farm; or he may take the view perhaps more often taken, that, at $375 a year, it will require the increase of six years' crops to pay up the $2,000 cost (with a margin for contingencies), after which the $375 a year is constant annual profit for an indefinite time.

If the $2,000 must be borrowed, perhaps secured in the form of a bond maturing in ten years, and bearing 6 per cent interest, the cost will be increased by the ten years' annual interest to $3,200, but as the ten years' annual increase of crop amounts to $3,750, there is still an ample balance on the right side, and after the maturity of the bond the increase of production will be clear gain as in the first case. It will very often be possible to secure the necessary loan on more favorable terms than these, in which case the gain will be proportionately increased.

PROFITS IN DRAINAGE OF WASTE LAND

The estimate of profits resulting from draining swamps or other waste lands, whatever their nature, is similarly arrived at, the only difference being the addition to the cost items made necessary by the fact that besides drainage there must be the additional expense of clearing the land, breaking up the soil, and preparing for the growth of the crop, cost of seed, cultivation for a year, etc., before any returns are realized. As this entire process often requires two or three years' time, this fact must be taken into account in reckoning the profits, since they cannot begin at once as in the case of cultivated land. Viewed as an investment, a larger amount per acre is required for the original investment, covering the expense of the entire non-producing period, but the yearly profits, or annual interest on the investment after the land becomes productive, is greater, being the value of the entire crop less the cost of production.

RETURNS FROM THE DRAINAGE OF RENTED FARMS

The assumption thus far in the consideration of this phase of the drainage question has been that the farmer was himself the cultivator of his farm, or made it his home and superintended its cultivation. But as there are many farms occupied by tenants whose non-resident owners are interested in this subject, it is well to look at it from their view-point.

Many, and perhaps most, of the improvements put upon a farm by the landlord owner are either to keep it in needed repair, or are demanded by the tenant for his greater convenience or comfort, and bring in no money returns to the owner, who for this reason is not always as ready as he should be, perhaps, to spend money in this direction, even to the extent of being "penny wise and pound foolish." But drainage is an improvement in which the non-resident owner shares with the tenant the resulting profits. If he is receiving a cash rent, it should be raised in proportion to the increased yield. If the rental is a share of the crops, he will get direct benefit in the increased number of bushels coming to him.

There is often a little difficulty in adjusting the matter of costs between owner and tenant, since drainage is an improvement of direct advantage to both. Where the tenant has a term lease of five years or more, he should, in equity, be willing to bear some of the expense, as, perhaps, the hauling and distribution of the tile and other work which he can do with his team at odd times at much less cost to himself than the non-resident owner can hire it done. Where the tenant has only a year's lease and is liable to leave at the end of the year, he cannot be expected to bear any appreciable part of the expense. If the holder of a several years' lease is so blind to his own interests as to refuse to share the cost of drainage improvement, the owner should not be too ready to dismiss the proposition as an unprofitable one because he receives only, it may be, one-third of the crop as rental. He may feel that it would be a money-losing proposition not to be considered, if he must bear all the expense. In the case assumed, however, where the total cost of the drainage of 100 acres was $2,000, and the value of the yearly increase in yield was $375, his increase of rental would have been $125 a year, or 6¼ per cent interest on his $2,000 investment. As this would be a perpetual yearly interest from a principal not subject to destruction or loss by any means, it is seen that the question merits careful study even when the owner must bear the entire cost. The fact that increase in the value of the land resulting from its drainage will make it possible for him to secure higher rent when a new lease is executed, and in case of sale to obtain a better price per acre, is also a matter for consideration. Whether the tenant is a good or poor farmer must, of course, be taken into account, for the best farm poorly worked is not sure to be a paying proposition. A poor tenant may, by his indifferent management, fail to get the extra yield which the ground has been rendered capable of producing.

ADDITIONAL PROFITS

There are other values of drainage, real and weighty, which merit attention. They are indirect or reflected, rather than positive and commercial. They relate to health, ease of moving over fields, economy of time and labor, attractiveness of the farm, abatement of mosquitoes, health of farm animals, and improvement of public roads. It is difficult to place a money value upon these, yet they are intimately connected with the building up of a contented rural community, and with the introduction of the amenities of life which lend dignity and attractiveness to farm work. They are recognized in State drainage laws as having a value, and in the minds of some individuals dominate all others.

CHAPTER XIII

COOPERATIVE WORK

THE owner of a farm which has within its limits a natural watercourse of a size and nature to provide sufficient outlet for the complete drainage of the entire farm is most fortunate, in that he is in a position to proceed with his plans without the delay and possible difficulty of securing an outlet on his neighbor's land. Too often this is not the case. In the humid sections of our country especially, there are large areas of practically level land which have no pronounced water channels. These in many cases are divided up into farms, all of which need more or less drainage to insure profitable cultivation. The interior ones among these, remote from any stream adequate to receive the discharge from a drainage system, must secure the right of way across intervening farms to the desired outlet. Often it is necessary, before such territory can be drained, for the owners of different farms to cooperate in the construction of a suitable outlet ditch for their mutual benefit. It sometimes happens in such cases that an agreement is reached between the owners as to adjustment of costs and method of work without invoking the aid of the law. Amicable agreements of this kind, where any considerable number of persons are concerned, are rare, however, owing to the frailties of human nature.

BY MUTUAL AGREEMENT

A few farmers, finding it to their mutual advantage to join in the expense of making an outlet for their joint use, do sometimes agree upon the details of the work, and the proportion of the expense each should bear, without taking it into the courts. As such a course is extremely desirable, in that unnecessary cost and delay are avoided, a few suggestions as to adjustment of costs, which is generally the point on which agreement is most difficult, will not be out of place here.

The necessity for cooperation of this kind usually appears when one owner, in order to reach a natural stream or public drainage channel, desires to lay a drain across another's land. In such cases the following is common, and generally quite satisfactory practice. Where a land-owner must cross the property of another with a tile drain in order to secure a sufficient outlet for the drainage of his land, but the land of both requires drainage which is secured by the tile drain, the upper owner should pay the lower one the additional cost incurred in making the drain enough deeper and larger to meet his needs. For example, if six-inch tile laid three feet deep will be sufficient for the lower owner, and the drainage of both will necessitate through the lower farm ten-inch tile laid four feet deep, the upper owner should pay the additional cost of the trenching and tile made necessary to provide for his drainage.

If, however, the land of the upper owner be more sloping than that of the lower, to such an extent that the land below is injured by the natural drainage of the land above, which injury will wholly or in part cease when the upper land is properly underdrained, then the extra expense of the larger drain should be shared by the lower owner in proportion as his land is benefited by the drainage of that above.

When the lower farm requires no artificial drainage and the drainage of the upper land will in no way benefit it, the upper owner should be permitted to construct the drain across the lower farm, but should do it at his own expense.

Whatever agreement is made between neighbors under any of these circumstances should be in writing and recorded, since it defines the ownership of the drain, and the rights of each in the case.

It is the consensus of opinion among men acquainted with drainage, and is incorporated in some State laws, that each land-owner must keep whatever natural drainage streams pass through his property, free from obstructions, and in good condition for the passage of water.

DRAINAGE DISTRICTS

In extended cooperative work, where there is, of necessity, a clash of interests and opinions; where, for the general good, concessions must be made by some, and sacrifices demanded of others; and where misunderstandings easily arise, it is seldom that all of the parties concerned are sufficiently generous and broad-minded to enable the work to progress to conclusion without recourse to law. The need of legislation to govern such cases has been recognized in most of the States, and suitable laws have been enacted providing for the organization of drainage districts in localities where cooperative work is necessary. As these laws vary in different States, no attempt will here be made to enumerate their provisions. If a farmer finds that the drainage of his land is impossible without the cooperation of his neighbors, he should endeavor to bring about a satisfactory agreement among them regarding the matter. If he does not succeed in this, he should procure a copy of the drainage laws of his State, and proceed as they direct.

DRAINAGE LAWS

The operation of drainage laws usually brings up some questions relating to the adjustment of damages, apportionment of costs, and the rights of individuals, which land-owners had not before considered. The following principles are fairly well recognized in the laws, and merit the careful attention of land-owners who find themselves under the necessity of working under their provisions in securing the drainage of their lands.

The office of such laws is to secure what is known as "combined drainage." They apply to the construction of outlet drains which will benefit the land of several individuals.

They are administered by county officials, or by commissioners selected by interested land-owners, as may be authorized by the legislative act.

The cost of the drains used in common is assessed against each property in proportion to the benefit it receives.

Damages or remuneration are awarded to owners whose property is injured by, or appropriated for, the construction of drains for the common good.

Recourse at law is given to those who regard themselves aggrieved by the acts of the administering board.

The object of the laws is to secure to each land-owner an adequate drainage outlet, for which he is compelled to pay his proper share of the cost, and in return receives a commensurate benefit.

ASSESSMENT OF COSTS

The equitable assessment of costs against the several tracts concerned is a fruitful source of contention, and often litigation between land-owners and the board charged with the administration of the law. It is not easy for a board to make a just assessment and at the same time meet the approval of the owners.

Lands which by nature are partially dry should be assessed less than those which are swampy and wet, provided both are furnished with equal drainage facilities. Wet lands situated some distance from the ditch are assessed less than those adjoining it, other things being equal, because the former have outlet privileges only, while the latter, in addition to the same outlet rights, receive direct drainage benefit also. Land through which a public ditch incidentally passes, greatly benefiting it, should be assessed higher than land given outlet only and merely touched by the drain. If land is situated near a natural stream which furnishes it an ample and complete outlet, it should not be assessed for the cost of improving the stream for the benefit of other lands for which it does not afford a satisfactory drainage outlet, except upon the ground of general public benefit. The drains of a district are a public improvement as well as a private benefit, and should be so regarded; and owners of property within the drainage limits of the ditches may properly be assessed slightly for their cost, even though they do not receive direct benefit from them, in the drainage of their land. This view of the matter, however, is not always sustained by the courts.

It will readily be seen that in the process of adjusting assessments for benefits, and awarding damages to owners for property which is taken for public use, differences of opinion between board and land-owners upon questions of fact and equity may easily arise. A candid discussion of such differences by those concerned and the members of the board, in joint meeting, prompted by an honest desire to reach an amicable adjustment, will often settle matters in dispute and clear up misunderstandings, and thus greatly expedite the work to be done.

CHAPTER XIV

DRAINAGE OF FARM PREMISES

THOUGH much more attention is now being paid to the appearance of farm premises than formerly, and the lawn, garden, outbuildings, etc., are much better cared for as a rule than twenty years ago, there still is room for great improvement on very many farms.

Drainage, as the basis of any permanent improvement of the farm grounds contemplated, should receive careful consideration. Since the site of the house and accompanying buildings has been selected often because of its rise above the surrounding land, it is possible that there may be good natural drainage, but not necessarily so, as it often happens, as shown in other chapters, that knolls and hillsides need drainage, and if there is any undue wetness in any part of the grounds, even at intervals, its cause should be investigated and the proper remedy applied.

DRAINAGE FOR IMPROVEMENT OF VEGETATION

The artificial drainage of the lawn, where there is any deficiency of natural drainage, will greatly increase its beauty by the added vigor of growth of the trees, shrubs and grass, while flowers will yield much more satisfactory results in a soil made friable by underdrainage.

The vegetable garden should be especially well drained, so that plants shall not be checked in their growth during spells of wet weather. The prompt removal of excess of water in early spring is a distinct advantage, permitting, as it does, early planting, and producing a warm soil, an exceedingly important matter in gardening.

Orchards located in clay soils, or even in sandy loams underlaid with clay, become much more vigorous and fruitful when drained. Drains placed between the rows of the trees have a most salutary effect upon the soil during the year, and do not become obstructed by roots except in irrigated sections, as mentioned in Chapter XVII.

The increased firmness of the ground in drives and walks, and the quickness with which they dry off after a rain or thaw, are decided improvements resulting from drainage.

DRAINAGE FOR HEALTH

While one may defer drainage for the beautifying of the grounds, or even for the benefit of plant life, he should not delay putting his premises in the best possible sanitary condition by the construction of whatever drains are necessary to accomplish this result, since the health of his family may be seriously impaired by neglecting to do so.

Dry earth is one of the most effective absorbents and deodorizers known, and if the soil surrounding the farm buildings is kept as dry as possible, injurious gases, unwholesome liquids, and the products of decaying organic matter coming in contact with it are robbed of pernicious health-destroying qualities, and the atmosphere is kept pure and healthful.

The removal of all stagnant pools of water from the grounds and the adjoining farm lands eliminates the mosquito, both the malarial one and the more harmless but no less annoying species, provided the open rain-barrel and cistern have been abolished previously.

The soil about the house or barn surface wells should be so drained that the excess of surface and soil water will be intercepted and prevented from entering them. The unsightly and disagreeable pools of water near wells, caused by the overflow from watering troughs, may be easily prevented by connecting a suitable overflow pipe at the trough with a near-by tile drain.

DRAINAGE OF CELLARS

Cellars excavated in clay lands are rarely dry without artificial drainage, since they serve as drainage pits for the earth about them. The effort to prevent water from entering the cellar by the use of cement and concrete walls often fails, and in any event is more expensive than draining.

The method of removing water after it has been collected into a pit in the cellar does not dry it as satisfactorily as the method of intercepting the water before it enters the cellar. If attended to at the time the foundation walls are laid, drainage can be provided quite easily by placing a line of drain tile directly underneath the walls, as shown in *A*, Fig. 39. The tiles should be laid upon the clay, protected on the top by the material used in such a way that the weight of the wall will not rest upon them. The drain should be laid upon a grade of one-half inch per rod (three inches per hundred feet), the lines uniting in a main outside the building, and thence extended to a free outlet point, which should be either a larger tile drain or a suitable ditch. A similar drain placed outside the cellar wall, as shown in *B*,

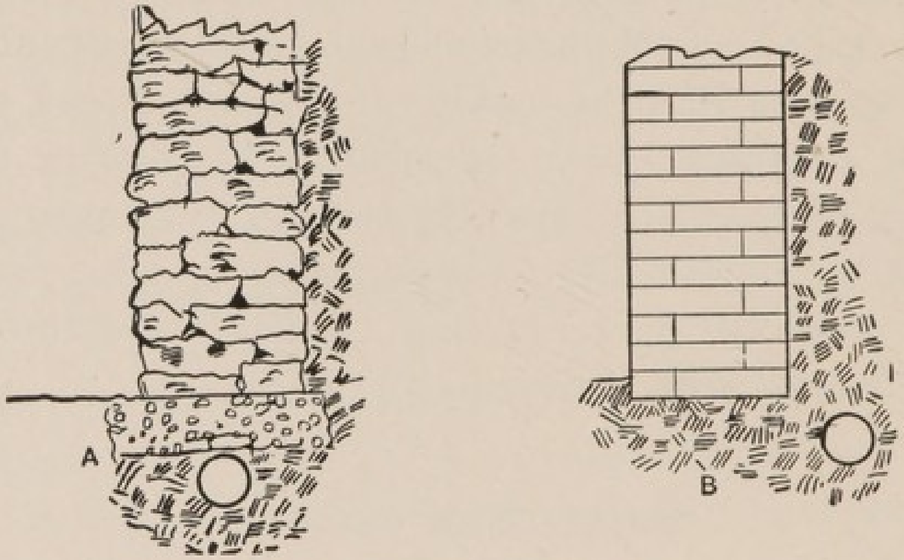

FIG. 39.—Drains for Cellars.

Fig. 39, is equally effective and can be made after the building has been completed. As in the case before described, the drain should be placed below the level of the cellar floor, so that outside water may be effectually intercepted. When buildings are placed upon land having a slope toward them, small springs or "seeps" on the up-hill side often make additional precautions necessary to keep the cellar dry. Such seeps should be sought out and the water from them collected in small underground pits filled with gravel, broken stone, or similar material, and connected with the drain which surrounds the cellar by a line of small tile or by an iron pipe. By the judicious use of such devices cellars may be kept effectually and permanently dry.

ROOF WATER FROM FARM BUILDINGS

Where water from any roof is not collected in cisterns, provision should be made to remove it by drains, so that it will not flood the yards and grounds adjoining the buildings. Each building should be provided with ample roof gutters or eaves-troughs, with down spouts which reach the ground. A tile drain laid four feet from the walls of the building, and about three and a half feet

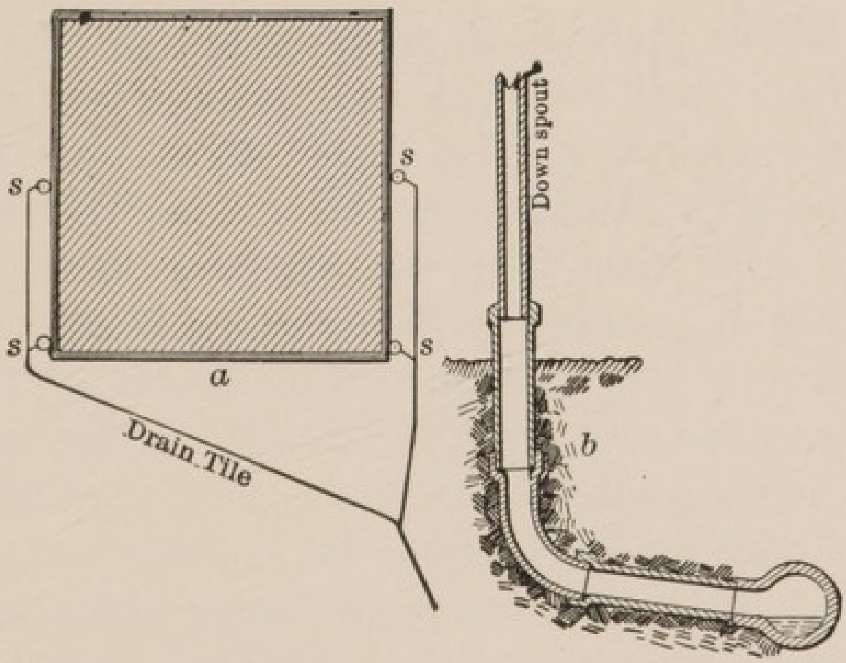

FIG. 40.—Tile Drain to Receive Roof Water from Barn.

deep, should be provided, and connected with an outlet as represented in *a*, in Fig. 40. For a large barn, the tiles should be eight inches in diameter, and nothing smaller than six inches should be used for any building. The pipes which connect each down spout with the drain should extend eight inches above the surface and be set close to the building. (See *b*, Fig. 40.)

The main drain for each building may be extended and connect with a farm tile drain in case a stream or open ditch channel is not available. The former is practicable and safe, because the water coming from the buildings will pass away through the main drain before water will reach it from the soil. A neglect to provide for roof water by underdrains results in needless inconvenience and annoyance from mud, especially where buildings are located on moderately level loam, or clay lands.

DRAINAGE OF STOCKYARDS

The above precautions taken to dispose of all roof water from such buildings and sheds as are grouped about the stockyards are of first importance in keeping the latter dry. Underdrains laid through such yards have no effect upon them, because the surface becomes so thoroughly puddled by the tramping of animals that no water will pass through it to the drains. They are, however, made to operate successfully by the construction of surface inlets to the drains located at favorable points. (See Fig. 31, Chapter IX.) Such inlets should be securely fenced so that animals cannot walk upon them and destroy their usefulness. Shallow open trenches made outside of the yard and so located as to prevent rainfall on surrounding land from flowing across it, will also be of great advantage in ameliorating the mud discomforts so common to barnyards.

DRAINAGE OF PASTURES

Well-drained pastures produce more nutritive grasses and are more healthful for live-stock, especially sheep and young cattle and horses, than those which are habitually wet. Paddocks, in particular, and small pastures within convenient distance of the barns should be so well drained that the surface will remain firm at all times. This may not be quite possible in northern climates when the frost is coming out of the ground in the spring, but even at that season well-drained pastures will become dry in much less time than undrained ones.

CHAPTER XV

ROAD DRAINAGE

THE use of underdrains in the construction and preservation of good roads is one of the applications of drainage whose value has for some years been more or less fully recognized by road-builders.

Earth roads are an important part of country improvements, and drainage is an essential factor in their construction and maintenance. There are three things which contribute to satisfactory results in the making of such roads. They are: a firm base, a crowning surface, and timely repairs. The attempt to obtain the first is often made by constructing an embankment of considerable height with earth procured by excavating deep ditches at each side. This plan usually results in a series of long pools, in the low or level sections, through which the road passes. These having no outlet, continue to saturate and soften the base of the road until the water evaporates. Under such conditions the embankment frequently flattens during the spring months, requiring additional earth to raise it to its original height. This is repeated each year, not only entailing much expense in making repairs, but subjecting the traveling public to hardship and inconvenience when the road is in unusually bad condition.

PROPER CONSTRUCTION OF EARTH ROADS

The best plan of making earth roads for either public or private use, where there are not deep open ditches belonging to an outlet system of an adjoining drainage district constructed along the roadside, may be described as follows: Make an embankment for the road by excavating a ditch on each side twelve to fourteen inches deep and of sufficient width to provide earth enough to make the embankment one foot high and of the desired width, twenty feet or even less being sufficient for country highways with only moderate travel. (Fig. 41.) Such

Fig. 41.—Section of Public Road with Underdrain.

ditches will be deep enough to collect the surface water and should be so sloped at the sides that a mowing machine may be used to cut the grass and weeds which grow in them. The road surface should be crowning, so that it will shed the water into the side ditches. Where it is desired to raise the road more than one foot above the natural surface, as through ponds or other depressions, the additional earth should be obtained from higher and more distant land, rather than by making the ditches deeper through the low land.

The roadside ditches should be supplemented by a line of drain tile laid about three feet deep along the inner edge of the road ditch, as shown in Fig. 41, at all sections where the road passes through low ground, or along the foot of slopes where the base of the road is liable to be made boggy or unstable by seep or spring water from the higher land. In most instances a drain on one side is sufficient, but occasionally drains should be placed on both sides, and in all cases they should extend to some good and sufficient outlet. For road service alone, the size of the tile should be not less than five inches in diameter, and if used both as a farm drain outlet and a road drain, as frequently is the case, the size should be determined as in other farm drainage. (See Chapter VII.) The tile drain laid in this position is four feet below the level of the land, and five feet below that of the road, and is equivalent to a roadside ditch four feet deep and so graded that the water will readily flow away. The soil beneath the road and the side open ditches is in its natural condition, and will permit the percolation of soil water, and consequent lowering of the water table as readily as will the cultivated field adjoining the road. This will keep the base of the road firm at all seasons of the year.

The perfect road surface, however, is entirely different. It becomes puddled from travel upon it when it is wet, and a crust is formed. This crust it is highly desirable to retain at all times, so that water falling upon the surface will pass off of, instead of through, the crust. To secure this end the surface should be shaped and smoothed after every considerable rain, by the use of the road drag.

It is perhaps needless to say that the thorough drainage of all land adjoining the public road would largely, though not entirely, obviate the necessity for roadside tile drains. Where this is done the farms and highways are more or less equally benefited, and it is customary and equitable for each to bear a part of the cost. The outlets of road drains are frequently dependent upon farm drains, without which road drainage could not well be perfected.

Farm roads may be easily made by back-furrowing the road track with a plow so as to make the surface

FIG. 42.—Section of Drained Farm Road.

slightly crowning. It then may be shaped and smoothed with a road drag. Where the land is level a line of drain tile four inches in diameter should be laid at the edge of the road as represented in Fig. 42, and connected with a farm outlet. If wagons with wide tires are used the road will remain in good condition with little care. This road occupies no land except the track used for travel.

CHAPTER XVI

SOME SPECIAL PROBLEMS IN DRAINAGE

Drainage has a much wider scope of usefulness than is generally supposed. Many difficulties encountered by farmers in the various sections of the country are surprisingly overcome by the judicious use of suitable drains. Each presents a different problem, requiring treatment according to the peculiar conditions existing, and the special needs of the situation.

DRAINAGE OF MUCK LANDS

Plans and instructions for drainage are usually based upon the theory that all water which will pass by gravity through the soil into drains may be safely removed, and that sufficient capillary water will be retained by the soil for the supply of plants. As a result clay and clay-loam soils are found less susceptible to drouth after drainage.

There are wet lands of quite a different class which are attracting more attention than formerly. They are the so-called muck lands, varying in composition from the black alluvial wash, with a good percentage of clay, to the light turfs of vegetable composition. Many hundred thousand acres of this kind of land are found in the United States, much of which, when drained, can, with the aid of suitable fertilizers, be put to a profitable use.

It requires draining, yet on account of its loose structure and small per cent of clay it parts with its moisture easily and may become too dry, this quality depending much upon its structural character and composition. Such soils may be drained with tile, provided there is a clay bottom in which they may be laid; otherwise only temporary open ditches can be employed, because such land will settle twenty-five to fifty per cent, effectually destroying the alignment of the tile. The same will be true of the gradient of open ditches. Ample provision should be made at the outlets for settling of both the surface of the land and the bottom of the ditches. It is observed that more ditches are required later than seem to be sufficient at first, for the reason that the soil continues to settle or shrink as the vegetable matter decays. It has been found of advantage to make movable drop gates at selected points in the ditches by which the water level of the soil can be controlled. These requirements need not be the same for all parts of the area, nor for all kinds of crops. It is also found that the lighter lands of this class respond satisfactorily to surface irrigation, so that the possibilities of such an improvement should be canvassed in connection with drainage.

Two classes of muck lands, distinguished as "clay-bottom" and "sand-bottom" mucks, are well recognized, while a third, called "marl-bottom" muck, is less common but more valuable than either of the others. When open ditches are excavated sufficiently deep to reach the sand or marl underlying the muck, no artificial underdrains are required, since the porous formation underneath will permit the ready percolation of soil water into the ditches. The clay-bottom mucks, while draining less readily, do not become dry too quickly, a common fault with the others, and when mixed with the underlying clay by subsoiling or other methods, they are supplied with an element which is highly beneficial.

Owing to the extremely variable character of these lands, it is impracticable here to do more than suggest a few points to be observed in their drainage. The open ditches should be not less than four feet deep, and may give satisfactory results if placed five hundred feet apart, especially if they penetrate the underlying sand or marl, and thus afford thorough underdrainage. Clay-bottom mucks may be tile-drained successfully if the tiles are laid in the underlying clay so that the shrinkage of the muck will not bring them too near the surface. Turf or mucks resting upon clay subsoils have been successfully drained for the production of hay by lines of tile three hundred feet apart. After the land became more compact, and it was desired to grow cultivated crops, lines of drains were placed between those first laid, making the final drains one hundred and fifty feet apart.

Preceding the attempts to drain such lands, they should be examined with special reference to the elements of fertility which they contain, and the crops to which they will be adapted when drained.

DRAINAGE TO PREVENT EROSION OF HILLSIDES

Farmers of the hilly portions of the Southern States encounter a difficulty peculiar to those regions. Owing to the steep slopes, the nature of the soil, which is a loose loam, and the excessive rainfalls to which this section of the country is subject, cultivated hillsides suffer greatly from surface washing, which carrying away soil and crops, cuts deep gullies in the fields from two to ten feet wide, and from five to ten feet deep. The crops at the foot of the slope are also injured by the floods of water and the deposits of sand.

As a protection against these destructive washouts, a system of terracing is quite universally practiced, which is, however, more or less superficially done. The aim in terracing should not be the detention of the water on the terraces, but simply its arrest and distribution sufficiently to lessen its force and spread it out so it will not cut channels. This is not always understood, and many attempt to prevent the erosion by turning a furrow with the plow, which leaves a ridge of dirt extending around the hill at intervals. This is often insufficient to check the water and allow it to percolate through the soil as should be the case. Instead, the water comes with such force that the ridge of dirt is swept away and the system becomes worthless. Terracing as done most effectually is quite different from this. The terraces are accurately constructed, the surface being made level, and then carefully seeded to grass, which is cut frequently but otherwise left undisturbed until the sod becomes firm. Water striking such a terrace spreads out over it and, with its force broken, flows gently and evenly on down over the slope below. By making the terraces wide enough to permit mowing with a machine, not only is there no waste of good land given over to weeds, as in the ridge terraces, but the grass forms a valuable crop, which can be cared for as expeditiously as on level land.

That underdrains will make terraces unnecessary in many instances has been ascertained. In 1903 an experiment was made under the direction of Drainage Investigations of the United States Department of Agriculture, to test the efficiency of tile drains in preventing the erosion of such lands, and if possible do away with terraces altogether. The place selected for the experiment was on a farm in Northern Georgia. It was a portion of a field which had been abandoned because of excessive erosion in spite of the best system of terracing. It had an average slope of one foot in ten, and the soil was a red sandy loam of good depth, with a firm clay subsoil. It had been observed that one cause of the great extent of damage seemed to be the condition of the soil at certain places, resulting from seepage water. Previously softened by this, the earth yielded readily to the action of surface water, and ditches or gullies soon resulted, down which the water flowed in torrents during heavy rains. In the experiment made, underdrains were laid in such a way as to intercept the seepage water and thus preserve the firmness of the soil. (Fig. 43.) These do not conduct all of the water away from the land, but permit an outflow through the joints of the drains. They thus serve not only to arrest the surface water, but to distribute and conserve it in the subsoil. The cost of the improvement in this experiment was $10 an acre for the land reclaimed, drain tile being difficult to procure and high in price. The gross receipts of the first crop on the land previously abandoned, however, paid the entire cost.

On this field the terraces are done away with altogether, the drains being sufficient to prevent the erosion, and this will often be possible. Even when this is not the case their use in conjunction with properly constructed terraces will never fail to prove highly beneficial. Too great care cannot be taken in the location and construction of such drains to meet the requirements of the particular locality, and thus secure a maximum degree of efficiency. The accompanying cut of the experiment

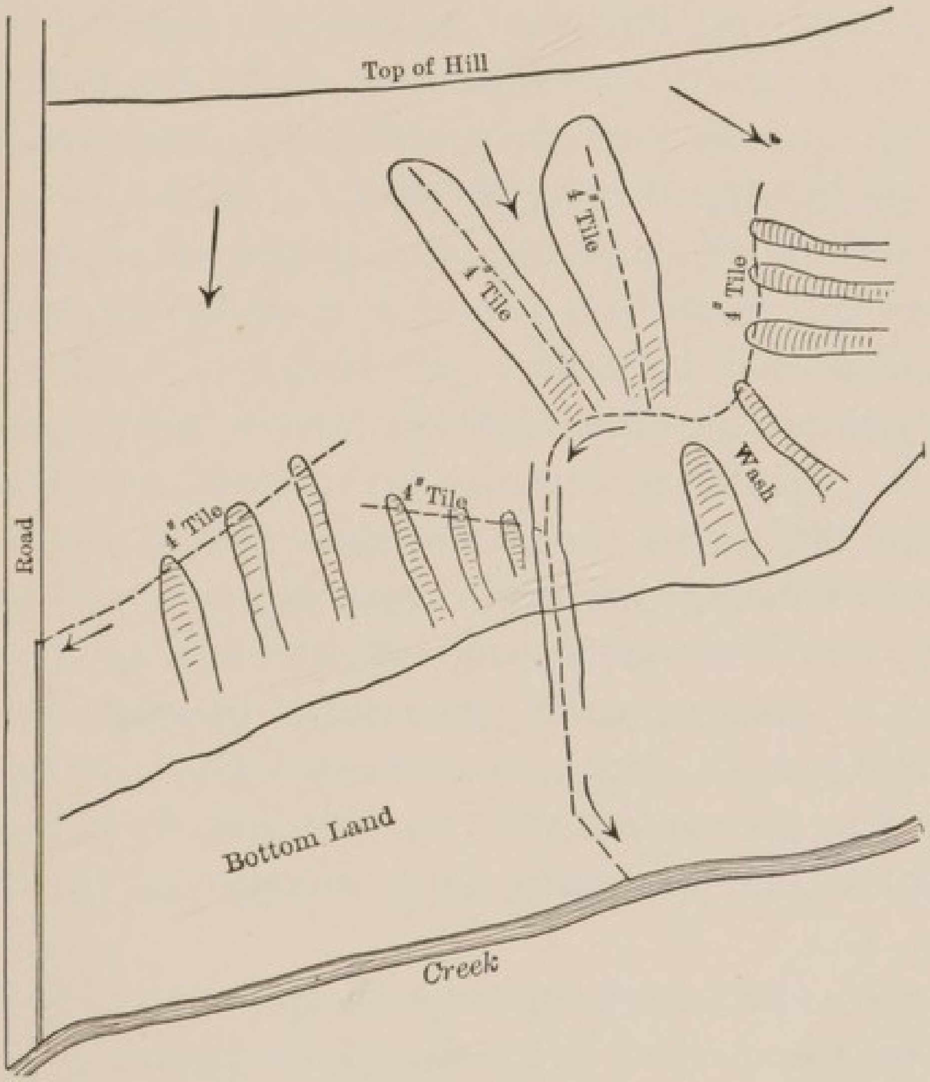

FIG. 43.—Tile Drains to Prevent Erosion of Hillsides.

referred to will show the method of locating the drains in this one instance, and will also serve to suggest the proper treatment in other cases. If, for any reason, drainage should not be feasible, terraces constructed as described above, where it is possible to maintain them will be found to facilitate greatly the cultivation of hill lands and increase the crop area.

DRAINAGE OF SALT MARSHES

Large areas of salt marsh land bordering the coast and along tidal rivers are subject to overflow during high tide, but are above the level of the sea at low tide. They frequently produce coarse grass, used for marsh hay, the quality varying much with the fertility of the land and the depth of the inundation to which it is daily subjected. More hay, and of a much better quality, is produced when the land is provided with ditches which will facilitate the outflow of the water as soon as the tide recedes. The crop can also be removed more cheaply because the ground is rendered more firm by the ditches. The surroundings are made more agreeable and healthful by the removal of pools of stagnant water, which afford favorable breeding places for mosquitoes. The collecting of all surface water into ditches, where it is subject to the movement of the tide, and the presence of small fishes quite effectually destroy the coast-land mosquito.

Such lands have been successfully protected from the sea by dikes, then drained and converted into fields suitable for cultivation. This is a work, however, which requires the services of an engineer with judgment and skill, and who has a knowledge of dike-building and draining. And it should also be understood that, after the necessary works have been completed and the land reclaimed, constant watchfulness and timely repairs are required to preserve the protecting banks and maintain the operation of the drains and sluices. For these reasons the treatment of this subject here will be restricted to an outline of the methods employed and the kind of work required, for the purpose of bringing the general features of such reclamation to the attention of farmers owning such lands, and of emphasizing the necessity of employing a competent engineer to direct the execution of main works.

Selecting the land and locating the dikes are the first matters for consideration. The land selected for reclamation should have a soil that, when drained and the excess of salt removed, will be fertile. It should be near good markets, because the expense of thoroughly reclaiming it will necessitate high-class management and remunerative crops. If two or more owners are concerned in the construction and maintenance of the dike, a legal agreement between the parties should be entered into, which will provide for sharing the cost and for efficient and continued maintenance of the dike and sluices. The dike should be located far enough from the sea to permit the outlet ditches when made three and a half feet deep to discharge freely and completely at low tide.

The dike and its construction should receive the most careful attention. This fact is emphasized by the numerous failures heretofore made in building dikes, or banks, as they are frequently called. The prevalence of storms which force the waves at times much higher than the tide, and the constant wave action, which is more serious at some points than at others, make high and strong dikes imperative. Just how strong and how high they should be made are matters for the skilled engineer to determine after he has carefully examined the locality and has become thoroughly conversant with the difficulties to be encountered. The factors to be taken into account in the construction are: the kind of material, the outside slope of the bank and its protection from wave erosion, the top width, and the height required to prevent overtopping of the levee during storms.

Sluices and gates are required to permit the outflow of rainfall and seepage water from the enclosed fields which can take place only upon a receding tide. Sluices are structures set in the dike and furnished with a swinging valve or gate at the outer end, which closes against the entrance of the sea water as the tide rises, and opens for the outflow of drainage water as the tide recedes. They must, like the dike, be made secure against the action of the waves.

Interior ditches to properly drain the land consist of a main and laterals. The main channel should extend from a gate back through the land, and not only provides an outlet for the drainage water, but affords storage for it when the sluice gate is closed. All lateral ditches should discharge into it, thus making the entire ditch system serve as a reservoir for surplus rainfall during the time that the high tide prevents the discharge of the main channel through the sluice and gate. Its reservoir capacity should be such that the water-table of the soil will not come nearer to the surface than fifteen inches.

Before the height of the dike or the plans for the ditch system can be intelligently decided upon, a fairly definite knowledge of the probable future shrinkage of the soil should be obtained. This latter is due to the removal of the water and the decay of the roots, and not uncommonly amounts to eighteen inches in the course of six years. Unless provision is made for it, the ditches may be found too shallow and the dike too low by the time the land is fully reclaimed and prepared for profitable cropping.

Freeing the land from salt is the final step in the reclamation of salt marshes. This is accomplished by the combined action of the ordinary rainfall and the drainage system, the former dissolving the salt in the soil, and the latter promptly conveying the solution to the sea. Usually not less than two years of this leaching process will be required before it will be wise to attempt a crop. In the mean time the ground may be pastured and the washing out of the salt will proceed more rapidly under that treatment than if marsh grass were allowed to mature. The first crop or two will show the effect of the salt, so that what are known as salt-resistant crops, such as sorghum or rye, should be first planted. The cost of reclaiming salt marshes may easily reach $50 or $75 an acre, which emphasizes the statement previously made that the work, when attempted, should be planned wisely and executed under the most careful supervision.

DRAINAGE FOR ALKALI LANDS IN HUMID SECTIONS

Alkali is found troublesome in some prairie lands, usually in limited areas, but occasionally in quite extensive tracts. Such spots are particularly noticeable in the valleys of the Missouri River and the Red River of the North, where several large areas are injuriously affected by alkali. These tracts are characterized by deficient natural drainage, and the alkali is more abundant at the close of a wet season, during which stagnant water has evaporated from the surface in considerable quantities. It is then very pronounced in appearance, lying upon the surface as a white powder or in white crystals, and may further be known by its disagreeable taste. What is known as black alkali is occasionally found on land where other kinds are present. It is even more injurious to plants than the others, and may be recognized by its corrosive and biting effect upon the tongue when tasted.

Alkaline salts are present in the soil in its natural state, and are brought to the surface in solution, there remaining as solids when the water has passed away in evaporation. They may be removed by whatever ordinary drains are found necessary to make the land dry and tillable. Rainfall dissolves the alkali, and when in solution it should be removed by either surface or underdrains as quickly as possible. In this way an excess of water may be made to serve an excellent purpose in freeing the land of alkali, if ample drainage be provided. The process may be hastened by thorough cultivation of the ground, and by planting a cover crop, like sorghum, rye, or oats, as soon as it will grow. Alkali and its effects are discussed more fully in the next chapter, in connection with its appearance on irrigated land.

DRAINAGE OF RIVER AND CREEK BOTTOM-LAND

Farmers not uncommonly own land through which a river or creek passes, and the soil upon one or both sides of the stream is often exceedingly fertile. These rich bottom-lands may be periodically overflowed to such an extent that they are used only for pasture or meadow. Their protection and drainage are desirable, since it will permit their cultivation and greatly increased profitableness. While the planning and direction of river systems should usually be given over to the engineer, the farmer whose land borders small streams may often improve it very materially by carrying out the few suggestions which follow.

The channel of the stream may sometimes be easily improved by cutting across a short bend, and nearly always by clearing the banks of weeds or brush or low, overhanging branches so that the carrying capacity of the channel may be substantially increased, thus lessening the amount of overflow at flood times.

If the land is subject to frequent and serious overflows it is necessary to build a levee or dike fully to prevent injury. The levee should parallel the bank of the stream and be set far enough away from it to permit all of the earth required for its construction to be taken from the stream side and leave not less than twenty feet between the bank of the stream and the outer edge of the borrow pits from which the earth is taken, and a berme of ten feet between the inner edge of the pits and the outer base of the levee. This will bring the levee at least forty or fifty feet from the bank of the stream, and in large rivers, subject to high floods, it may be necessary to construct it at a distance of several hundred feet from the bank. Levees for streams of this size, however, should be built under the direction of a competent engineer.

The ground upon which the farmer is to construct his levee should be cleared thoroughly of all grass and trees and then be well plowed in order to make a good union between the natural earth and the levee. If the soil is sandy or permeable to water, a trench, called a "muck ditch," should be excavated three feet deep and not less than two feet wide along the center line of, and beneath the levee and filled with clean earth or clay, the more impervious to water the better. This will destroy all natural crevices or seams in the ground, and prevent seepage of water underneath the levee. The latter should have side slopes of one and a half to one, and should be built of earth entirely free from roots and rubbish, two feet higher than the usual flood reaches. A top width of three feet is considered sufficient for small levees which are to protect lands from floods of short duration. The levee at the ends should extend back from the stream to some point of high land in such a way that the field will be entirely protected.

Since the low land has been practically enclosed by a solid levee and all natural drainage channels have been cut off, sluice gates must be provided at places which, before the levee was made, served to drain the land. These are wooden boxes, cast-iron pipes, or sewer pipes which extend through the levee to convey drainage water off the field into the stream as soon as the high water recedes. The sluices are furnished with valves or gates which close during the time of high water in the stream and open when the water recedes, remaining in this position until a rise in the stream again occurs. These gates are similar in construction and operation to the one described in Chapter IX and illustrated in Fig. 33, but should be considerably larger.

These suggestions are offered more to caution the farmer to undertake such work advisedly and with an understanding of the precautions necessary and the principles involved, rather than to give specific instructions for levee-building. A good drainage engineer should usually be consulted regarding the location and construction of works of this kind.

Should the lands be subject to but slight overflows of short duration, the thorough drainage of them by the usual method will greatly hasten the drying of the soil as soon as the water recedes.

CHAPTER XVII

DRAINAGE OF IRRIGATED LAND

THE only need of most of the arid lands of the Far West to make them productive is an ample supply of water. The soil of these lands contains a plentiful store of fertility, which, however, remains latent under existing climatic conditions, the scant rainfall not affording sufficient moisture. When water is skilfully distributed upon such land there is a quick response in large crops, and what was formerly a barren desert becomes transformed into productive fields of great value.

IRRIGATION

The process of irrigation consists in diverting the water of some accessible stream in such a way that at regular intervals it may be led to flow over the land, thus providing the needed moisture. This is accomplished by the erection of a dam across the stream and the construction of a canal which leaves the stream at a point above the dam and conducts the water to the land to be supplied, which may be a number of miles distant. This supply canal, upon reaching the area to be irrigated, passes along its upper side, permitting the water from it to be conveyed down the slope, across the land, in lateral ditches constructed for the purpose, and extending to the several farms within the territory. Each farmer provides for the proper distribution of the water over his farm by means of shallow ditches, or furrows, so arranged as to best accomplish the desired end. The movement of the water is regulated by gates, and the amount given to each land-owner is governed by rules contained in the agreement entered into between him and the company controlling the supply and owning the canal.

When wild arid land is first prepared for cultivation by irrigating, a large quantity of water is required to wet the soil sufficiently to grow crops. The dry atmosphere causes the evaporation of a considerable volume of it, while the earth, being wholly devoid of moisture to a depth of twenty or thirty feet or more, absorbs it rapidly, so that it is practically impossible at first to apply a quantity of water sufficiently large to be injurious. The extreme dryness of the lower strata converts them into an immense reservoir into which the water rapidly descends. Thus it has happened that water to a depth of twelve, and even sixteen, feet over the entire area under irrigation has been applied in a single season when a depth not exceeding four feet was sufficient for the needs of the crops. The rest was either lost by evaporation, or passed into the lower soil, there to remain. Each irrigation, of course, increased this accumulation, but so ample was the underground reservoir that for years it seemed to provide ideal drainage.

INJURIOUS EFFECTS OBSERVED

After a time in many of the older irrigated sections of the Far West, swamps, swales and bogs suddenly appeared in hitherto attractive and profitable farms. Their formation had been gradual and hidden from view, and often the farmer was entirely unaware of their presence until the land was seriously injured or, in some instances, rendered useless. In other localities there appeared upon the ground, without warning, accumulations of various alkaline salts which were destructive to the crops, and whose evil effects spread consternation among the farmers. The alkali usually found consists of one or two, and sometimes all, of the following salts: sodium chloride (common salt), sodium sulfate (Glauber's salts), magnesium sulfate (Epsom salts), and sodium carbonate (common soda), usually called "black alkali." They are all harmful to plants in their concentrated form, though not in the same degree.

The cause of these alarming conditions on irrigated land was not difficult to discover, and is not hard to understand. They are all the result of excess of water; but not, as at first thought might seem probable, of the water applied directly to the land in the process of irrigation, but that which has seeped through from higher irrigated land, or the leakage of supply canals.

THE FORMATION OF BOGS

The water carried into the lower strata because of their extreme dryness, passes downward through the porous earth until its course is arrested by some hard stratum, like clay or hardpan, which in the West resembles rock more nearly than clay. It then moves along the slope to a lower level with less slope, where it is retarded and begins to fill the soil from the bottom up as in a reservoir. This rises year by year until the surface is reached and a bog or swamp is the result. Such water is known as *seepage water*, and land injured by it is called *seeped land*. The layers of hardpan not always following the contour of the surface causes the water to ooze out on the hillside, or to appear at other unexpected points. With these exceptions the water rises from the lower soil a little each year, the surface, of course, being the last to become saturated. It will then be found that in some kinds of land the entire subsoil is an unstable mass of earth, completely filled with water, and in many instances the surface is covered with alkali. In other localities tule ponds have formed which retain water upon the surface during a large part of the season. The level of the water, both before and after it appears upon the surface, naturally fluctuates, rising higher through the irrigating season, and falling through the winter.

ALKALI CONDITIONS

Alkali often appears upon land before it becomes excessively wet, but its presence is always an indication that the water-table is approaching dangerously near the surface. Alkaline salts are present in the soil in a distributed condition, as are the elements of plant food. These salts dissolve readily in the water of the soil, the greater the excess of water the larger the quantity of alkali held in solution. When the water comes sufficiently near the surface to saturate the soil by capillarity, it is carried off by evaporation, leaving the salts it contained either upon or quite near the surface. A continuation of this process results in the accumulation of a large amount of alkali, and the consequent destruction of crops.

Before the land becomes saturated to the surface, resulting either in swamps or in alkali deposits, it not infrequently appears to have reached a most desirable state, when little or no irrigation is required. The reason of this is that the plane of saturation has approached sufficiently near the roots so that capillarity supplies all the moisture needed by the crops, while the alkali has not yet reached the point of injuring them. This favorable condition often continues two or three years before the land becomes too wet or the alkali appears. Sometimes the land does not become entirely useless, but salt grass takes the place of alfalfa, fruit orchards, or cereals, enabling the owner to use the land for grazing. Where there is no alkali, shallow-rooted grasses take the place of crops with deeper root habits, but large areas of irrigated land have become utterly waste ground.

DRAINAGE THE REMEDY

It may be logically inferred that underdraining will prevent the evil effects described, and also restore seeped land to its original productiveness, and this has been proved in practice. Where surplus or free water is promptly removed from the soil, those conditions which produce large amounts of injurious salts in solution are wanting, and there is no danger of their concentration at the surface, for the salts remain in their natural distributed condition.

Proper drains will keep the water-table four or five feet below the surface and prevent the formation of swamps and bogs on land for which costly water rights have been obtained. It is always wise to take preventive measures, or, when these have been neglected, promptly to employ the necessary drainage that shall redeem the land from the sway of the alkaline water.

METHOD OF DRAINING

As before stated, the water which causes the unwholesome conditions of irrigated land is not that which is distributed upon it during irrigation, but that which seeps through the soil, perhaps from a considerable distance and at quite a depth, and appears upon lands lying at lower levels. The attempt to drain such lands by the methods commonly employed in the humid sections for removing the surplus rainfall has not proved efficient. The water comes from the bottom under a constant head, by reason of the higher position of its source in the irrigated land above or in the canal. The supply is constant during the irrigating season, so that the soil is not permitted to dry out periodically, as it is where the supply comes from rainfall. Under these conditions, the principle discovered by Joseph Elkington, of England, over one hundred years ago, and successfully put in practice by him in many parts of the United Kingdom and in Sweden, should be applied. It is, in brief, the interception and removal of the water causing the wet land before it reaches it.

As a means of accomplishing this, two provisions are made. First, the construction of deep intercepting ditches between the source of the water and the wet land, thus cutting off the water delivered upon the latter through porous saturated earth adjoining; and second, the supplementing of these by auger holes, pits, or wells, sunk deep enough to penetrate lower supplies of water which are pressing upon the earth above them. Such wells furnish a means for the water to rise readily and pass off through the drains.

There are two sources from which the water that does injury to irrigated land comes. It comes either from the supply canal directly, because of leakage, or from irrigated lands on a higher level, by seepage, and these conditions are met by a difference of treatment. Some lands are affected by water from both sources.

When it is **leakage from the supply canal** a ditch constructed parallel to the canal and sufficiently deep to

FIG. 44.—Drain to Intercept Leakage from an Irrigation Canal.

intercept the underflow which generally comes through gravel, shale, or other porous material will usually dry the entire stretch of land below it. It should be distant one hundred feet or more from the canal, if the earth is very permeable, and should be continued to a point where leakage from the canal is no longer troublesome. The water may then be discharged into an irrigation ditch, and made available as a supply. Fig. 44 shows a drainage ditch which successfully intercepts the leakage from an irrigation canal in Colorado and dries a valley which had become boggy and unproductive.

It may occur to some one that if the supply canal were lined or in some way made watertight, the possibility of injury to the land from that source would be obviated. However desirable this may appear to the land-owners, the increased cost of construction does not make it seem practicable from the standpoint of the proprietors of the canal, and in lieu of this, water-users must take other methods to protect their land, since they cannot afford to have it ruined if possible to prevent it at reasonable cost.

When **seepage from higher irrigated land** is the cause of the injury, a similar intercepting drain is required as the first means of restoring the seeped land to dryness. This cut-off drain should be located so as to skirt the upper border of the saturated land, and should usually be about seventy-five feet down the slope from the line where saturation appears. Its proper depth is the most difficult part of the plan to determine. The soil water moves down the slope through crevices, along hardpan layers, or as a volume distributed through the earth. It is desirable to locate the drain as deep as the lowest water supply, a matter which can be determined only by careful observations and test borings. Unless the first ditch is deep enough to intercept the flow, a second one, parallel to the first, will be required. The gradient should be as uniform as practicable, and not less than .3 per cent; but since the position of the water-bearing strata largely determines the depth at which the drain should be placed, the grades cannot always be as uniform as desirable.

It may be observed here that intercepting drains are laid across the slopes and serve their purpose by breaking the pressure head of the underground flow, thus diverting the greater volume of free water before it reaches the lower land. Such drains do not intercept all the water, but the land being otherwise dry and requiring irrigation, may receive, and is able to care for, a certain amount of water which may pass the drains without injuring it. The location of intercepting or cut-off drains is illustrated in Fig. 45.

While such drains frequently dry the land and restore it to productiveness, unless it has become charged with

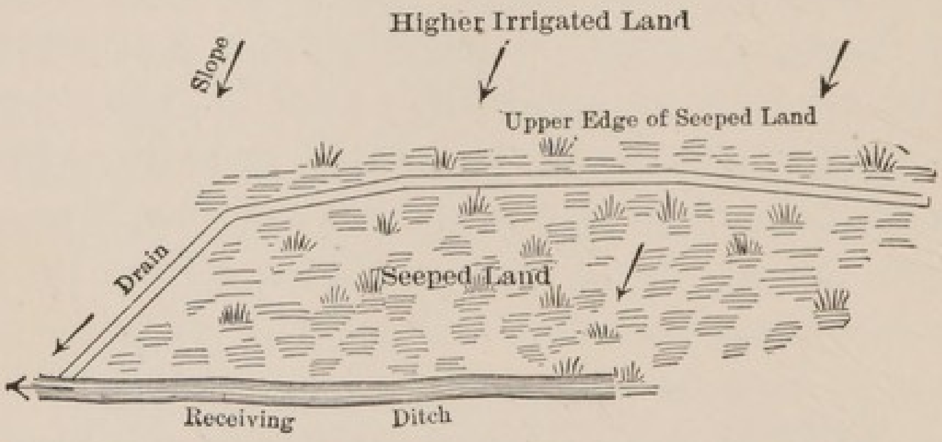

FIG. 45.—Location of Intercepting Drain in Seeped Land.

alkali, in which case it should receive treatment for the removal of the latter, it is frequently necessary to lay some drains through the lower depressions to relieve these from surplus water supplied by irrigation. They are especially needed where the cut-off drains do not intercept a sufficient volume of outside water to dry the land thoroughly. Such ditches should not be less than four and a half feet deep.

When the intercepting ditch is not sufficiently deep to reach the water-bearing stratum, it may be supplemented by small wells placed on the upper side of the ditch, and sunk deep enough to tap the water supply, which may be ten feet below the surface. The wells should be connected with the ditch by tile pipes or other covered drain, through which the water will flow from the wells as fast as it rises to the level of the outlet. The relation of well, connecting pipe, and receiving drain is shown in Fig. 46. This plan is particularly effective in locations where the under stratum contains sand or gravel, but has also proved helpful where the earth is loam throughout the entire depth. The wells should be placed from one hundred to three hundred feet apart, the latter distance having given good results in several

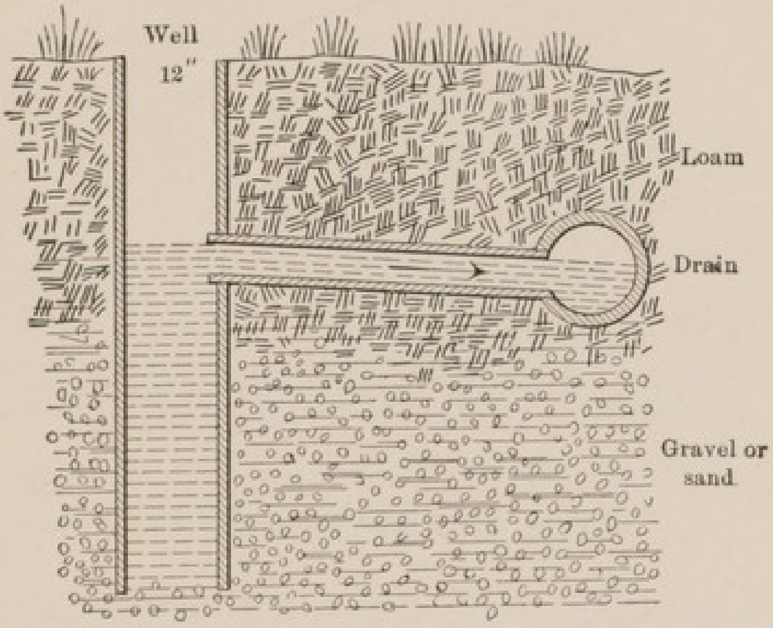

FIG. 46.—Well and Drain for Irrigated Land.

instances. They are commonly made by excavating a pit so that a curbing three feet or four feet square, made of plank two inches thick, can be sunk as deep as necessary to reach the water. This work is identical with that required in sinking an ordinary surface well. A row of such wells may be made along the upper edge of the wet land, and each one connected with a covered drain laid four feet below the surface, thus obviating the necessity of an open ditch.

Since the water which makes the drainage of an irrigated field necessary comes from an area wholly outside the tract requiring drainage, the quantity of water to be removed depends upon the size of this area. It may be, in some instances, the waste from a large territory, and in others from a small field. It is not the size of the wet tract that measures the volume of water that must be removed, but the area of land occupying the higher level adjoining it, together with the openness of its soil. This amount is sometimes as great as one cubic foot per second for each one hundred and sixty acres of irrigated fields above the wet section, while in other locations it may be the same volume for six hundred and forty acres. It is exceedingly variable, reaching in some cases to nearly one-half of the water applied in irrigation, in some of the older irrigated sections where the entire lower depths of the land have become filled with water.

KIND AND SIZE OF DRAINS

Any of the kinds of drains described for use in humid sections may be employed for draining irrigated land, but great care is required in the adaptation of the several kinds to the peculiarities of the soil in which they are to be used. Drains must be made from four to seven feet deep to be effective. The soil at such depths is often unstable, and any kind of drain is difficult to make and maintain. If the open ditch can be maintained at the depth required, it is usually effective. Drain tiles may be used where the bed upon which they are laid is firm. In other places box drains like those described in Chapter III (Fig. 9) are better.

Owing to the manner in which drains for irrigated land must be located, and the office which they perform, the sizes of nearly all drains should be large, corresponding to mains used in draining humid land. Tiles should be six-inch, eight-inch, and ten-inch, nothing smaller than five-inch being permissible ever, and box drains not less than six by six, while ten by twelve, and often twelve by twenty, inside measurement, are used.

When covered drains are employed in loose soils, it is difficult to pack the earth returned to the trenches sufficiently close to prevent water applied to irrigate the field from entering the drains too freely. If one or two intercepting drains prove sufficient, the inconvenience is not as serious as when drains are placed in the interior of the wet field. To reduce this difficulty to a minimum, the excavated earth should be packed as hard as possible as it is returned to the trench, and when the field is irrigated the course of the ditch should be watched constantly and the water turned away as soon as the top of the excavated earth becomes wet.

OBSTRUCTION OF DRAINS BY ROOTS

There is much more danger of stoppage of covered drains by roots in irrigated land than in that watered by rainfall, especially in the very open soils, or where for some reason the drains are shallow. In such soils it has been found necessary to make manholes at intervals of five hundred feet along the line so that the lines may be cleaned by brushes devised for the purpose. This precaution is especially necessary in land growing vines and trees. The root-cutter or brush, which it is necessary to pass through the drain two or three times each season, is made by covering a cylinder of wood, one foot long and of a diameter suited to the drain to be cleaned, with a leather sheath through which sharp-pointed nails, three inches long, have been driven. The brush is drawn back and forth through the pipe by means of a wire to which a horse is attached. One roller at the bottom of the manhole and another at the top guide the wire as the horse pulls the brush. Roots of sugar beets and of alfalfa not infrequently grow into tile drains in injurious quantities. For these, as well as other reasons, it is essential that drains in irrigated land be carefully located, laid deep, and be as few in number as possible consistent with efficiency.

DRAINING SHOULD NOT BE DELAYED

The great variety of conditions found in irrigated land and the peculiar difficulties encountered in draining it preclude the treatment of special cases in this brief treatise. It should be said, however, that some kinds of soil are exceedingly difficult to drain after they have become fully and permanently saturated. Fields should be watched closely for the first indications of permanent saturation, which, when seen, should be forestalled by promptly constructing a drain in the proper place. This precautionary measure may obviate all future difficulty.

The injurious alkali which so frequently accompanies the seeping of land is a potent incentive to timely and careful draining. A chemical analysis of the soil before it has received its first irrigation may not disclose any hint of a need of drainage which will later appear. Alkali and saturation are evils which develop with time, and are most insidious in their progress.

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