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Experiment Station

Drainage and Irrigation

The Drainage of "White Land" and Other Wet Lands in Oregon

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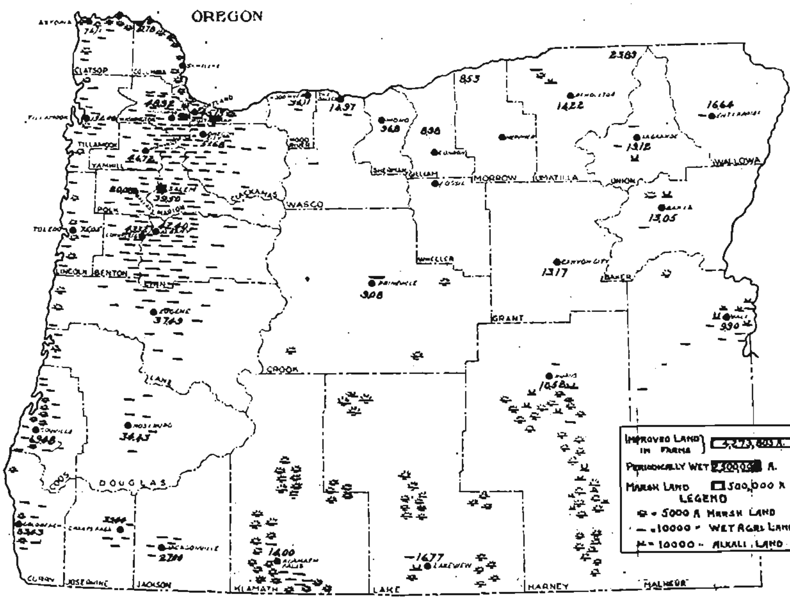

Figure 1. Frontispiece—Amount and Distribution of Wet Land and of Precipitation in Oregon.

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SUMMARY

1. This bulletin describes experiments to determine the most suitable depth, distance apart, and size for field drains in white land, and also gives information regarding the drainage situation in Oregon in general.

2. There is in the state, a great variety of wet lands of which three classes are easily chief; namely, white land, marsh land, and alkali land. Drainage of much of this wet area appears to be feasible, as good quantities of plant food and friable layers have been found therein.

3. The aim in drainage should be to get the most drainage at the least cost and secure the highest possible efficiency for every hundred feet of tile employed.

4. Subsoils are more important than surface soils in determining drainage qualities of land. A study should be made of subsoil and ground water conditions and the drains so located as to encounter excess water in the most porous layers.

5. Studies of subsoil and ground water in white land generally show a friable streak at 33 to 36 inches depth and show also that tile placed in these areas have lowered the water table most promptly. The water table is lowered for 25 to 30 inches back from the tile within twenty-four hours after saturation.

6. A depth of 33 to 36 inches has been found most effective for lateral drains in typical white land, while deeper drains are desirable in the less retentive areas.

7. An interval of 60 to 66 feet between laterals affords the most practical drainage for typical white land under present conditions and this distance may be increased in less retentive phases of this soil.

8. Measurements of outflow indicate that main drains should have a capacity of one-half acre inch runoff to the acre in twenty-four hours for areas up to forty acres and one-third inch for larger fields. The total and percentage runoff in the Willamette Valley is large.

9. Since drainage is costly and white land subsurface is retentive, farm operations should aim to aid water in entering the tile. When drained fields are in clover, a larger outflow from tile and less surface water have been observed, and the structure and fertility of the land gradually improves.

10. Reports from farmers having over one hundred miles of tile in operation in the white land and other wet land in this valley, show that tiling has generally been successful here.

11. The tendency is toward larger tile in place of small open ditches. A combination of tile with a surface run is good practice.

12. Nature has determined the general location of ditches, and the size of the natural channel is an index to the required capacity. The grade should be low enough to receive the discharge from all laterals.

13. Careful construction will return good interest by lessening maintenance fees.

14. The *farmer* should study subsoil and ground water conditions in wet areas and then view out a full system of drains with the aid of a level, if necessary. The system may be installed in units, the most necessary parts first, but it is best to order tile in car lots. The farmer should make a study of drainage so he can superintend and inspect his own work. He should sketch the tile lines installed and note results, extending the system as needed.

15. The *community* needing an outlet ditch should secure preliminary topographic and soil surveys to learn the feasibility and extent of the proposed outlet system. If feasible, a petition for a drainage district should be prepared according to the State law and presented to the county court. The district officers then secure a plan and estimate, after which the court appoints three viewers to assess costs in proportion to benefits received. The district officers secure bids and let contracts for construction of ditches. The drain tax may be paid in installments which return in increased crops.

ACKNOWLEDGMENTS

Experiments herein described were carried on under direct charge of the major author the past several years, and under the general direction of Prof. H. D. Scudder. Helpful suggestions regarding the arrangement have been given by Prof. J. E. Larson.

Valuable assistance has been rendered in arranging sketches by advanced drainage students; namely, A. E. Engbreitson, Leo Laythe, F. L. Ballard, V. E. Currey, and Claire Wilkes.

Figures 18, 39 and 40 were kindly furnished by the Oregon Bureau of Mines and Geology, Figure 16 by Wisconsin Experiment Station, Figure 36 by R. B. Magruder and Figures 2, 3, 4, 19, 20, 26 and 32 by Professor Scudder.

Helpful suggestions have been received from the Director and other members of the Station staff.

To all these persons the authors extend their sincere appreciation.

THE DRAINAGE OF WHITE LAND AND OTHER WET LANDS IN OREGON

By W. L. Powers, Professor of Drainage and Irrigation

Introduction

No other state offers a greater variety of drainage problems than Oregon. There are about half a million acres of marsh land to be reclaimed on the coast, in the lake counties, and along the Lower Columbia and other streams. There are seeped lands in the hills of Western Oregon and in the irrigated valleys of Eastern Oregon, and there are alkaline lands both under irrigation and in the virgin state which it is feasible to reclaim at present. There are perhaps two million acres of wet land in the Willamette Valley and other valleys of Western Oregon that will be greatly improved by under drainage. In this valley in early spring, thousands of acres of land are too wet to work and in late summer the same lands are baked, parched, and bear only one-half the crop that they could be made to yield by drainage. Altogether, there are at least three million acres of wet land in this state that can be reclaimed or greatly improved by drainage. This is an area larger than that reclaimable by irrigation in Oregon; an area equal to one-fourth of the total land in farms, or three-fifths of the improved land in farms, in the state, as given by the last census. Few people realize the great importance of drainage in the development of the farm lands of Oregon. The increased production, based on an increase in crop returns of $10 an acre, due to drainage would add thirty million dollars to the annual agricultural production, and over $100,000,000 to the permanent land value of the state. Drainage of our wet lands will become of increased importance with more intensive development of the agricultural resources and increase in the intrinsic value of the surrounding naturally drained upland.

The first tile drains laid in Oregon were placed about forty years ago in the vicinity of Scholls and are still working. The practice of drainage has spread until we now have records of over two hundred miles of tile drains in Oregon, about ninety-eight percent of which are in successful operation. The Oregon Experiment Station has been a consistent advocate of farm drainage and has conducted experiments, published articles, and given assistance to farmers in laying out their drain systems. A State Drainage Association has been organized and a modern District Drainage Law secured, so that recently the use of tile for farm drainage has rapidly increased. The Experiment Station, in cooperation with the U. S. Division of Drainage Investigations, has made soil and topographic surveys of forty thousand acres included in proposed projects the past year. Numerous drainage districts are being organized.

Lands needing drainage in Oregon are generally well supplied with plant food and are mostly located where there is a remarkably long growing season.

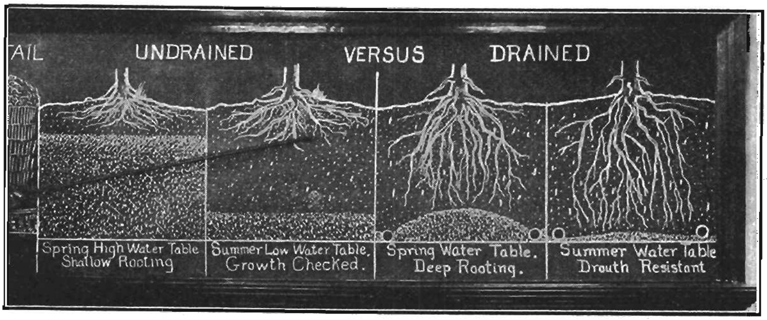


Figure 2. Drainage Permits Development of Deep-rooted, Drought-resistant Plants.

They are generally within reach of market and transportation and free from timber or rock. It is believed that much of this wet land will now pay a better rate of interest on the total investment if drained, and the time seems ripe for extensive drainage development.

The aim in designing a drain system should be to get the most drainage at the least possible cost and secure the highest possible efficiency for each hundred feet of tile employed. This bulletin is written to describe what has been accomplished by drainage in this state, to point out the best methods to follow as indicated by experiment and experience, and to advise and encourage the increasing numbers seeking information along the line of field and district drainage.

SECTION I. FIELD DRAINAGE

SOILS AND SOIL WATER AS RELATED TO DRAINAGE

Wet Soils. Soil and water are the two substances which we deal with primarily in drainage. The soil is composed of minute particles, irregular in shape and size. Under field conditions, the particles are usually surrounded with moisture films. The empty spaces between the soil particles connect, forming irregular channels. In wet soils, the materials are massed with the finer particles filtered in between the coarser ones, causing a minimum amount of pore space for air or usable moisture and producing an arrangement like cement. In well-drained soil, the particles are arranged in clusters with empty spaces between the clusters, permitting a maximum amount of usable moisture and air to be stored with the soil. The arrangement of a soil in good tilth is more like popcorn after it is coated with molasses and worked into balls.

Subsoils are more important, from a drainage standpoint, than are surface soils. Subsoils are usually finer in texture; and hardpan, shale ridges, or other impervious strata are apt to occur, which cause ponding and interfere

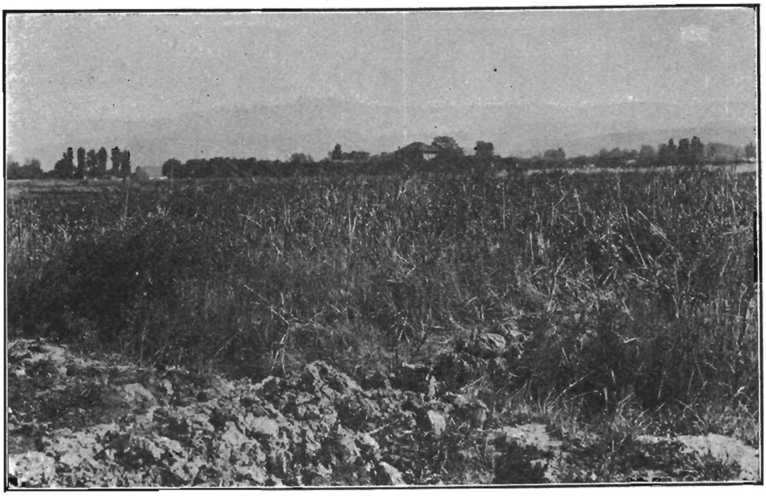


Figure 3. Marshy Land, Union Experiment Station, Before Drainage.

with the movement of free water through the soil. Fine-grained, impervious soils are more difficult to drain, due to hard layers through which the water will not move as fast as it is received. Sandy or gravelly layers in the subsoil offer channels through which seepage water will move and in which drains may be placed to collect excess water. The chief wet soils of the state are: the marsh, alkali, and white land.

"White land" is the local name applied to the most important wet soil type in the State. It occurs chiefly in flat prairies of the Willamette Valley and is used for pasture or oats. Sorrel, tar weed, velvet grass, and dog fennel thrive on the wet areas of this type. Physical analyses class this soil as silty clay loam. Physical Analyses of White Land made by Prof. C. V. Ruzek at the College are given below.

TABLE I. PHYSICAL COMPOSITION OF WHITE LAND FROM DRAINAGE PLOTS

Soil Sample	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
Surface gray silty clay loam.	1.52	1.70	0.54	1.46	10.44	63.73	19.86
Subsurface blue clay.	0.00	0.48	6.54	6.52	9.92	44.39	33.64
Subsoil yellow silt loam	0.00	0.84	1.04	4.18	16.60	58.79	17.45

The surface soil is underlaid with an impervious subsurface layer of blue clay, which hinders percolation. Below this there is a yellow silt loam subsoil. This soil is easily puddled and the continuous grain farming, plowing when wet, or pasturing with sheep in wet weather have aggravated this condition and developed a "plow sole" or compact layer just below the furrow slice. The type is closely associated with the brown valley loam which occurs

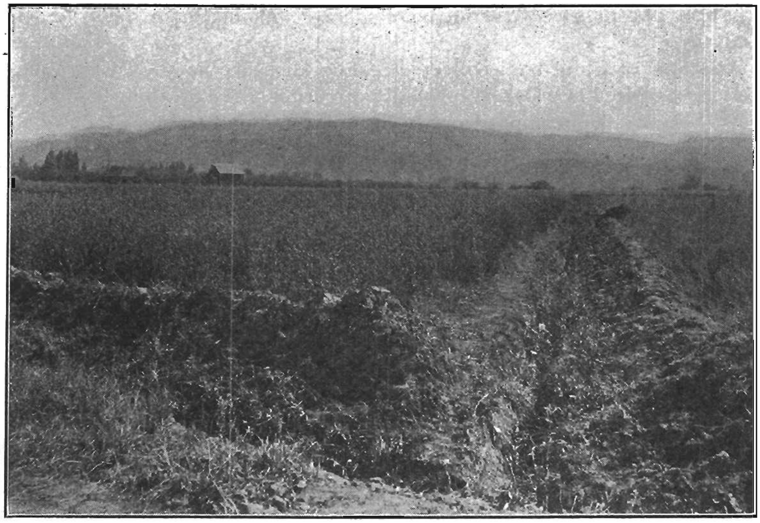


Figure 4. Wheat on Same Land, Union Station, After Drainage.

in elevated, naturally drained places on these prairies, the deep subsoil of both types being very similar. The color of this wet land is light gray before reclamation, but a darker color develops with drainage and constructive treatment. A soil survey of a white land area north of Salem disclosed the fact that 39% of the area was typical white land, 36% brown loam, and the remainder was an intermediate phase.

Chemical analyses show a uniformly good total supply of potash and a

Figure 5. Drained and Undrained "White Land".
a. One Side of Fence, Undrained. b. Over the Fence, Drained.
Photographs Taken Feb. 19, 1916.

supply of phosphorus with only a moderate amount of nitrogen or active humus.

A sample of white land collected a short distance north of Corvallis was analyzed by Mr. F. G. Carpenter under direction of the Station chemist, Prof. H. V. Tartar. The composition of the soil was found to be as follows.

TABLE II. CHEMICAL ANALYSIS OF WHITE LAND

Moisture	3.68
Volatile matter	4.15
Nitrogen	0.10
Phosphorous (P_2O_5)	0.15
Lime (CaO)	1.43
Magnesia (MaO)	0.22
Potash (K_2O)	2.18

Prof. Tartar states that the lime requirement was found to be 1124. pounds of ground limestone to each acre foot, and that the nitrogen content is rather low.

The reaction of this soil is acid and liming is beneficial. Experiments of the past several years have worked out with a fair degree of definiteness the methods to follow whereby successful drainage, which is the key to improvement of this soil, may be accomplished. Reclamation of this type is given special attention later.

Peat and Muck form the main body of the more important marshes. These organic soils are light in weight and very porous. "Beaver Dam" is a local name for peat soil and explains its origin in places in the Willamette Valley. Variations in respect to depth and amount of inorganic materials are important points in the drainage of these soils. Deep peat occupies the central part of marshes and is frequently formed from a rank growth of tules or marsh grass. Such soils respond readily to drainage. Shallow peat may be underlaid with silt or clay, making it less attractive and more difficult to drain. Tule grass, sedges or flags commonly grow on such land. Where there is fair depth of partly decomposed vegetation mixed with mineral material forming a muck soil, fairly thorough drainage may be necessary for complete reclamation. Such soils are apt to be better balanced in plant food supply and generally justify reasonable expenditures for drainage. The vegetation on such muck soils is frequently grasses, mint, and rushes. Chemically, these soils in Oregon usually have an acid reaction and the mineral elements may be lower than average so they may respond to treatment with lime, manure, or potash. Such soils are rich in nitrogen and humus and can generally be made very productive when drained. The greater part of the marshland on the coast is fresh water marsh near stream outlets. A soil survey of Warner Valley* made by the writer for the Reclamation Service discusses drainage conditions in a typical area of this land. Considerable drainage development is taking place in the peat soils of the State.

Alkali Soils occur in the native state or develop from irrigation due to accumulation of weathered soluble salts by evaporation of soil moisture at the surface. Drainage of arid soils so affected is the chief remedy, as it affords a means of washing these salts down and out of the soil. The texture of alkali

*Whistler, J. T. and Lewis, J. H. Warner Valley Rept. Ore. Co-op. Works, U. S. Reclamation Service, 1916.

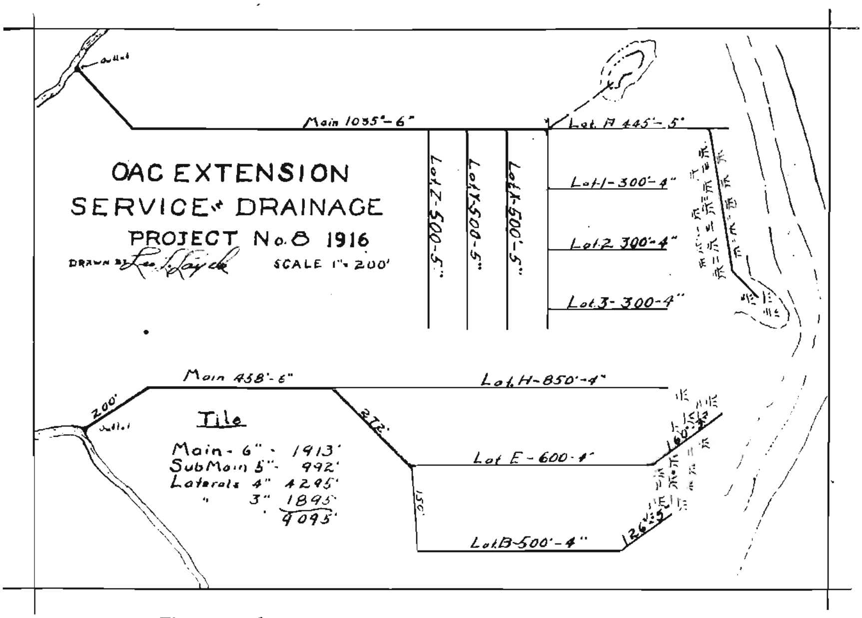


Figure 6. Plan of Drainage System Installed Near Philomath, 1916.

soils ranges from light loam to heavy clay loam. The former type usually bears mixed sage and salt grass or some grease wood (Atriplex), and where underlaid with porous layers a few feet from the surface these soils are feasible to drain.

The heavier soils may be flushed off where outlets are close at hand but at higher altitudes these greasewood lands are often too heavy, rough, and alkaline to be very attractive for reclamation purposes at present. Drainage of typical areas of alkali lands are fully discussed by the writer in soil surveys of the Ochoco†, Silver Lake† and Malheur† Projects.

Soil Water. The soil water dealt with in drainage is the free water which moves by gravity to lower levels or fills the larger pore spaces, causing soil to be water-logged. Most field crops do not flourish with their roots in saturated soil. If this water is kept moving or is **"live water"** and contains some air, crops can tolerate it more or less in the free state. If the water table is near the surface indefinitely the plant roots will not grow into it or, if the water table rises near the surface, the plant roots already in the subsoil will be rotted off. In a wet climate, excess water comes from the sky more directly, while in irrigated lands, it has been stored and seeps off through gravelly strata, damaging the low lands. In drainage, we must deal with excess rather than average rainfall.

The rate of flow of soil water depends mainly on the available head or gra-

† Whistler, J. T. and Lewis, J. H. Ochoco Rept., Silver Lake and Malheur Rpt., Ore Co-op. Work, U. S. R. S., 1915.

dient, relative porosity of soil, and temperature. In Table III, summarized from U. S. Geological Survey data, the velocity of flow is based on a fall or grade of 100 feet to the mile, a porosity of 32% and temperature 50°F.

TABLE III. RATE OF FLOW OF SEEPAGE WATER AS AFFECTED BY SOIL TEXTURE

Kind of soil	Diameter of soil Grains, m. m.	VELOCITY	
		In feet per day	In miles per year
Silt	0.01	0.0038	0.00026
Very fine sand	0.05	0.0923	0.00638
Fine sand	0.10	0.3690	0.02551
Medium Sand	0.25	2.305	0.1594
Coarse sand	0.50	9.224	0.6377
Fine gravel	1.00	36.90	2.551

Usable Soil Moisture. The soil moisture which is usable by plants is mainly in **capillary form.** Wet soil may dry and bake quickly after rain, for in its water-logged condition there is a minimum amount of pore space, and such a soil does not retain moisture well in time of drought. In the wet soil, cementing materials which should hold the soil particles into clusters are dissolved; the film attraction is eliminated so the soil structure is broken down and the pore space reduced. Drainage removes the excess water and makes room for more usable moisture. Excess water finds its way to the tile drains through the line of least resistance in the soil and enters between the ends or **"joints."** This process of drainage does not leave the soil without moisture but simply removes the excess and makes room for more usable moisture and some air.

Benefits of Drainage. The primary object of drainage is to remove the excess water. This enables crops to root deeper and a larger soil layer is thereby provided in which to store usable or capillary soil moisture. This deep rooting and improved moisture condition causes the soil to become more mellow and friable. Drainage encourages aeration by emptying the large pore spaces which are filled with water and making room for soil air. Drainage makes the soil warmer because it dries out early in the spring. This firms the soil and lengthens the growing season so that the whole field can be worked early. The presence of air in a drained soil aids decay, nitrification, and the liberation of plant food; it prevents erosion by making the soil more absorbtive; it prevents the heaving or freezing out of the clover and grain on wet land, or the rise of alkali on irrigated land. In addition, drainage improves sanitary conditions, aids transportation and highway improvement and development of the country in general. Timely drainage increases crop yields and land values and is one of the most permanent improvements that can be put on land.

Materials for Under Drains

Covered or under-drains give the most complete form of drainage and will nearly always improve wet soil that has incomplete natural drainage. Many materials have been used for under-drains but in recent years, the practice has narrowed down to the use of box drains, cement tile, and red tile.

Quality of Red Clay Tile. Red tile should be well burned, cylindrical, and straight. A good tile of this kind will give a sharp ring when

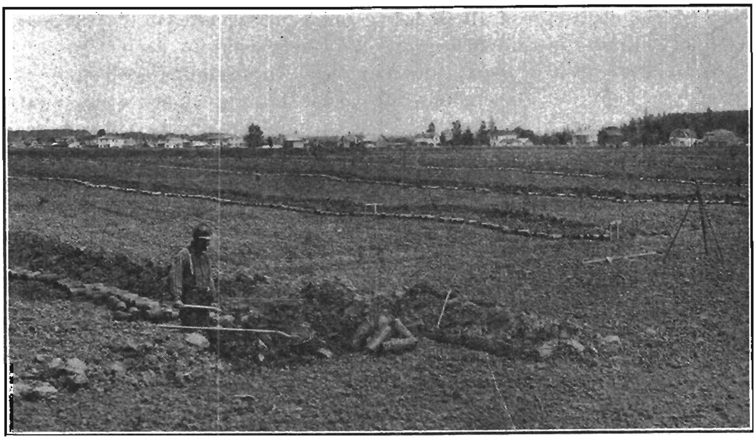


Figure 7. View of Laterals, Oregon Experiment Station.

struck with a piece of metal. Since the clay shrinks in burning, the length and thickness of the walls and the diameter may vary somewhat with the degree of burning. The over-burned tile will be smaller in dimensions. The well-burned pieces are usually one foot long. For smaller sizes of tile, except in the hardest burned pieces, there will be some over-run and in good tile this should off-set the breakage. Good tile are durable, easily laid, and last indefinitely under proper conditions. Vitrification is desirable, especially where tile is exposed to freezing but for ordinary drains it is unnecessary. Freezing and thawing tend to disintegrate clay tile and vitrified tile or other types should be used in exposed places. Generally there is a slight imperfection in the tile that causes it to be curved in along one side slightly and humped along the other side. Usually the side with the hump is the longer side. By placing this side up or on top in the trench, the top edges of the tile will fit tightly together. The imperfections in the tile can be taken advantage of in making slight turns in a line of tile.

Cement Tile. During the last decade, cement tile have come to be used extensively for drainage purposes. They have an advantage where fire clay is not obtainable within a reasonable distance. The mixture which is found most satisfactory for smaller sizes is 3½ parts of clean, sharp sand to one of cement. For larger sizes, a slightly richer mixture is preferred and wire mesh should be used for reinforcement. Cement tile should be made of a uniform, first-class mixture; to be strong it should be dense rather than porous. Such tile should be made with a pressure machine using a wet mixture and carefully cured, if failures are to be avoided. Where freight is an important item, it is suggested that the farmer choose whatever he can secure the cheapest, whether red or cement tile, provided he can get good, strong tile and get the breakage refunded. Certain alkali salts cause cement to deteriorate and in irrigated districts some precautions should be taken to determine the character of alkali before choosing cement tile. The presence of sodium sulphate is said to be especially detrimental.

Box Drains. Box or plank drains are used where timber is cheap or where they can be kept wet throughout the year. Lumber under wet conditions near Astoria has lasted in drains at least thirty years and is still serviceable. Plank drains are most frequently used in draining arid lands or in peat soils. In either case, the drains are placed deep and have large capacity. In a peat soil, tile would settle out of alignment unless underlaid with a board or fir boughs. It is generally best to use a fourth plank on the bottom side of the drain so as to inclose it underneath and to provide a small grove along the side of the drain at the bottom edges through which water may enter. The top and bottom planks should be milled or notched so that the box will not cave in after nails are destroyed.

Standard methods have been developed for testing drain tile and standards of strength have been established. The farmer can usually learn the ware of the local factories, however, and with a little experience he can learn to judge tile fairly well at the factory.

Types of Drains and Their Location

Types of Drains. To be most beneficial, drainage should be deep. It is practically impossible to over-drain a soil. While the open furrows or field ditches are of value for temporary drains, there are several objections to them. Permanent shallow open ditches or **surface runs** in the field should be made to follow fences or direct lines as much as possible. They may be kept in grass and be used to remove the flood water in case of extremely heavy storms after which under drains will remove the excess water from the subsoil. Drainage by pumping is practiced to some extent in connection with dyked land.

A single line or **string of tile** has an upper end or **head** and a lower end or **outlet**. The finished tile base at each **hub** stake or **station** is called the **grade** and the slope of this line, usually expressed in fall for each hundred feet, in the **gradient.** A drainage system will have a **main** or a line of large tile which serves mainly as a **conducting** drain and which receives the discharge from sub mains and laterals. The **laterals** are usually single lines serving mainly as **collecting** drains and they are frequently arranged in **parallel systems** as in Fig. 6.

For ordinary field crops on undulating land, natural or **random systems** or drains are used following the natural depressions of the land and diverging like the frame of a tree. Parallel systems are well adapted to the drainage of flat-lying land situated with a gentle slope in one plane. Long parallel laterals give the least amount of double drainage with less expense for junctions and large tile. It is often convenient to have the laterals run parallel to the fence lines and to the dead furrows so that supplemental surface drains can be provided, and the land given a slight slope toward the drains.

Vertical drainage is only practical where there is wet land with a tight subsoil and then a coarse layer underneath, through which water will pass. A vertical drain can be made of small wells, lined with a column of drain tile

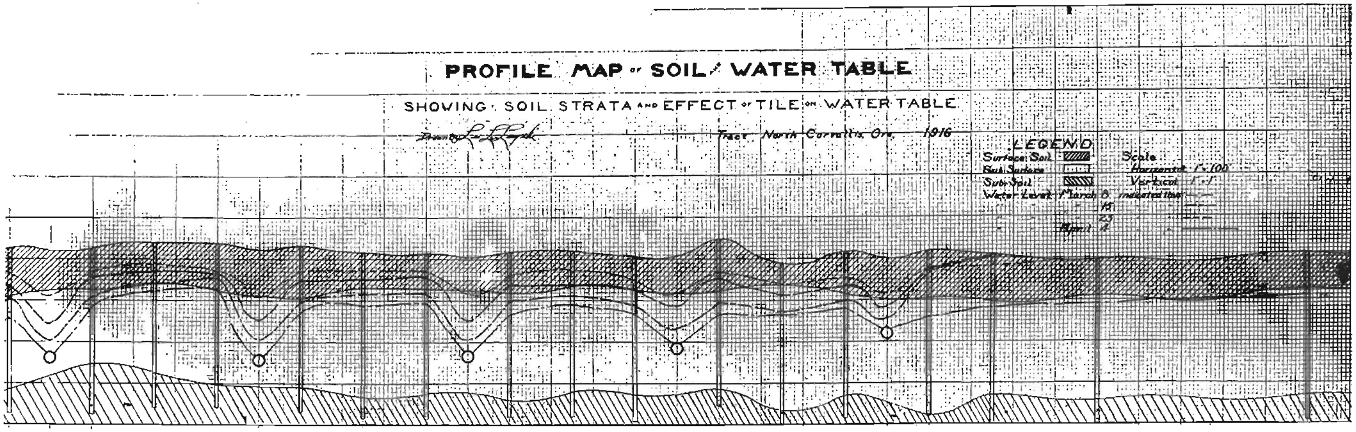


Figure 8. Water Table in Drained vs. Undrained White Land.

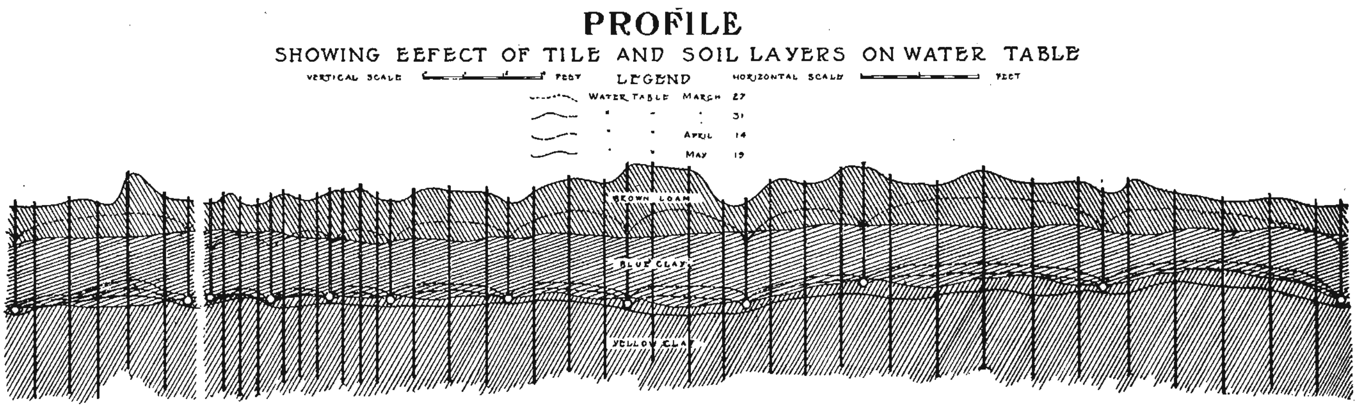


Figure 9. Typical Section of White Land Showing Effect of Tile on Water Table.

surrounded with gravel, and covered, below reach of the plow, making a permanent passage way down through the impervious layers.

The Location of Drains: A carefully planned drain system may be installed in units as time and means permit and can be developed so as to afford more thorough drainage as general economic conditions come to justify a higher state of improvement.

In locating drains, best authorities consider it good practice to lay the main in the line of natural drainage where the water collects; for the surface and subsurface strata will convey the water to these depressions. This should always be done except where a cutoff drain or a **protecting** drain run across the slope will be economical. On our flat lands, the laterals should run in the line of greatest slope; and long, parallel laterals should be used where possible. The tile lines should be run straight or with easy curves. This makes them easier to lay and to find in later years and it reduces friction. A drainage system should be designed to take care of all of the wet land on the farm though only the most necessary part of it is to be installed immediately. A surveyor's level should be used wherever the land is very flat or has less fall than three or four inches to each hundred feet. Plan the drain system to reach the source of excess water and convey it away as directly as possible. Plan to handle a maximum amount of water with a minimum number of tile, so as to get the highest possible efficiency out of every hundred feet of tile employed.

Location of Drains with Auger and Level. When designing a drain system begin at the outlet and determine the depth the drain can be placed and have a free discharge. The level will be useful here. All leveling data should be referred to a permanent bench mark. Make test pits with a post hole auger or soil auger at frequent intervals as the examination proceeds upstream and observe the character of the subsoil to determine how deep to put the drain so it will be in the most free-working soil. (See Figs. 8 and 13.) The occurrence of under-ground water can be noted and any seepage water traced to its source to determine whether it appears under or over any hard layers of soil. The drains can then be designed to intercept and convey this water away as directly as possible. A few range poles or stakes should be set at points in the field through which it is desired to have the survey for the drains pass. Preliminary levels may be taken to decide on the best possible outlet and determine the lay of the land. A series of readings taken across the field in both directions or around the field will usually disclose variations in a fairly flat piece of land. A contour map of a wet farm having irregular topography would be very desirable.

Because drainage is a rather expensive improvement and some soils, like the white land, are rather slow to respond to drainage, it is necessary that we locate our drains and handle the land after drainage so as to loosen up the soil and facilitate the entrance of water into the tile in order to make the drainage enterprise thoroughly profitable and successful.

Use of catch basins, allowing subsoil to crumble before filling the trench or use of sods over the tile will aid the water in entering the tile.

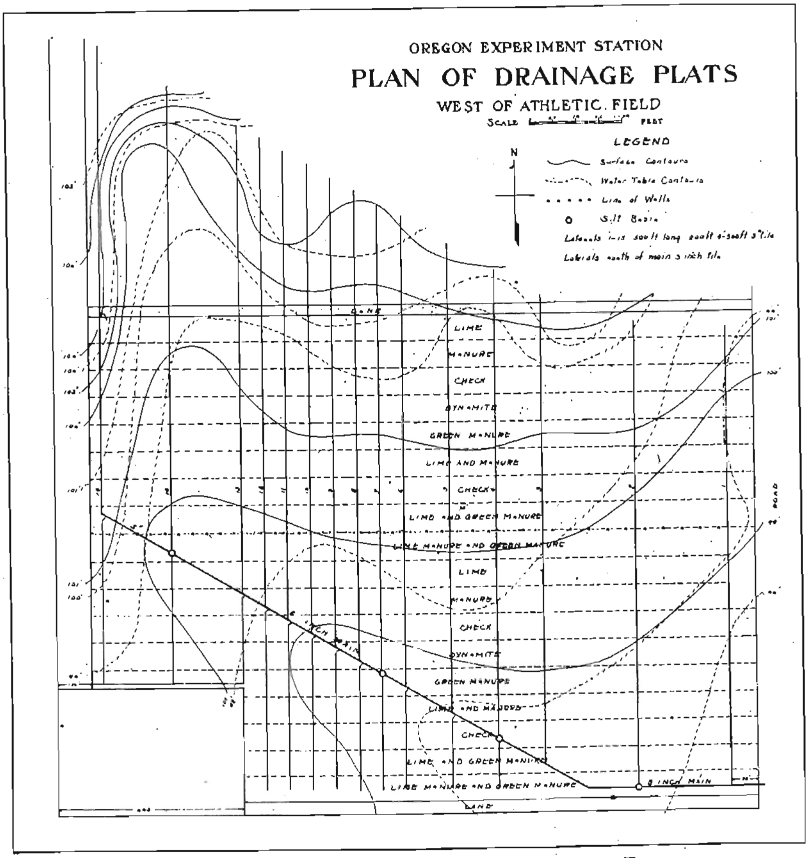


Figure 10. Plan of Drainage Plots on Experiment Station Farm.

Depth and Distance Apart for Tile

The depth, distance apart, and size for tile are subjects which are closely related and constitute some of the largest questions to be decided in tile drainage. These factors can be definitely determined only after the character of soil and subsoil has been studied, the amounts and distribution of rainfall, topography of the surface and the amount of runoff, the crops to be grown, prevalence of underground water and the grade obtainable and area to be drained have been determined. The drain system should always be arranged with reference to these conditions.

Depth. The kind of crop affects the depth for drains. King states that the depth must be such that water can get to the tile before it seriously injures the crop. If water is kept moving and contains some air, the crops are less liable to injury. Some crops are more tolerant of an excess of water than others. The drains should be in the water to be removed and below the bulk of the roots. Deeper drains, as a general thing, will be necessary in orchards and with deep-rooting crops.

The **soil** also affects the proper depth. In porous soils, drains can be placed a good depth; say three-and-one-half or four feet. This will permit deeper drainage and a single line of tile can then be made to drain a greater area. In general, it is not desirable to lower the water table so far in sand as in clay, for there is less capillarity in sand from the water table upward to the plant roots. In some of our peat soils, sub-irrigation by capillarity upward from the water table supplies moisture at an elevation of thirty to thirty-six inches above the water table. In porous soils, drains attain their full efficiency almost at once, but in dense clay there is an increasing efficiency as the soil becomes granulated and the drain system becomes effective. Some silt is washed out through the tile and tiny streamlets are formed leading to the joints in the tile after a few years. To dispose of the water promptly, the drains must be placed shallower in clay and under such conditions must be fairly near the surface and used chiefly to dispose of water in the surface layer. Tile should be placed on the boundary between sand and clay, if there is a change in soil texture at any reasonable depth; for this allows water to move to the tile through the sand or through the line of least resistance. The depth for different soil types and conditions is further discussed below.

Distance Apart. The distance apart is closely related to the depth and is affected by about the same conditions. The relation of depth to distance apart in a porous soil is fairly definite. For example, twenty-four hours after a sandy soil has been saturated by rain, a study of the water table extending back at right angles to the tile line will show it to have an even grade toward the tile. At a distance of fifty feet back the elevation of the water may be a foot above the elevation of the tile. Under this condition, with the porous soils, the tile placed a foot deeper should lower the water table a foot farther from the soil surface at the fifty-foot point and should pull the water table down to an elevation of two feet above the level of the tile at a distance of one hundred feet back. In a clay soil this grade would run in an arc instead of a straight grade and at a distance of perhaps twenty-five feet from the tile, the water table might be two feet above the level of the water in the tile, twenty-four hours after a heavy rainfall. The soil texture, therefore, affects the distance apart the drains may be placed. Fine-grained or heavy soil offers a great deal of friction or resistance to the movement of water and such soils require frequent laterals for thorough drainage.

The **amount of rain** and the time allowable during which to remove it also affect the distance apart, and, if water must be removed in a short time from the heavy soil, drains will necessarily be placed close and shallow.

Experiments Relating to Depth for Drains. For several seasons, hundreds of miniature wells have been maintained during the wet season in typical drained and undrained white land areas to observe the fluctuations in the water table and the effect of the soil layers and tile lines upon the position of the ground water. In typical white land, a section of which is shown in

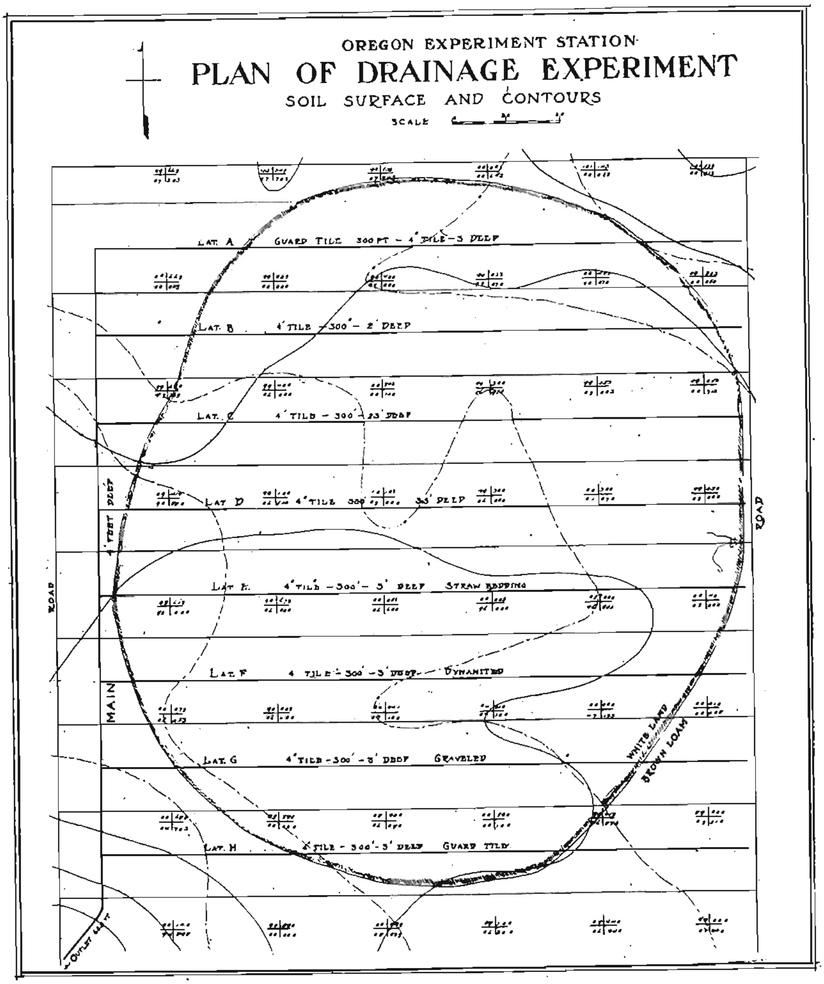


Figure 11. Plan of New Drainage Experiment.

Figure 9, there is usually a heavy clay sub-surface, beginning at a depth of twelve or fifteen inches and extending to a depth of thirty or thirty-six inches below the surface of the ground. The soil then changes to a yellowish, silty clay loam, and there is usually a somewhat more gritty and porous streak just below this change. The soil farther down is usually rather firm, yellowish silt loam to considerable depth, and is somewhat mottled with brown places where the soil is set a little with larger amounts of iron and clay. From these studies, it is found that generally about thirty-three inches depth will enable the tile to be placed below the blue clay sub-surface and in the most porous layer to be encountered, in the flat areas of white land. Placed at about this depth tile **drains have lowered the water table** sufficiently for cultivation or about 2½ feet while water still stood on the surface of adjoining land of the same character (See Fig. 8).

In two drainage systems on the Experiment Station farm at Corvallis, where the laterals average about thirty-three inches in depth, these drainage systems frequently discharge as much as a half-inch of rainfall an acre in twenty-four hours for the area drained. One of these drainage systems has been in operation for twenty-five years and the other has been installed two years. **The structure of this land since drainage shows gradual improvement.** Observations of the discharge from other drainage systems on College land and near Albany where the tile laterals are forty to forty-two inches in depth, show that these drains do not discharge more than one-fourth to one-third of an inch an acre in twenty-four hours under the same soil and weather conditions that cause a half-inch runoff from the shallower drains. A drain system with a capacity to remove a half-inch to the acre in twenty-four hours is regarded as fairly good capacity for Willamette Valley conditions.

A series of lateral drains were installed on a piece of white land near Albany by the U. S. Office of Drainage Investigations in 1908, the laterals being placed the same distance apart which in all cases was sixty feet. The depth varied from two and one-half to four and one-half feet.

Results of Experiments Relating to Depth. Frequent observations of the water table and the discharge from these drains show no advantage has been secured from the drains deeper than the average in this type of soil. The present owner of this land states that he has been unable to discover any difference in crop yields or conditions in favor of the deeper drains on this type of soil. A study of water table conditions in the vicinity of these drains indicates that the drains laid four and one-half feet deep are less effective with this class of soil than those laid to a depth of thirty-three to thirty-six inches for at least two weeks or more after heavy precipitation. This is probably because the so-called "white land" has a rather impervious sub-surface layer and the most friable stratum that can be found underneath occurs in depths of about thirty-three inches below the surface. The water that falls on such land and accumulates there comes from heavy rainfall rather than seepage and does not find its way into the deep drains as readily as in those of average depth.

A new experimental drainage system is being installed on the three-acre piece of white land on the Experiment Station farm having a deep outlet near at hand and a further study is being made here of the effect of drains at different depths. The soil has been found to be fairly uniform. Manholes are being constructed in which the runoff from laterals of different depths can be measured. In one section of this experiment the relative value of straw and gravel placed over the tile lines as bedding is being studied. The accompanying map, Figure 11, shows the topography, soil types, and drainage system. The tile is being installed by College classes and the system will not be com-

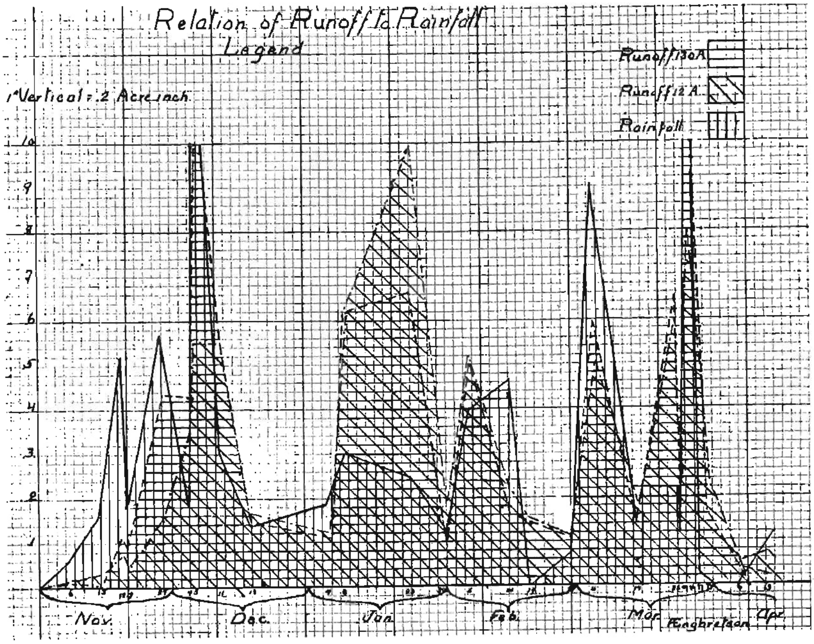


Figure 12. Hydrograph Showing Mean Daily Rainfall and Outflow, Experiment Drains.

pleted until next year. The north part of the field temporarily serves as an undrained check.

Experiments Relating to Distance Apart. On a portion of the Albany tract used for experimental purposes, the Division of Drainage Investigations installed drains sixty feet apart and at greater distances including intervals of seventy-five, one hundred, and one hundred twenty-five and one hundred fifty feet between laterals. The drains **sixty feet apart have given fairly thorough drainage** and the land so drained can usually be passed over dry-shod. Studies of the water table on this tract have been made by the writer for the past four years, and it is found that the water table is affected twenty-five to thirty feet back from the tile twenty-four hours after the rains have caused saturation or rise of the water table to the surface. Where the laterals are a greater distance apart, water frequently stands in the dead furrows for several days at a time.

Experiments at Corvallis. A field of white land on the Experiment Station at Corvallis was provided with an experimental drainage system in 1914 in which the laterals were installed at a depth of about thirty-three inches at distances of twenty-five, fifty, seventy-five and one hundred feet apart. The surface and water table topography, as well as the arrangement of tile drains and the subsequent surface treatments are shown in Figure 10.

Results of Experiments Relating to Distance Apart, Fig. 9. For several seasons, wells have been maintained at regular intervals over this area during the early spring season. Before drainage, the water table ranged within a few inches of the surface during March and April, while the year following drainage the water table in the more thoroughly drained part of the field averaged perhaps two and one-half feet below the surface during the same season.

During the past two wet seasons, the rate of discharge from guarded laterals representing each spacing studied has been measured at regular intervals in wet weather. These laterals are each five hundred feet long. A twenty-five foot lateral drains approximately one-third acre, while the fifty-foot laterals drain two-thirds of an acre each, and so on. Table IV gives the rate of discharge for each spacing expressed in acre inches runoff an acre in twenty-four hours and also the crop yields to the acre.

TABLE IV. DISCHARGE FROM LATERALS PLACED DIFFERENT DISTANCES APART
Winter 1915-16

Distance between laterals	*Max.* Discharge in A. ins. an A. per 24 hrs.	*Mean* Discharge A. ins. an A. 24 hrs.	Mean Daily rain previous two days. Inches	% Daily outflow	No. tile per acre	Mean acre ins. discharge per 1000' tile in 24 hours	Yield barley per acre 1915. Bushels
25'	1.20	.48	0.60	80	1742	.96	33.73
50'....................	1.35	.55	0.60	92	872	1.10	29.90
75'	.80	.33	0.60	55	586	.66	27.90
100'	.90	.32	0.60	53	436	.64	20.35

Winter barley on undrained land under similar conditions yielded sixteen or eighteen bushels to the acre, whereas marked increases are shown for this crop from drainage. Laterals removed the excess water more promptly than was anticipated considering the heavy nature of the soil. Little outflow from laterals occurred preceding the maximum runoff on March 26. Rainfall for March 25 was 1.28 inches and for March 26 the maximum discharge was observed at the close of the wettest day of the year with 1.89 inches precipitation. Dry weather followed and laterals had nearly ceased discharging by March 28.

These experiments are being continued and equipment secured that will enable more nearly continuous records of rainfall and runoff to be kept.

The effect of these tile lines upon the water table has been studied for two seasons and the water stage at regular intervals following saturation of soil for the spring 1916 is shown in Figure 9. Tile wells surrounded with coarse sand are used for these observations.

These results and observations so far made indicate that the twenty-five foot spacing handles excess water most quickly. The fifty-foot spacing gives the highest efficiency for each hundred feet of tile employed, while the hundred foot spacing continues to drain for a longer period of time but more slowly. The deeper main drain also continues to drain after the laterals have ceased to discharge into it at the manholes where measurements are taken. It is believed that deeper drains will act slower but will continue to drain longer periods of time than will drains of an average depth in this soil. The soil is

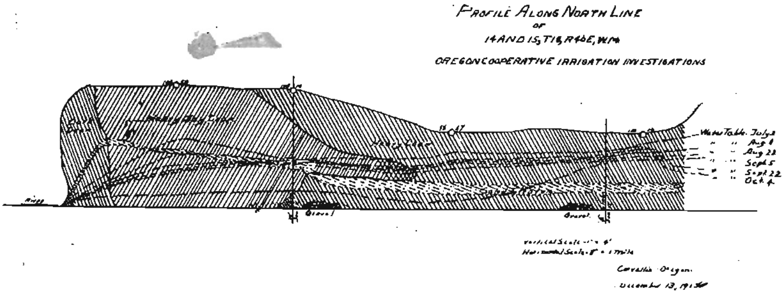


Figure 13. Profile of Alkali Soil and Water Tables—Malheur Valley.

dry enough for tillage and seeding operations, however, a few days after the water table has been lowered to an average depth of say thirty inches below the surface, a reduction which takes place promptly with laterals placed as in this system.

Soil moisture determination made on drained and undrained white land show as much as 4% more moisture in drained land in dry weather.

About a year ago, a list of questions was sent out to farmers who had installed drainage systems. Replies from some fifty farmers covering their experience with approximately a hundred miles of tile in the Willamette Valley show that the average depth of laterals installed on their farms is thirty-seven inches. The average depth of mains is approximately four feet. The average depth they recommend is three feet. The laterals range from four to ten rods apart and the average distance reported is eighty-three feet. The average distance apart recommended by these replies is four rods, though fifty feet was a common reply. Practically all of these tile systems were declared successful by the land owners themselves.

Field Drainage for Other Willamette Valley Soils. Brown loam in this valley requires usually but a random or natural system of drains, larger tile being placed up the natural depressions in the land. These laterals should usually be of good capacity and good depth; perhaps three and one-half feet for smaller sizes and four feet for the larger sizes would be a reasonable depth. Generally the soil will be a little heavy in these draws but the drains can be placed deeper if frequent catch basins are installed. Drains placed in natural depressions should be deep enough to receive the discharge of any laterals that may need to be installed later. Flat areas of the brown loam that are wet require thorough drainage and can be drained fairly well with tile lines six rods apart. Gray-brown silt loam or "near-white land" in this valley requires more thorough drainage, and tile three feet deep every five rods should provide good drainage under average conditions for this rather wet land.

Black Clay or "black sticky" soil can be greatly improved by the use of protecting drains to collect the water before it gets onto the sticky area from higher land or by surface drainage within the sticky area. It is at least very doubtful whether it would pay to provide the thorough expensive underdrainage necessary for the highest development of this land at present. Much

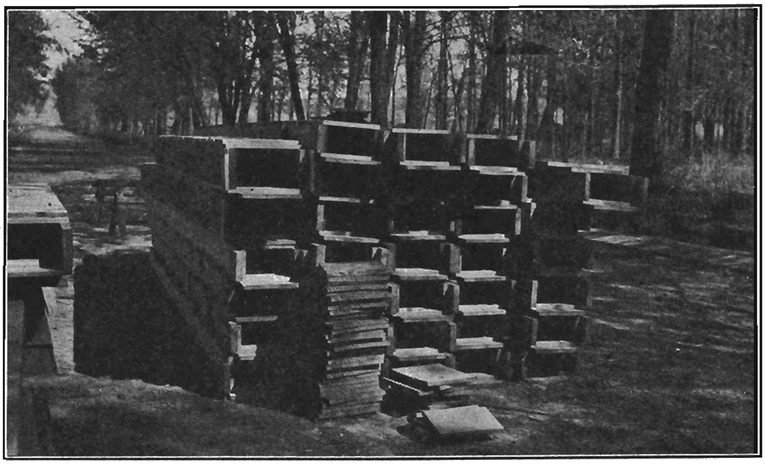


Figure 14. Box Drains—Mallet, Oregon.

of this type is underlaid with a rather porous layer of sand at a depth of four feet or so and by the time the surface water is disposed of no water table is to be found in the subsoil and the land is ready for cultivation, which must be performed while the land is still rather damp.

Field drains for red hill soils are usually to control erosion or to collect seepage water from springy areas. If the land to be drained is in orchard, tile lines should be located between the tree rows following spaces diagonally, if necessary, and avoiding the trees as much as possible. Study of the subsoil conditions will usually reveal hard layers of shale or clay which are responsible for the water crowding out to the surface, and intercepting or collecting drains sometimes, with the aid of relief wells, will be effective in drying up seepage from these hill lands. The cutoff for protecting drains should usually pass along the slope with a fall of at least three to six inches per hundred feet and just through the upper edge of the springy area. Short laterals may need to be added a year or two later to complete the drainage.

Field Drainage for Peat and Muck Soils. Raw peat is subjected to considerable shrinkage upon drainage and four feet is regarded a minimum depth. Deep, raw peat soils will be greatly benefited by laterals placed five hundred or even one thousand feet apart. Where considerable silt is present so that the soil is a rather dense muck, it will require more thorough drainage and the drains should then go only three or four feet deep. Such muck is found in the vicinity of Tillamook and Astoria, and where a sufficient depth of outlet can be secured, field laterals may be placed three to four feet deep and seventy to one hundred feet apart in such land. Shallow peat that is underlaid with black clay loam or blue silty clay loam is less attractive and less susceptible to drainage improvement. Peat, with some organic material, especially some sand deposited by water action, is readily drained and is apt to be more evenly

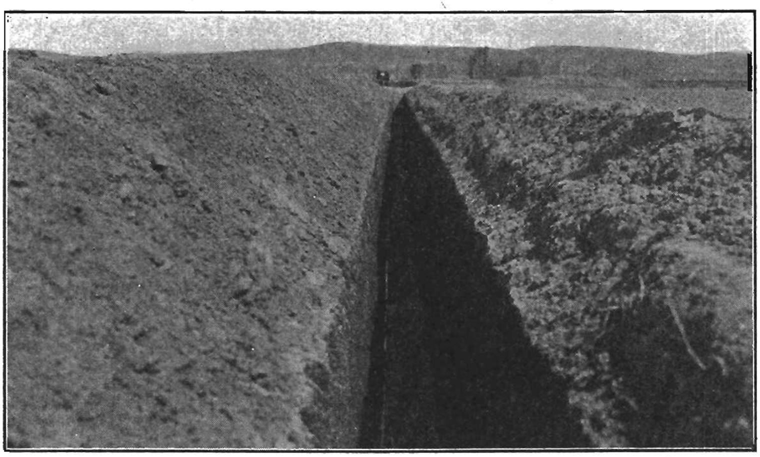


Figure 15. Box Drain in Place, Mallet, Ore. A Deep Lateral in Alkali Land.

balanced in the supply of plant food. In some of our "beaver dam" areas in the Willamette Valley where the water table naturally disappears late in the season, permitting thorough maturing of onions and other crops, the growers prefer to have laterals only thirty or thirty-six inches deep in order that the crop may sub-irrigate early in the season. Raw peat may not sub over 18 inches while silty peat may subirrigate 30 inches to 36 inches above the water table. It would probably be better to have the laterals at least four feet deep and to provide check gates in the outlet drains to delay the removal of the water table beyond the reach of crop roots until later in the growing season where sub-irrigation is desired. Grass will flourish with a water table two feet from the surface while a depth of three or four feet is better for grain and four or five feet would be better for clover and other legumes. A large amount of valuable marsh land awaits reclamation in this State and the subject warrants special treatment in a later bulletin.

Field Drainage for Irrigated or Alkali Lands. In draining irrigated lands, the drainage must be deep; and frequently a drain, which must be placed to intercept seepage, is located in some deep, porous stratum where the water can be collected before it injures the field below. Six or eight feet is a common depth in draining irrigated land. Silty loam is the prevailing type of such land that appears feasible for reclamation at present in this State. There are areas of heavy loam or clay loam "Grease wood land" in places in Eastern Oregon, which are so located that they can be improved by surface drainage and flushing off the alkali salts through open ditches. At high altitudes where outlets are not readily secured, the reclamation of such types by underdrainage does not appear feasible at present.

For thorough drainage of alkali lands where protecting drains cannot be employed, 5 or 6-inch laterals placed 440 to 680 feet apart, making two or three laterals to a forty, should provide fairly thorough drainage where a porous layer can be encountered at a depth of six or eight feet below the soil surface. The capacity of such drains will depend upon the prevalence of water and the amount of irrigation employed for the particular texture of soil to be dealt with. A study of subsoil conditions will reveal the presence of porous layers through which water is feeding and in which drains can be placed to collect it. These layers must be deep enough so that drains placed in them will overcome the capillary action between the water table and the surface.

Studies of the relation of the water table to the concentration of alkali on the surface have been made in several valleys in Eastern Oregon by means of systems of wells whose elevations have been determined and from which regular observations of the water stage have been made. Results of studies of this kind on the Malheur bottom west of Ontario are shown in Figure 13.

Studies on the Malheur bottom reveal the fact that a sandy streak may be encountered at from five to nine feet below the surface while a quite porous gravelly layer can usually be found at a depth of eight to twelve feet down. The maximum accumulation of alkali occurs where the water table is about three and one-half feet below the surface, in this heavy loam soil. Water comes into the post holes from these porous layers in the subsoil rapidly and from these studies we are convinced that the drainage of these lands is feasible, considering the high amount of plant food these soils contain, and the favorable climate in which they are located. Similar studies have been made on alkali lands near Haines and in other places.

Drainage of irrigated land in the Klamath Basin is being secured most readily by cutoff drains across the slope or along below the canals. There is a layer of water-bearing sand on the chalk rock at a mean depth of about five feet, a depth in which drains work best. A 14-inch Austin ditcher is being used for the excavation by the U. S. Reclamation Service.

Valuable areas of alkali land located at moderate elevations as in the Umatilla, Crooked River and Walla Walla Valleys offer very attractive fields for reclamation. At high elevations where thorough underdrainage is not justifiable under present economic conditions, there are many places where winter or late fall irrigation could be practiced and the alkali flushed off into available outlet channels.

In draining irrigated land, relief wells may be used to bring up water from deep water-bearing gravel to a depth to which it can be encountered by drains. Precautions may need to be taken in water-logged soil to avoid caving in during construction, and the back filling may need to be tamped, in order that irrigation water may leach out the whole soil instead of percolating directly into the drains. Some manholes should be provided to afford an opportunity for observation and for cleaning out roots and silt from the drains. A separate bulletin is needed for a thorough treatment of this subject.

The Size and Grade for Tile

Size. The size of tile to use for a main drain should be determined after all data regarding the available fall and the land and water conditions are at

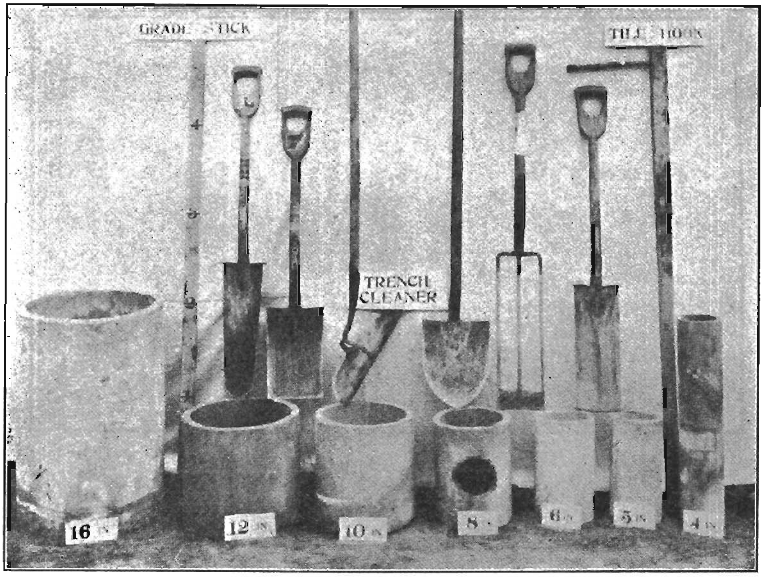


Figure 16 Tile-laying Tools and Samples of Tile.

hand, in order to secure fairly complete drainage at the lowest possible cost. The size of tile depends on the amount, intensity, and seasonal distribution of rainfall or amount of irrigation, as well as surface runoff, and evaporation. It is also important to consider the rate of removal of excess water that is necessary to avoid injury to the crops to be grown, the fineness and storage capacity of the soil, and the extent and topography of the watershed area to be drained.

There are times when the soil is so dry that three or four inches of rain will scarcely start the tile. At other times when the soil is nearly saturated it will be necessary to remove the larger part of the rainfall within forty-eight hours. At times, water cannot pass through the soil fast enough even though the tile is amply large, so that the surface runs or surface inlets are needed. Following a very dry season, rains began November 5, 1910, and continued to November 10, amounting to 4.94 inches. This rain was just sufficient to start tile drains on the College farm and cause light runoff. The average depth of these drains is about 33 inches so the water-retaining capacity of this land under field conditions is a little less than 2 inches rainfall for each acre foot of soil. The size of the tile must be sufficient to deal with the heaviest rainfall excepting only the unusually heavy storms.

The main tile collects water from the laterals, yet it is unnecessary for the main drain to have a capacity equal to the combined capacity of laterals, for laterals rarely flow more than half full.

Figure 17. Cyclone Ditcher.

Size of tile refers to inside diameter expressed in inches and the area of cross section of tile increases as the square of the diameter. Friction and eddies are less important in large tile so that an eight-inch tile has more than four times the capacity of a four-inch tile with the same amount of fall.

Yearly Precipitation in the Willamette Valley is about 42 inches; the maximum monthly rarely exceeds 12 inches. Although as much as 2 inches in 24 or over 3 inches in 48 hours may occur once or twice each winter, there are only 8 or 12 days each year when as much as one inch of precipitation occurs in 24 hours. The monthly precipitation for typical stations of the principal humid sections of Oregon taken from U. S. Weather Bureau data is as follows:

TABLE V. NORMAL PRECIPITATION FOR HUMID SECTIONS OF OREGON

Month	Inches Precipitation			
	Toledo (Coast Section)	*Corvallis* (Willamette Valley)	*Grants Pass* (Southern Oregon)	*Hood River*
September	2.64	1.34	.95	1.44
October	5.35	2.94	1.96	2.42
November	12.52	7.32	4.97	5.79
December	10.14	6.60	5.18	6.80
January	10.67	7.60	6.21	5.92
February	9.68	5.60	4.57	4.47
March	8.80	4.41	3.55	3.36
April	6.43	2.81	1.73	1.85
May	3.14	2.25	1.68	1.25
June	3.14	1.24	.96	.91
July	.52	.26	.16	.17
August	.51	.38	.27	.27
Normal Annual	73.54	42.29	32.19	34.65

Excess water in more arid sections comes less directly from precipitation. The evaporation from a water surface at Corvallis from April to October

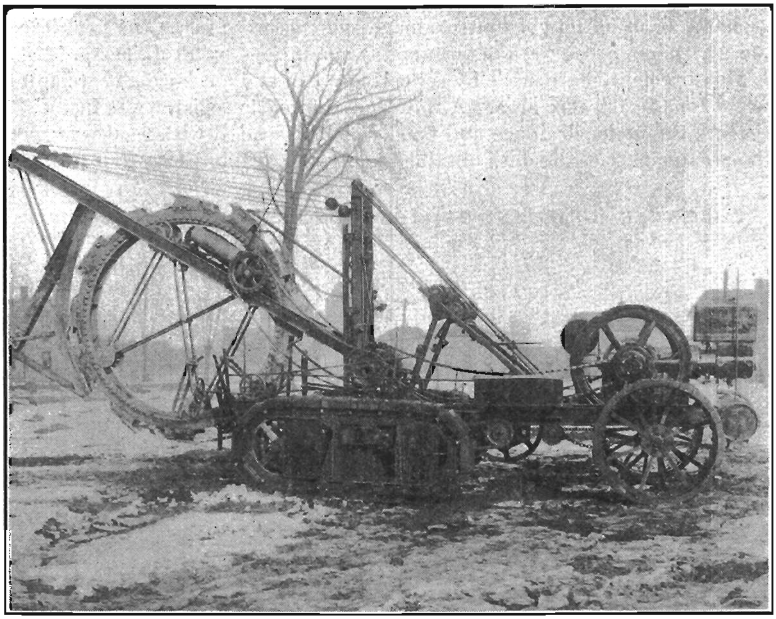


Figure 18. Buckeye Trencher.

averages about 24 inches. The remainder of the year the evaporation is very low.

The Outflow from Underdrains has been studied by the Office of Drainage Investigations, which office determined the capacity of a large number of tile systems in Illinois and Iowa, where the capacity was regarded as satisfactory by the land owners. The annual rainfall in those districts was thirty-three to thirty-five inches, which was fairly evenly distributed. From these studies, it was concluded that tile having a capacity to remove one-fourth inch to the acre in twenty-four hours from the area tiled would provide satisfactory drainage under those conditions.

Measurements of the outflow from a tile system draining three acres at Uniontown, Alabama, determined that from 23 to 68 per cent of heavy rainfall was discharged within a few days after rain.*

Experiments Relating to Size for Tile. Measurement of discharge from several drainage systems in the vicinity of Corvallis designed with capacity to handle one-half inch rainfall or more for each acre in 24 hours have been made the past three years. The outflow has frequently exceeded the half inch coefficient. One tile system with no surface inlets draining 30 acres of white land and having one-half inch capacity was charged at least three times the past winter for one or more days. Fairly regular measurements of the

*Newman, J. S. Alabama Canebrake Sta. Bul. No. 5, 1889.

discharge from outlets of four drainage systems were made the past season. The watershed areas were determined from surveys by Prof. Teeter.

Measurements were made by collecting water and measuring or weighing it except for the 130-acre area. A weir and automatic register was installed to measure the under-drainage and flood water was rated with a current meter. The greater part of the data obtained is given in Table VI.

TABLE VI. RAINFALL AND OUTFLOW FROM DRAINAGE SYSTEMS—1915-1916

Period	Precipitation inches		Outflow main drain (130 A.)		Outflow exp. drain system (12A.)	
	Total for period	Mean daily	Second feet	Acre ins. an acre	Gal per min.	Acre ins. an acre
1915				In 24 hrs.		In 24 hrs.
Oct. 30–Nov. 6	.50	.07	.01	.00	36	.02
6 13	1.15	.16	.01	.00	48	.03
13 18	2.62	.52	.08	.01	150	.08
18 19	.17	.17	.05	.01	135	.04
19 27	4.56	.57	2.36	.43	300	.16
27 Dec. 4	1.31	.19	2.36	.43	600	.32
Dec. 4 5	1.28	1.28	5.50	1.01	1000	.53
* 5 P. M. 6-8 hrs	....	....	8.00	1.47	1000	.53
5 11	1.87	.31	3.05	.56	1000	.53
11 18	.89	.13	.84	.15	330	.18
1916						
18 Jan. 4	3.11	.18	.47	.09	1186	.10
Jan. 4 8	1.19	.30	3.46	.64	1200	.64
8 23	3.67	.25	3.57	.66	2000	1.06
* 23–6 hrs	....	....	7.40	1.37	....	....
23 30	.87	.12	.53	.10	250	.13
30 Feb. 5	2.37	.39	2.55	.47	1000	.53
Feb. 5 14	4.16	.46	.90	.17	460	.21
14 19	0.00	.00	.77	.14	299	.16
19 29	.58	.06	.53	.10	203	.11
29 Mar. 4	3.53	88	3.57	.66	1000	.53
Mar. 4 14	2.11	.21	.77	.14	284	.15
14 23	1.86	.21	3.57	.66	1122	.60
23 24	.12	.12	1.26	.23	561	.30
* 24 26 P. M	3.17	1.57	12.00	2.21	1496	.80
26 27	.01	.01	4.50	.83	818	.44
27 31	.01	.00	.90	.17	141	.07
31 Apr. 6	0.00	.00	.23	.04	112	.06
Apr. 6 13	.75	.11	.11	.02	141	.07
13 21	.70	.87	.11	.02	112	.06
21 28	.46	.66	.08	.01	95	.05
28 May 1	0.00	.00	.08	.01	95	.05

*Includes surface runoff.

The twelve-acre area is the experimental drainage system and has no surface inlets. The two smaller areas receive a little water through surface inlets and the area of 130 acres has surface inlets but the tile system extends under less than half the area. The chief outlet tile for this large area is fourteen inches and there are also two seven-inch tile leading to the outlet weir box. Following the heaviest storm of the year, the runoff from the 130-acre area was twelve second feet for a few hours and was at least five second feet for twenty-four hours. On three or four occasions the total runoff reached eight second feet or twice what the underdrains would carry.

The measurements of runoff and underdrainage indicate that the percent of runoff from small areas here in winter is very high, at least 80% of the rainfall. This is largely due to the wet atmospheric conditions, heavy nature of

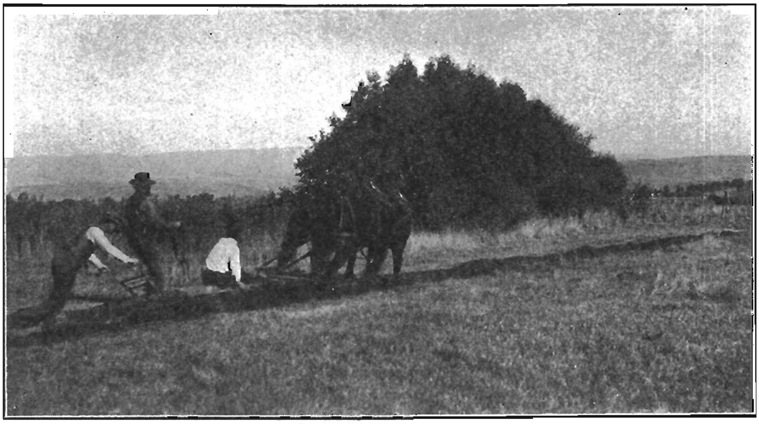


Figure 19. Starting a Ditch in Tough Sod.

the soil, and limited amount of vegetation at this season of the year. The mean daily rainfall and mean runoff in acre inches an acre is shown diagrammatically in the accompanying hydrograph, Figure 12.

The mean maximum discharge appears to be about one-half inch for each acre in twenty-four hours, while the mean discharge is about three-tenths acre inch for each acre in twenty-four hours.

Plant Food in Drainage Water. Samples of the first outflow in November and of drainage from the experimental drain outlet taken again in April were collected for analysis. The chemists found about three times as much nitrogen in the first outflow as in the latter sample. Determinations by Mr. Carpenter follow:

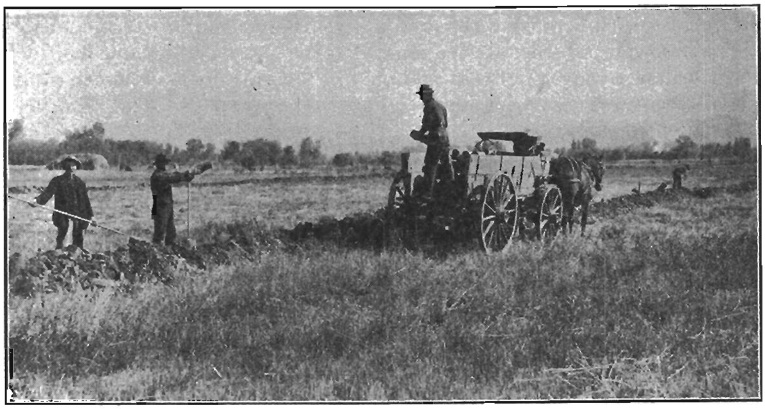


Figure 20. Hauling and Distributing Tile.

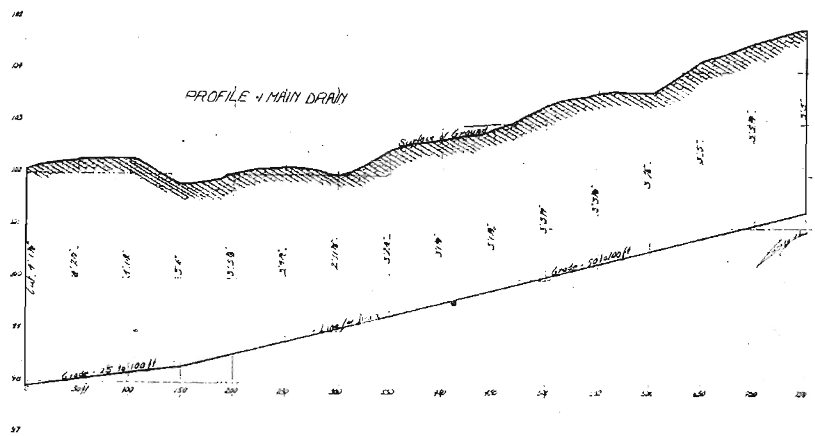


Figure 21. Profile of Main Drain, Experiment Station Plots.

Sample collected Nov. 24,'15; 9.09 parts per million of nitrate nitrogen, NO_3.

Sample collected Apr. 7,'16; 3.60 parts per million of nitrate nitrogen, NO_3.

The total rainfall an acre received by drainage plots for November 30 to May 1 was 44.13 inches. The total acre inches discharge an acre was approximately 35.30 or 78% and the total amount of nitrate nitrogen removed then was 50.62 pounds an acre, worth $2.28 if nitrogen is valued at 20 cents a pound. Without **tile the heavy runoff must occur** over the **surface carrying rich surface soil** with it. Tile water is clear while runoff is very clouded.

Conclusions Regarding Size for Main Drains. Under these conditions, a coefficient of one-third inch is indicated as suitable for large fields. For areas of forty acres or less where some surface inlets are to be used and little provision is to be made for surface runoff, capacity sufficient to remove one-half inch for each acre from the area in twenty-four hours is recommended.

The following table shows the number of acres from which one-half inch of rainfall will be removed in twenty-four hours. If only one-fourth inch capacity is desired the area may be doubled.

TABLE VII. CAPACITY OF MAIN DRAINS (1000 Feet in Length).
After C. G. Elliott

Tile, Diameter, Inches	Fall in feet for each 100 feet					
	0.05 (5/8 in.)	0.10 (1 3/16 in.)	0.2 (2 3/8 in.)	0.3 (3 5/8 in.)	0.4 (4 3/4 in.)	0.5 (6 in.)
	Acres of Land Drained					
5	8.8	9.9	11 7	13.3	15.0	16.0
6	14.0	15.6	18.5	21.0	23.2	25.2
8	28 6	32.0	37.8	42.9	47.5	51.6
10	50.0	55.6	65.8	74.6	82.6	89.6
12	76.1	87.4	103.4	117.2	129.6	140.9

To use the table, find the area to be drained through any point and choose the size according to the area to be drained and the grade above that point. It seems feasible to use tile twelve to sixteen inches in diameter in many

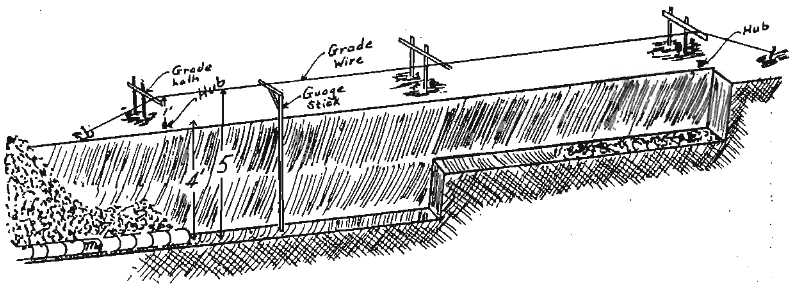


Figure 22. Perspective Sketch Showing Use of Grade Lath.

parts of Oregon. Lower grades of sewer tile of greater diameter have been used here successfully. The quantity of water flowing in a drain can be determined by measurement with a trapezoidal weir such as is commonly used in measuring irrigation water. Directions for making this measurement or a weir table giving discharge will be furnished upon request. A rough estimate of the capacity required can be made by placing a large tile in the ditch and filling around it with dirt so the stream will pass through the tile.

Size of Laterals. A lateral usually drains a strip only a few rods in width. Unless springs are encountered, a four-inch tile is large enough up to 1000 feet in length. There is so much advantage in the larger tile that the slight difference in price of three-inch tile does not justify use of the smaller size except possibly for short lines in heavy soil where there is a large amount of fall. A greater length gives low capacity due to increased friction in the small tile. In peat or alkali, where laterals are often 440 feet apart, and perhaps six feet deep, a five- or six-inch tile is needed. The size depends on prevalence of water or amount of irrigation.

Grade. The greater the fall the greater the capacity. Laterals of four-inch tile should have a fall of at least an inch in five rods and usually twice this amount or two-tenths foot for each hundred can be secured. A lateral that is to run across a springy slope should have three to six inches fall for each hundred feet to make the water go through the tile instead of with the slope of the land. Large tile may be laid with a fall of as little as five-eighths of an inch or .05 feet in 100 feet. The grade should be carefully fixed by the use of a leveling instrument where the fall is less than three inches for 100 feet. Avoid changing from steeper to a lesser grade or install a silt basin if such a change is necessary.

CONSTRUCTION OF UNDER-DRAINS

When to Tile. The best season of the year to drain white land is from April up to July. Earlier than this, excess water and heavy rains will interfere and later in the season the soil becomes dry and hard so that it is more expensive to work. "Beaverdam" and marsh land will be least subject to excess water in late summer while the irrigated land may contain less excess water in early spring before irrigation begins.

Figure 23. Finishing Trench and Laying Tile, Oregon Experiment Station.

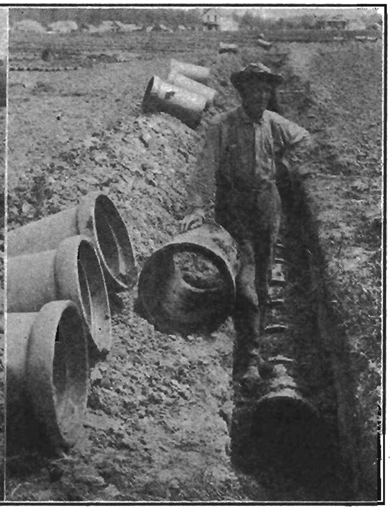


Figure 24. Laying Large Main Drain, Oregon Experiment Station.

The Permanent Survey. While the entire drainage system should be planned before construction begins, it is useless to set grade stakes for more drains than can be installed during one season as these will be plowed out or tramped out by animals and will need to be replaced in a few months. Where the system is small and there is a fall of greater than three or four inches to each hundred feet, the drains may be successfully laid by water grade and the amount of tile needed can be estimated by chaining or carefully pacing out lines to be installed.

Accurate data and good construction are necessary to secure the highest efficiency in a drain system, and where the land is at all flat it will usually pay to get a surveyor to test the feasibility of the system and set grade stakes or "hubs" so that the tile can be carefully laid to a calculated grade.

In staking out a drain system, hub stakes are set at regular hundred- or fifty-foot intervals beginning at the outlet. These stakes are set in a straight line just at the side of the proposed drainage ditch. The hubs are driven nearly flush with the surface and a surveyor's rod is held on these. Guard or guide stakes are driven near the hub and are large enough to be easily seen. Stakes should be provided in advance.

Where a small amount of leveling is to be done and there is sufficient fall so that extreme accuracy is not required, a carpenter's level provided with sights may be used for rough leveling work. A fairly accurate farm level may be bought for about $15 while any farmer or group of farmers with considerable drainage to do could provide a surveyor's level costing $30 or $40.

Getting the Tile. The survey should determine accurately the number

Figure 25. View of Junctions Showing Y Tile in Place.

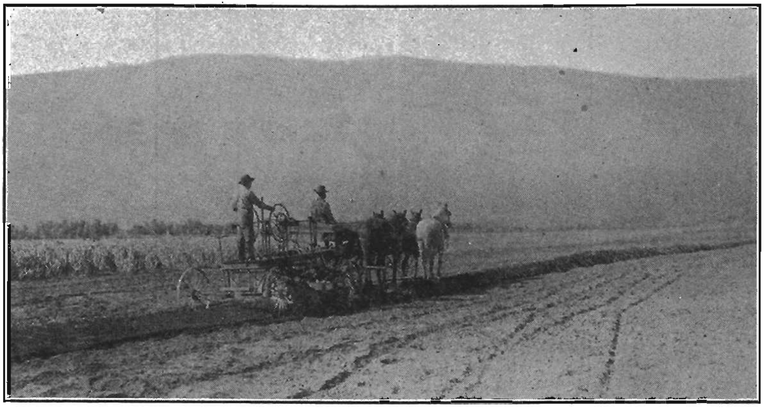


Figure 26. Filling Tile Ditch with a Light Road Grader.

of feet of tile required for the units of the drain system which are to be immediately installed. After the size of tile is decided upon for the different lines, a tile bill may be prepared and bids secured. The tile should be ordered in carload lots if freight is involved and should be hauled directly from the car to the ditches, being distributed along the trenches within reach of the tiler when standing in the trench. (Fig. 20.)

Where there are many long parallel lines of tile to install, a trenching machine may be employed. The wheel type of machine may be secured by a district or contractor. Horse-drawn ditchers may save money where labor is scarce and where deep drainage is not required.

Digging the Trench. The use of the plow in starting the trench is favored only in tough sod where the work is done by unskilled hand labor. A trench thirty-three to thirty-six inches deep can be provided by removing two courses with the tile spade and should be started about eleven or twelve inches wide at the top. A three-course ditch will need to be sixteen inches wide at the surface. In starting the ditch, a guide string is stretched on the ground at one side of the stakes. At bends a one-fourth-inch rope should be laid on the ground in a smooth curve. An eighteen-inch, square-pointed tile spade is commonly used for removing the first spading. The trench should be kept straight and the sides smooth and plumb. A good spademan will set the spade a little angling and will not need to trim the side of the trench much with a spade. A skilled worker will not leave much loose dirt in the bottom of the trench. Crumbs left in the trench should not be removed until the second spading is to be dug, if the weather is dry. A round-pointed shovel can be used to remove this loose dirt, after which the second spading is dug within an inch or so of the proposed grade. Some workmen prefer a round-pointed tile spade for removing the second spading, which makes the trench a little narrower at the bottom. The grade lines should be set before the second spading so that in no case will the ditch be cut below the proposed grade line. The last inch or two is taken out with a shovel and tile scoop, leaving a smooth, firm, tile base.

The Use of the Grade Lath. The depth to dig at each station is measured from the top of the hub stakes. In order to dig a trench to grade or with a finished straight tile base between these grade points, it is best to use a gage line and gage sticks, as shown in Figure 22. Grade lath are set over each hub stake at a uniform and convenient distance above the proposed tile base. A wire is stretched over these grade lath a uniform distance above the proposed grade line and parallel to it. If the grade lath are four feet above grade the ditch should be trimmed out until a four-foot gage stick will just reach from the string to the bottom of the trench when held in a vertical position. **To set the grade lath at a proper height, subtract the depth of the cut from the length of the gage.** Grade laths may be set across the ditch or at one side with a cross arm extending out even with the near edge of the trench. A No. 18 gage galvanized wire makes a good gage string, as it is light and strong as well as durable. In cutting through high ridges, a longer gage may be required. The gage line must be kept tight.

Laying the Tile. Tile laying should start at the outlet and proceed up the stream just as soon as the trench is finished to grade. A careful workman can be selected to handle the tile scoop and shovel just ahead of the tile layer. A tile scoop should leave a firm tile base and a little running water will help to make the tile base smooth. A carefully finished trench facilitates laying the tile. The grade should be tested for every length of tile and the pieces should be placed in a straight line with the long side up so that the joints fit tightly at the top side and are nearly flush at the lower inside edge. An opening of one-eighth inch is allowable but larger openings should be covered with fragments of broken tile called "bats." The tile may be rotated to fit, and imperfections in the tile may be taken advantage of in making slight turns. Ill shaped, cracked and broken pieces should be discarded. Where quicksand or muck causes a soft bottom in the trench, it is best to lay the tile on a board.

Figure 27a. Tile Outlet and Protection.

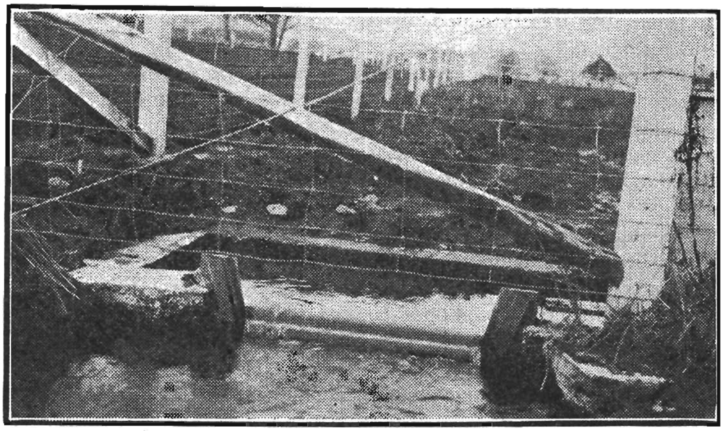


Fig. 27b. Outlet and Weir.

Clay, burlap, or straw may be used to prevent quicksand entering the joints. Curves can be fitted by chipping off the inside edge of the tile carefully with a chisel and hammer. The Y's can be constructed, but it is best to order these when ordering the tile. Inspection of the drains before filling should be made by the land owner to see that no inferior pieces have been used, that there are no wide joints which appear unprotected, and that the tile is laid true to grade. If there is no running water, a level can be used to test the line at frequent intervals for dips or swells in the grade. If muddy water is encountered in the trench, it may be dammed up and held back until it can be passed through the tile in quantities sufficient to avoid silting. Where the ditch banks are unstable, curbing may need to be resorted to or the tile blinded in each evening. Precautions should be taken against damage by storms at night during construction.

Filling the Trench. After inspection, tile are blinded by a workman who stands beside the trench and shaves mellow dirt from the sides of the ditch with a spade. A layer of mellow dirt three or four inches deep prevents the tile getting out of line. Plowing off the shoulders of the trench with a plow that is equipped with long eveners, will put the surface soil in the lower part of the trench. Other tools used for filling trenches are lateral cleaners which are shod, light road drags, or light road graders. (Fig. 26). Filling is more readily done before the dirt has become compact and settled.

Tiling Contracts are frequently let in the Willamette Valley at twenty-five to forty cents a rod. The contractor usually furnishes the tools and the land owner furnishes the tile along the proposed drain. Whether board is to be provided and whether the trench is to be completely filled should be stated in the agreement. The contractor is usually required to begin at the outlet; lay true to grade and to pursue the work with due diligence. Arrangements are frequently made for securing pay for a part of the finished work during con-

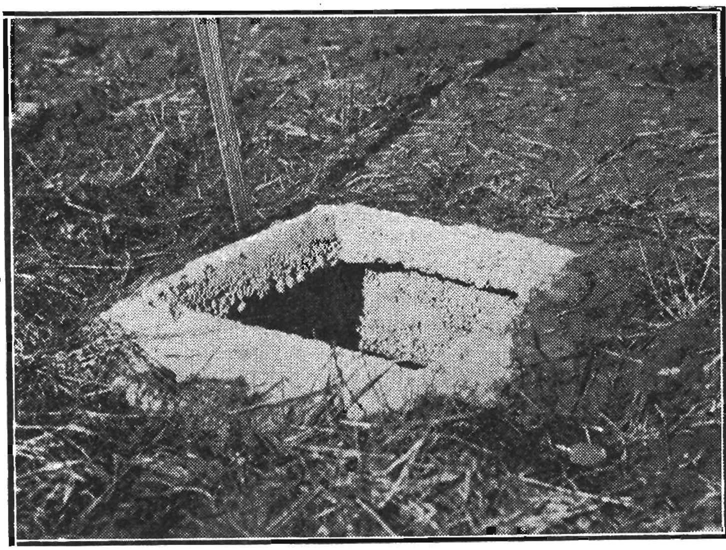


Figure 28. Concrete Silt Basin.

construction. While the data are fresh in mind and before the tile are hidden, a sketch should be made of the tile lines, showing their length, depth, and distance apart. A compass can be used to locate the bearings of different tile lines and permanent land marks such as trees and property corners should be referred to so that any part of the drain system can be located in after years. Maps may be simple but should be definite. A memorandum of the items of cost should be filed with this map.

There are numerous important details in tiling that are necessary to attend to if the drain system is to be permanently successful. A few important points upon which numerous inquiries have been received are herein described.

Outlets. It is of primary importance that the drain system have a good outlet. It has been said that a drainage system without an adequate outlet is like a man who is all dressed up with no place to go. Where the outlet is submerged, the velocity of the outflow is checked and sediment is apt to collect and clog the drains. The water should have a free spillway at the outlet. A partly submerged outlet can be kept clear where there is considerable volume of water and velocity of flow if a barrel or box is provided for collecting sediment and is cleaned out perhaps twice a year. The submerged outlet, however, is not desirable, as the land will never drain below the level of the water in the outlet.

The outlet pipe or tile should be vitrified or a corrugated culvert may be used. Such material is not affected by freezing or tramping of animals. The end of the outlet should be screened, as in Figure 27a, with quarter-inch iron rods placed perhaps an inch apart to prevent rodents entering the tile. Where

Figure 29. Tile Silted. Due to Poor Outlet.

the outlet is submerged at times, an automatic flap gate may be provided which will be hinged at the top so as to close during times of high water or when the drainage ceases in the summer. A small bulkhead should be provided at the outlet to force the water to run out through the tile instead of cutting out around it. This will also retain the earth bank and serve as a monument to mark the location of the outlet. The footing should extend out below the tile to form an apron on which the tile may discharge without causing erosion.

Silt Basins. Silt basins are small cisterns or man-holes in the drains extending to the surface from a foot or more below the tile grade. These are usually provided in fence corners where two or more lines of tile join. Silt basins afford a means of collecting and cleaning out silt; they help to collect surface flood water quickly, prevent the drain from becoming clogged and may sometimes be arranged to afford watering places for the stock. Silt basins also permit inspection of tile and may increase the head of water on the outlet drain in time of high water. A small silt basin can be constructed by placing a twelve-inch sewer tile, having the required outlets, on end. For larger silt basins, brick or concrete may be used.

On the Experiment Station, we have found it convenient to construct silt basins or manholes of concrete (See Fig. 28). The soil is used for the outer form and the inner form is made of staves like a silo, one of the staves being beveled so it can be removed after the concrete has set. The form makes the manhole five feet deep and three feet in diameter with a twenty-inch opening in the top, which may be covered with a concrete lid. The walls are about four inches thick. The tile lines are in place when the silt basin is constructed and the form sets tightly against the tile emptying into the silt basin. A surface inlet to the silt basin may be provided. The water should be screened and brought in on a grade to prevent roiling the sediment with the water in the silt

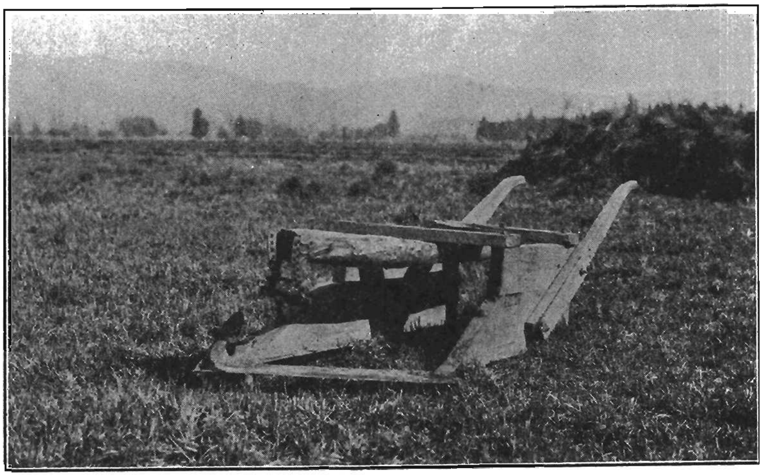


Figure 30 Rush Cutter. This Tool is Used to Slice off Rushes Just Below the Surface. After Drainage, Rushes may be Killed out.

basin. A few cubic feet of ground or broken tile in the trench will make a fair inlet at the head of the drain.

Junctions. The laterals may be laid out perpendicularly to a main drain but should join the main with a curve so that the connecting tile or Y will have an angle of about 30°, as in Figure 25. The curve should have about a five-foot radius. There should also be a drop where the lateral joins the main, which will permit free discharge into the main drain.

Obstructions. The principal obstructions to tile are small animals, roots, and silt (Figure 29). Protecting all exposed ends of the tile system with screen or broken pieces of tile will prevent small animals entering. Roots of trees, such as willow, elm, tamarack, and soft maple, are troublesome. Cultivated plants, such as alfalfa, grape vines, and kale also give trouble where spring water runs in a tile line throughout the growing season. Water-loving trees within twenty or twenty-five feet of the drain should be girdled or cut down, or the tile can be cemented at the joints where the drains pass within this distance of the trees. Silt will be less troublesome in large tile. Small tile must be laid true to grade to prevent trouble and the carrying capacity will be greater and friction will be less if the lower inside lines of the tile are flush.

To locate obstructions, dig holes in several places over the tile. A tile map and an end-gate rod will be of value in looking up and probing for tile lines. Below the obstruction the water will not rise in a dug hole but will fall away into the tile. Above the obstruction the water will rise and stand in the hole. The tile can be uncovered above and below the obstruction and can be cleaned out with a jointed sewer rod or by use of a long, limber pole or wire cable that is frayed out into a wire brush at the end.

A tile line to be permanently successful must be given some attention.

Figure 31. View of Tillamook Drainage District Showing Watterlogging Before the Old Ditch was Deepened and Enlarged.

Inspection and cleaning out of outlets and silt basins should take place at least twice a year,—in the fall before the rains begin and again during the highest water of the season.

COSTS OF TILE DRAINAGE AND PROFITS

The cost of drainage varies greatly with the kind of soil, size of tile, thoroughness of drainage, method of construction and labor conditions. First of all, we must determine the number and size of tile required before we can make definite estimate of cost.

The Tile Bill. From the permanent survey, a tile bill should be arranged showing the number of feet of different sizes of tile required for each main and each lateral, and the total number of different sizes of tile to order. The tile should be ordered in carload lots for delivery at the nearest railroad point, requiring the shipper to be responsible for breakage in shipment. The following table shows the approximate prices and weights of tile on board cars at Willamette Valley points.

TABLE VIII. APPROXIMATE PRICES AND WEIGHTS OF TILE

Size in inches	Price per 1000 ft.	Weight per ft. in lbs.	Average carload in feet	No. of ft. per ton
3	$17.00	4½	7500	400
4	22.50	6½	6500	334
5	30 00	9	5000	250
6	40.00	11½	4000	182
8	65.00	18	2400	111
10	105.00	25	1600	80
12	150.00	33	1000	60
14	180.00	43	800	56

It may be necessary to make an allowance for freight in addition to the prices indicated in the table. Thirty-thousand pounds is a minimum weight for a car of tile and the average weight of a carload of tile is about forty thousand pounds. As tile are rather bulky, a ton makes a fair wagon load. About five hundred four-inch tile or about two hundred six-inch tile can be hauled at one load. Two men with wagons when hauling to the same field can assist each other in loading up and unloading.

Trenching. Digging the trench, laying the tile, and blinding in with three or four inches of mellow dirt commonly costs, in the Willamette Valley, from twenty-five cents to forty cents a rod. The latter price frequently includes filling the trench. Reports on tile drains aggregating one hundred miles of tile that have been placed in the Willamette Valley show that the average cost for digging and laying for each rod has been thirty cents. The cost of digging and laying varies greatly with the kind of soil, size, and depth of tile and difficulties encountered. Table IX, arranged by Prof. E. R. Jones of Wisconsin, shows the relation between depth and size of drain and the cost for each rod:

TABLE IX. APPROXIMATE COST PER ROD OF DIGGING TRENCH, LAYING TILE, AND BLINDING

Size of tile	Depth in feet			
	3	4	5	6
4 inch	$0.30	$0.50	$0.80	$1.25
5 "	.35	.55	.85	1.30
6 "	.40	.60	.90	1.35
8 "	.45	.65	.95	1.40
10 "	.50	.70	1.00	1.45
12 "	.55	.75	1.05	1.50

Filling the trench with a plow or road drag has been done locally for ten or twelve cents for each hundred feet. Where the filling must be done by a more laborious process, it may cost twenty to twenty-five cents a hundred feet. To these items should be added five per cent for surveys, and superintendence, or ten per cent including outlets, silt basins, tools, and miscellaneous expenses.

The tile required for each acre, if laid in parallel lines and four rods apart, will be forty rods or, if six rods apart, thirty rods of tile will be required. At a total cost of seventy-five cents to one dollar a rod for laterals, this would mean thirty to forty dollars an acre for thorough drainage of the wettest areas on the farm. It rarely happens that more than twenty-five percent of the average farms will require such thorough drainage. More frequently, wet swales or springy spots are drained with a random system of tile lines, making it possible to work the whole field at one time as well as increasing the production of the low area. In order to direct attention more fully to the cost and profit connected with drainage, a few typical examples of actual costs and results from different sections of the State are here given.

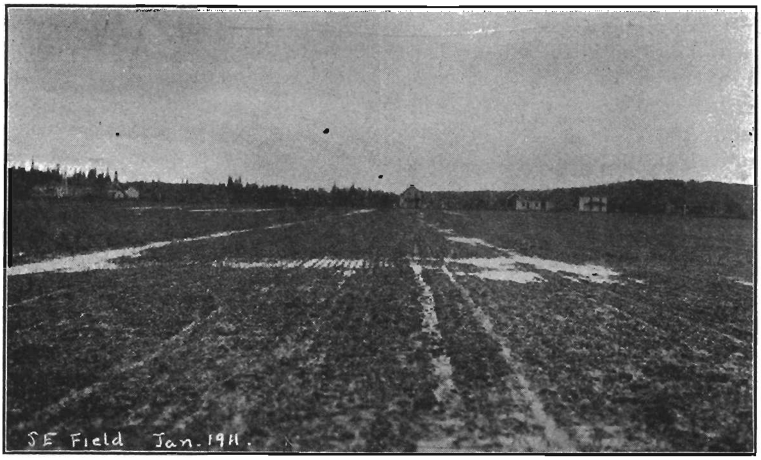


Figure 32. Field on Experiment Station Farm Before Drainage, Jan. 1911, Looking South.

Results from Tile Drainage in Oregon. A drainage system was installed on a 72-acre field of **white land** one mile south of Albany by the U. S. Government in 1908. From three to ten-inch clay tile were used, and the depth varied from three to four feet, and the distance apart was purposely varied from sixty to one-hundred-fifty feet. Grades ranged from two-tenths of a foot to five-tenths of a foot for each hundred feet and the entire cost of draining the seventy-two acres of land was $19,292.79 or $26.80 per acre. Drainage has made it possible to raise clover on this land and the amount of underdrainage is gradually increasing each year. The system is declared a success by the owner of the tract who estimates that the land is actually worth now for farming purposes four times what it cost previous to being drained.

Nearly twenty-five years ago, a drain system was installed in a white-land area on the College farm at Corvallis under the direction of Professor French. The professor states that before being drained this area was so wet that it produced little but wild oats, tar weed, sorrel, and cat tails. Since it was drained, its yields have steadily increased. Last season, about five tons to the acre of clover hay was produced on this land. The drains have paid for themselves over and over and are more effective today than ever.

Project No. 40 is installed near Troutdale. The field contained seven acres of **peaty loam** too wet to farm and producing only a marshy growth, providing a little pasture. The drain system installed included:

Tile, 5000 feet, 3-inch, 4-inch and 5-inch, costing	$129.00
Freight bill	12.00
Hauling of twelve loads at $2 per load	24.00
Digging 306 rods at 30 cents per rod	91.80
Total	$244.80

or $34.97 an acre.

Figure 33. Field on Experiment Station Farm After Experimental Drainage Plots were Installed. Looking North, Jan., 1916. Not a Barrel of Surface Water Stood on this Field the Past Winter.

The owner states that until they drained the land, they did not work the field on account of wet places. The drain system was installed in 1912 and the following winter the main ran full for several days at a time. The following year, according to the owner, the piece produced $176 worth of potatoes to the acre. In 1914, this same field threshed out sixty-four bushels of oats to the acre. A stand of clover has been secured which was impossible before draining. The owner says, "We have received full returns already for our investment."

Project No. 43, an **alkali** area, is located in Crooked River Valley three miles east of Prineville. Before this land was drained, it was regarded as practically worthless because of the presence of black alkali in the soil. Four acres of black loam were drained with the following costs:

Tile, 1500 feet	$ 35.00
Freight from Portland to Redmond	72.00
Hauling tile to ranch	17.50
Labor seven days at $2	14.00
Total	$138.50

or $34.63 an acre.

These figures are given by the owner who states:

"The tile were laid sixty feet apart and three feet deep and easily drained at that distance. If placed four feet deep and one hundred feet apart the tile would have drained six acres instead of four. We were unable to get the latter depth owing to difficulty in securing an outlet for that level. Securing the tile in carload lots would have reduced the expense to $89 or $22.25 an acre.

"Before the land was drained the crop in 1914 for the four acres was twenty bushels of barley or five bushels an acre. The crop in 1915 for the four acres was 278 bushels of wheat and barley or 69½ bushels an acre. Placing a value of eighty cents a bushel on this crop the result is $222.50, which, less the cost of draining $138.50, equals $83.90 net gain this year from the above operation. From these results, we firmly believe that tile drainage is an unqualified success. This four-acre tract we tiled only as an experiment and we intend to drain forty acres more as quickly as possible. There are few investments which pay so well."

Successful Drainage Practices in Willamette Valley. A circular letter was mailed in 1914 to a list of farmers in the Willamette Valley who had tiled their land, for the purpose of learning something of the extent and success of tile drainage. About fifty replies were received, over forty of them giving answers to the list of questions asked.

The replies came from farmers having from three to thirty-five years' experience with tile located in the "white land" and other common soil types of the valley. The reports cover experience with approximately 100 miles of tile which drains several thousand acres of low land and which cost about ten dollars an acre for the total area affected by the drains.

The average fall reported for drains in operation was about one foot for each hundred feet, and eighty per cent of this tile was laid by water grade while the rest was laid with the aid of a surveyor's level.

A common wage for digging trench and laying tile for four-inch lateral three feet deep as reported is thirty cents a rod. Most of the ditches were refilled by use of a plow with a long evener. Under fair soil and weather conditions the amount dug and laid each day averaged about one hundred feet for each man. Under good conditions as much as one rod an hour was installed.

Question 23 in the circular letter read, "**Has your drain system handled the excess water as well as expected?**" Thirty-nine replied to this question. Thirty-six of these replied "Yes"; one replied "Better"; one replied "Yes, except in small lateral"; and one stated that tile "did not handle flood water as expected."

Question 24 read, "**Has drainage improved your soil?**" Twenty-nine replied "Yes"; the other replies to this question were as follows: "Wonderfully," "Very much," "Indeed it has," "Greatly," "As far as completed," "Too soon to tell."

Question 26 read, "**Do you consider that drainage pays under your conditions?**" Thirty-seven answered "Yes." The other replies received were "Decidedly," "Certainly," and "It pays big." There was no negative reply.

Question 25 read, "**Can you cite any definite results?**" Replies to this question were generally favorable and some of these should prove of interest. One replied "One hundred per cent better," another "Soil can be worked earlier in the spring." Other replies were as follows:

"We lost 1500 prune trees out of 5000 set out before draining and only 300 out of 7400 set out after draining."

"Water before draining stood on the field all winter but now it drains after only two days."

"The land is dry enough to farm and produce good crops where before draining it was waste."

"Yes, one-half of the field could be used only for spring crop and then dried out hard as a bone. Now with drainage it is better than the other fields."

"Yes, land that formerly did not pay taxes now produces good crops. I consider that tile has doubled the output of the farm and the system is not yet completed."

"We get fair crops now and obtained nothing before draining."

"Land can be worked more conveniently and earlier."

"Yes, could not raise winter wheat on the land previous to tiling; since tiling winter wheat does well."

"Yes, we can plow wet spots a month earlier on some soils."

"I put in about 3000 feet each winter. One-year-old ditches are drying the ground about ten feet wide, two-year-old ditches twenty feet wide and three-year-old ditches forty feet. I had black soil that was hardly paying taxes before tiling. Since tiling, I have fine corn, clover, and kale and not any water. It would be best to come and see the real benefit. There is but little wet land in this section that it would not pay to tile."

"Our drainage system is fifteen to thirty-five years old, handles the excess water so ground can be plowed after we have two days of clear weather following any hard storm. The drainage system has improved soil fully one hundred per cent."

"After the soil is thoroughly drained, it becomes very porous and will hold the moisture in dry weather fully one hundred per cent better. The soil becomes warm and the rootlets of crops can penetrate the soil a great deal deeper."

"I am more than satisfied with my drains. The main drawback to drainage is lack of funds. I am putting in about three thousand feet more this winter. Last summer I raised corn eight feet high on what was the very wettest part of my farm before draining, and my oats were doubled in yield. Three neighbors are putting in a little tile as a result of my making a start last winter."

"Yes, land that formerly did not pay taxes now produces good crops. I consider that tile has doubled the output of my land and the system is not yet complete. I certainly do consider that it pays."

"Yes, where once was a swamp I now raise fifty to ninety bushels of oats to the acre."

"Indeed, I have drained my land with success, I should rather have 160 acres drained land that 320 undrained if I had to live on it and farm it."

Profits from Drainage in the Willamette Valley. Timely drainage usually pays in increased crops and increased land value. Those who have drained say that it pays. The writer has examined the greater part of the tile systems in use in the Willamette Valley and other parts of Oregon and, while a few drains in use are too small or too deep, or have been poorly constructed, we fail to find a tile system properly installed in the Willamette Valley which has not been successful. Tile drains usually improve for years. If properly installed, they should add value to the land equal to their cost. The profits from drainage are large and drains frequently pay for themselves within a few years. It costs money to hold wet land. Most of our wet lands, particularly in this valley, will pay a better rate of interest on the total investment if drained. Drainage is a permanent improvement; is the fundamental step in the improvement of our wet lands; it makes rotation with soil-building crops possible and constructive soil treatment effective.

FARM OPERATIONS THAT AID DRAINAGE RECLAMATION

Experiments with Drained Land. The plan of drainage plots, Figure 10, shows the general plan for studying the effect of different soil treatments for improving the drainage qualities of the land included in the drainage experimental tract on the Station farm. It is planned to seed the whole field to one crop each year and to employ a three-year rotation; namely, spring barley, followed by clover, one crop a year, then a cultivated crop such as corn. The value of lime, manure, green manure and combinations of these treatments are to be tried out on duplicate plots and their value will be judged by the use of check plots.

In the new experiment field, the value of straw as compared to gravel, cost and effectiveness considered, in helping the water to enter the tile, and the effects of each, will be measured and judged by the comparative yield and the relative amount of runoff.

Operations that Aid Water in Entering Tile. From studies already made, it appears that the following things can be done to aid the tile in collecting water in white land or other retentive soil: (1) In draining a retentive, saucer-like area, lay out the protecting drains so as to collect seepage water or surface water before it gets onto the retentive soil. (2) Use catch basins in the upper side of the field or at points where the surface water is apt to run onto the heavier soil. Also, use catch basins in the lower points in the field, if necessary, to permit water to pass down into the drains. (3) After laying and lining the tile, allow the trench to remain open a few weeks, if possible, so air can come in contact with the subsoil and cause it to slack and crumble. (4) In filling your trench, put in sod or straw and then the top soil immediately over the tile. Straw will decay, thereby increasing the open space, whereas gravel may silt up. However, where the grade is steep, gravel would protect tile from washing out better than straw. Put the sticky, sub-surface soil in the top of the trench, if it is used. (5) Plow the land deeply when it is dry enough to crumble. (6) After draining, lime will become more effective and will aid in mellowing the soil. (7) Drainage and liming will make it possible to raise clover on the land in most cases. Clover roots will penetrate the drained soil and will be of great value in loosening up our valley land so that water can pass through and get into the drains. (8) Where possible, plow the land so that the dead furrows will fall directly over and parallel to the laterals giving the surface a slight slope toward the laterals. Surface water that collects in these dead furrows will pass into the laterals more readily. If it remains on the surface temporarily, catch basins can be provided that will aid in passing into the drains underneath.

Treatment for White Land. **Clover should be grown** on the white land about each third year and grown **on heavy land like our white land about every third year** in rotation with grain and cultivated crops or other similar crops. A decidedly larger relative outflow has been observed in the wet season following a clover crop and water has stood less on such fields. With manure and clover plowed under once in each rotation, the yields of these crops on our white land can be built up to compare very favorably with the naturally drained brown loam soil in this valley.

Treatment for Peat Lands. Peat marshes can be burned off to dispose of the rank vegetation when there is moisture enough to protect the soil from burning out. The use of a rush cutter as shown in Figure 30 will facilitate disposing of rushes on low land. This native growth can be largely replaced by cultivated grasses and clovers to supply pasture and forage until the native vegetation is subdued. The first cultivated crops may depend on altitude but large-seeded, rank-growing crops which are hardy and resistant to excessive moisture, such as rye or oats or field peas or barley, can be used while the sod from the newly broken marsh is decaying. Open ditches for laterals will frequently be used during this process (See Fig. 36), and as the marsh settles more permanent drains will be put in which can be extended as needed to perfect drainage so that more intensive cultivated truck crops can be grown where climate and market facilities permit.

Treatment for Alkali Lands. Alkali land, after being drained, can be improved, where water is available, by flushing off accumulated surface salts by late fall irrigation. Shallow open ditches may help remove heavy alkali crusts quickly. In one or two seasons, irrigation will usually remove and disperse the alkali sufficiently so that by deep plowing hardy crops such as rye or sweet clover can be established. It may take from one to three years to complete the reclamation of these lands, depending upon the amount of alkali and the retentiveness of the soil. Such crops as rye or sweet clover plowed under will supply humus and nitrogen and loosen up the soil so that moisture conditions may be more readily controlled. During the process they may provide some return in the form of pasturage. The alkali lands when thoroughly reclaimed are usually strong in the necessary plant foods and suitable for alfalfa and the other staple crops of the region.

The treatments above described are calculated to assist in loosening up and aerating the drained soils and to assist water in entering the drains provided. Legumes and manuring crops suggested will also supply humus and nitrogen, which are ingredients none too plentiful in much of the white land and irrigated and alkali land. This treatment would pave the way for cash crops and make it possible to get the highest possible benefit out of the drains installed in order to render the enterprise thoroughly successful and profitable.

II. DISTRICT DRAINAGE

DRAINAGE DISTRICTS AND DRAINAGE LAWS

The greatest obstacle in draining our so-called "white lands" and other large areas of nearly flat land, is the lack of an outlet for the individual farm. In these areas, a community interest is imposed on the land owners by nature. To secure a community outlet ditch where many owners are concerned it is necessary to have a practical district drainage law and to organize the locality to be benefited into a drainage district. **Such a law has for its object the construction of outlet drains for the community through cooperation of the owners benefited and of meeting the cost of equitable assessment.**

Fundamental Principles. The **principles involved** in the undertaking are (a) it must be cooperative and optional, (b) it must be for the public welfare, (c) the assessments are adjusted in proportion to benefits, (d) the right of way must be paid for, (e) the owner has the right to appeal and secure equitable assessment, (f) the right of outlet should be perpetual and attached to the land title, (g) the drainage tax should be a first lien on the land.

The Oregon District Drainage Law. Such a law, to be successful, must of course conform to the laws of the State. The assessors should not be related to the owners by blood or marriage, the benefits should be more than cost plus damages, the bonding should be decided on by the owners of the land in the district only.

The first practical district drainage law was enacted by Illinois and this was followed by similar laws in other corn-belt states. These laws were improved by amendment from time to time until they became complicated. The National Drainage Congress appointed a commission to draft a uniform and model district drainage law in 1912. The modern law drawn up by this commission was promptly adopted by the State of Missouri where drainage bonds are now said to sell above par. The Oregon legislature enacted a district drainage law in 1911. Many difficulties were encountered in attempting to organize drainage districts under this law and but little progress was made. Partly through the efforts of the Agricultural College, the State Engineers' Office, and the State Drainage Association, a drainage law patterned after the model drainage law, refitted to Oregon conditions, was passed by our 1913 legislature and became effective May 22, 1915. This law was recommended by the leading drainage authorities in the United States. Such a law has recently stood the test of the United States Supreme court. The successive steps necessary to secure outlet ditches under the new law are shown diagrammatically in Fig. 34. The principal features of the law are as follows:

(a) The owners of fifty per cent or more of the acreage in the proposed district must petition the county court, which has general supervision of drainage districts, for the organization of a district. The petition must contain the name of the district, approximate acreage, and the names of land owners within the district. It must state the general plan of reclamation and that the drainage proposed is regarded as feasible.

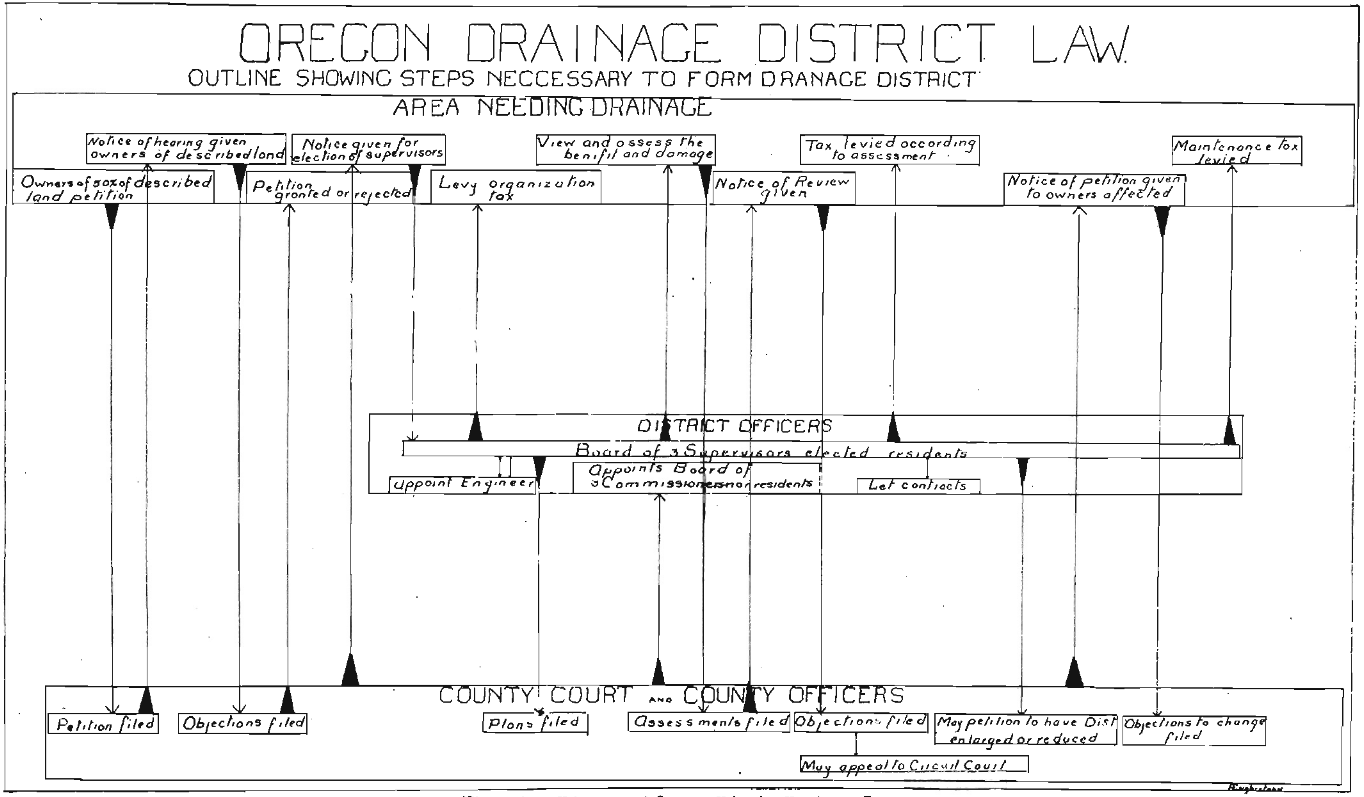


Figure 34. Diagram of Oregon District Drainage Law.

(b) A formal notice of petition and of hearing must be sent by the county clerk to all the land owners. The county court considers the petition and any objections filed, and thereupon establishes the district or dismisses the petition.

(c) After approval of the petition the county clerk calls a meeting of the land owners for the purpose of electing a board of three supervisors who are land owners in the said district, to have general charge of the enterprise, and to hold office as determined by lot from one to three years or until their successors are elected and qualified.

(d) The board elected has power to appoint a drainage engineer and to levy a tax of not over fifty cents an acre for the purpose of paying expenses incurred or to be incurred in organizing said district. The board files with the county clerk a plan of reclamation prepared by the engineer and may petition the county clerk to alter the boundaries of the district. The board is required to keep a record of their proceedings.

(e) The county court appoints three commissioners who are disinterested land owners to make the assessments of benefits and damages and file a report with the county clerk.

(f) Property owners are notified of this report by publication and may file acceptance with the county court.

(g) The drainage board must levy the assessments, let contracts, secure the construction of all drainage work; they may issue bonds and collect the assessments in annual installments. They may also levy maintenance tax and define terms whereby existing drains may be connected to the ditches in the district.

The new law places the important work in the hands of the land owners who are directly interested. It is believed by good attorneys that the new law will be found adequate and clear in the methods of organization, administration and maintenance of reclamation districts and that it will prove thoroughly practical.

Where a few persons all agree to drain, they may petition the county court and undertake drainage on their own responsibility. There is also a

TABLE X. ORGANIZED DRAINAGE IN OREGON

Name of district	Area Acres Approx.	Chief Soils	Cost per Acre Approx.	Officers
Under 1911 Law				
Umatilla	1,500	Fine sandy loam	$10–$30	
Louisignout	1,000	Silt, loam and peat	20.00	C. J. Birdsell, Pres., Hillsboro
Lower Klamath	27,500	Peat	6.00	A. A. Mehaffey, Sec., Klamath Falls
Fairfield No. 1	200	Peat	15.50	G. A. Miller, Pres., Gervais
Lake Labish	2,000	Peat	7.50	
Under 1915 Law				
Clatsop No. 1	1,425	Peaty muck	26.31	W. M. Jones, Pres., Blind Slough
Beaver District	4,705	Peat	40.00	R. B. Magruder, Sec., Clatskanie
Tillamook	700	Peaty muck	3.00	Burr Beals, Sec., Tillamook
Big Nestucca	1,000	Peaty muck	20.00	Petition presented May 3d
Nyssa	5,050	Loam	17.00	Frank D. Hall, Sec., Nyssa
Ontario	5,000	Loam	15.00	Petition ready.

state dyking district law in force which has proved to be simple and practical. Drainage districts organized under similar district laws have effected a wonderful transformation in much of the corn belt, and district drainage will make it possible to double the productiveness of three or four million acres of wet land in this State.

Organized Drainage in Oregon. The extent to which drainage districts have been organized in this State is shown in Table X.

Several other districts are taking steps towards organization of districts, the most notable of which are the Oak Creek and the French Prairie districts, each containing some nine thousand to twelve thousand acres. Other districts proposed are the Long Tom, Warner Valley, Columbia Slough and numerous smaller projects. Drainage canals have been dredged in the Blitzen Valley, Chewaucan Marsh and Wapato Lake by private enterprise.

DRAINAGE DISTRICT PROCEDURE

Preliminary Survey of The Tillamook Drainage District. The Tillamook district was the first to be organized under the law and since it has been carried to completion, is used herein as an example. At the request of parties interested, through their County Agriculturist, the writer, accompanied by Mr. G. A. Hart, Engineer of the U. S. Office of Drainage Investigations, made a preliminary examination of the districts May 15, 1915. The tract a mile or so wide and a mile and a half long, shown in Figure 31, is located just south of the City of Tillamook and includes a marshy area too wet to afford much pasture. The soil below the tenth contour is peaty muck underlaid by blue clay at five or six feet. Silt loam covers the remainder of the bottom land, while a gravelly loam extends over the bench. The rainfall is perhaps 75 inches a year. Preliminary levels and soil examinations were made to determine the feasibility of the drainage and a canvass was also carried out to determine the sentiment of owners in regard to the organization of the district. Very little opposition was encountered, and as the soil and topographic conditions were favorable a petition for drainage district was prepared.

Organization. The petition prepared and notice of hearing issued are given here to exemplify the definite idea of procedure under the new law, which went into effect May 22, 1915.

"NOTICE OF HEARING PETITION TO FORM DRAINAGE DISTRICT"

In the County Court of the State of Oregon, for the County of Tillamook.

Notice is hereby given that hearing on the following petition will be held at the Court House in the City of Tillamook, County of Tillamook, State of Oregon, on the 16th day of July 1915, for the purpose of determining whether the prayer of said petition shall be granted.

All persons owning or claiming an interest in lands described in said petition are hereby notified to appear at said place and on said date if prayer in said petition should not be granted.

(Signed) Clerk of the County Court.

To the Honorable County Court of Tillamook County, State of Oregon.

The undersigned, being owners of more than fifty percent of the acreage of the contiguous body of swamp, wet, and overflow land in Tillamook County, Oregon, hereinafter described, do hereby petition your Honorable Body to cause to be organized a drainage district for the purpose of having such lands reclaimed and protected from the effects of water for sanitary and agricultural purposes and for the convenience and welfare of the public utility and benefit, and for the purpose of this petition we state the following mattersas required by Chapter 340 of the General Laws of Oregon, for the year 1915:

I

The name proposed for such district is "Tillamook Drainage District."

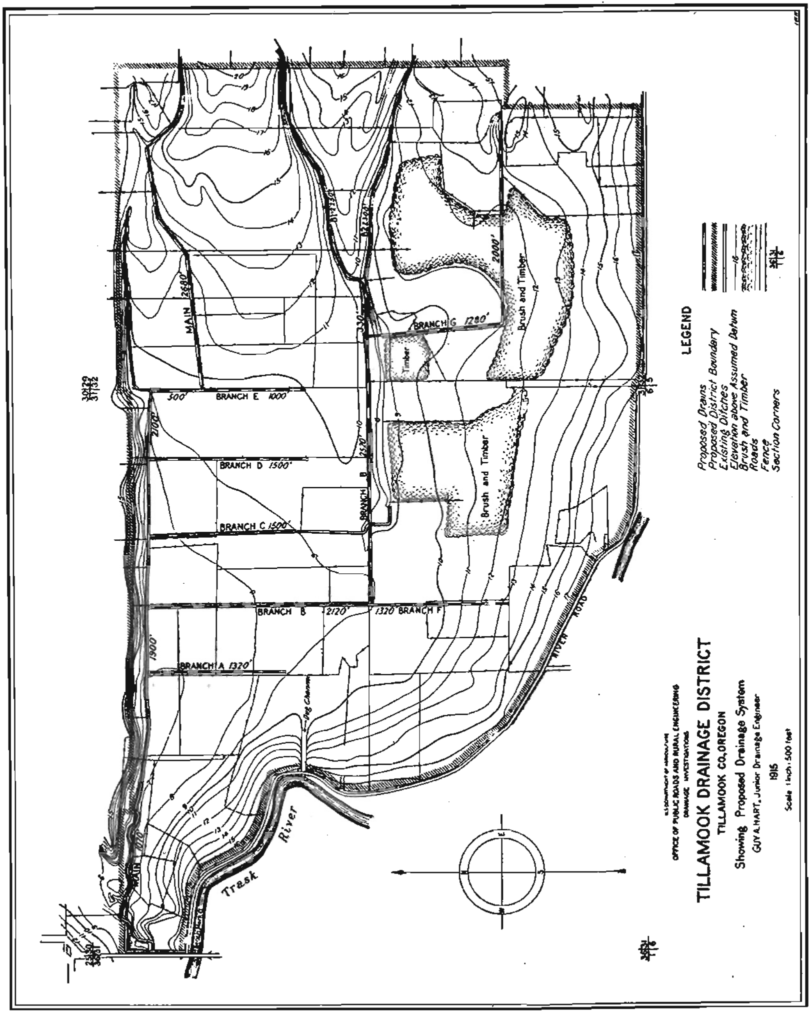


Figure 35. Map of Tillamook Drainage District.

II

The boundary lines of the proposed district are as follows:
(Here followed description of boundaries by legal subdivisions)

III

The total acreage included in the said proposed district is 555 acres.

IV

The names of the owners of the land in said proposed district, as shown by the records of Tillamook County, Oregon, and the acreage owned by each of said owners is as follows:
(Here followed names and acreage owned by owners concerned)

V

The proposed reclamation and protection of said lands is for sanitary and agricultural purposes, and such proposed reclamation and protection will be conducive to the public health and welfare. and of public utility and benefit.

VI

All of the lands included in said proposed district are properly included therein. and will be beneficially affected by the operations of the proposed district.

VII

The benefits of such proposed reclamation and protection will exceed the damage to be done. and the best interest of the land included, and of the owners of such land as a whole, and of the public at large will be promoted by the formation and proposed operation of said district.

VIII

The formation of a drainage district under the provisions of Chapter 340 of the General Laws of Oregon for 1915. under the provisions of which this petition is proposed. is a proper and advantageous method of accomplishing the reclamation and protection of the land in said proposed drainage district.

IX

The proposed plan for the reclamation and protection of the property in the proposed drainage district is. that a ditch shall be put in. running from the West side of the proposed district (connecting with a ditch running along the West side of the district which empties into the Trask River), easterly along the foot of the hill which is along the North side of the district, following the line of the ditch already partially constructed in that locality to the East side of the district. Also there is to be constructed another ditch connecting with the ditch above mentioned running South on the West line of the East half of the Northeast quarter of Section 31, in Township 1 South, Range 9 West, to the quarter section line running East and West through said Section and running thence East along the quarter section line to the East line of the proposed district or so far as may be found necessary for the drainage purposes in this section. The two ditches are to be the main ditches for the drainage proposed and they are to be constructed with such laterals as may be found necessary to make the drainage effectual. The land included in the proposed district is so situated that without ditches being constructed the water is not drained off and the land remains cold and sour. There is a fall of about 25 feet from the East side of the district to the West side thereof, and it is believed that with the construction of the ditch as proposed the water will be drained off from all of the lands so that they will dry much more rapidly. and the same will be in proper condition for cultivation. and much more productive.

X

The signers of this petition agree that they will pay any and all expenses incurred. and any tax or taxes that may be levied against their respective lands for the purpose of paying the expense of organizing or attempting to organize the proposed district. such expense to be taxed against the lands of the signers in proportion to the number of acres owned by them and affected by the proposed drainage.

XI

Wherefore. your petitioners pray that the lands described herein, or such of them as may be found by the court to be properly included in the proposed drainage district either permanently or until further investigation and surveys may permit elimination, shall be declared organized into a drainage district under the provision of Chapter 340 of the General Laws of Oregon for the year 1915.

Dated this May the 28th. 1915.

(Here followed signatures of owners).

State of Oregon, }
County of Tillamook } ss

I............, being first duly sworn. say that I have read the foregoing petition and that I believe the allegations thereof to be true, I further state that the signatures appearing to said petition are true and proper signatures of persons whose names appear signed thereto, and that each and all of said signers of said petition are owners of the land within the proposed drainage district as set forth in said petition.

....
Notary.

Subscribed and sworn to before me this 2nd day of June. 1915.

....
County Clerk.

First publication June 3rd, 1915.
Last publication July 1st. 1915.

In June, Mr. Hart returned and made the field survey with assistance furnished by the district and prepared a plan of reclamation indicated on the accompanying map of the district. Poor drainage and the shallow water table were due to lack of outlet. The present purpose of the new drains is to remove the winter flood water quickly in the spring and supply outlets to the individual tracts. The main ditch and the several laterals were laid out with a mean depth of about six feet.

Assessment of Benefits. It is fundamental in a drainage district that the assessment be in proportion to the benefits, so that each may receive a square deal and pay for only the drainage he gets. Tracts far from the outlet are taxed higher. Assessments are less where only partial drainage is provided as in case of land located back further from the ditch. Damages are allowed for good land which is taken as an outlet, for replacing bridges, or for fractional acres isolated. In assessing drainage benefits to agricultural land, the land is frequently divided into classes. The heaviest benefits to the acre are assessed against the very wet or marsh land and a lighter assessment is levied against the wet agricultural land, while only a minimum assessment is levied against land already tillable but which should gain some benefit from the drainage ditch. Special benefits are also assessed against the highways, railways, town lots or other concerns benefited. The assessment list of the Tillamook District is here given as an illustration.

TABLE XI. ASSESSMENT LIST OF THE TILLAMOOK DRAINAGE DISTRICT, STATING THE BENEFITS AND DAMAGES

Owner	Acres assessed	Points of drainage ass'd per acre	Total points of drainage		Total acres
No. 1	10.33	100	1,033		
No. 1	28.33	5	141.65		......
No. 1	21	9	189		......
No. 1	40.34	100	4,034	5,897.65	106.63
No. 2	100	100		10,000	110
No. 3	62	100		6,200	80
No. 4	22	100		2,200	27.51
No. 5	10	100		1,000	12
No. 6	5	100		500	6.28
No. 7	5	100		500	5
No. 8	2.5	100		250	2.5
No. 9	8	100	800		......
No. 9	6	100	600		......
No. 9	13.51	50	675.5	2,075.5	27.51
No. 10	8.5	67		569.5	33.58
No. 11	9	52		468	46.28
No. 12	9	52		468	37.52
No. 13	12	52		624	30
No. 14	34	100		3,400	40
No. 15	5	90		450	44
No. 16	60	100		6,000	76
No. 17	12	100		1,200	14
				41,302.65	698.81

Benefits of Old Ditch which was appropriated by the Tillamook Drainage District, to be refunded as follows by the Tillamook Drainage District.

Owner No. 1	$160.00
Owner No. 2	140.50
Owner No. 4	25.00
Owner No. 16	25.00
Owner No. 3	113.00
Total	$463.50

....Clerk

....Commissioner

....Commissioner

....Commissioner

Subscribed and sworn to before me, this 13th day of Dec., 1915.

....
County Clerk.

Construction and Cost. In the Tillamook district there were 698.81 acres and each acre was assessed the number of drainage points corresponding to the amount of benefit. The total drainage points as shown by the assessment list for the district were 41,302. These were assessed five cents per point; raising $2,065.13. The total cost of securing the outlet drains amounted to $1,612.57, leaving a balance of $452.56 in the treasury to be used for maintenance. The construction work was carried to successful completion in the summer and fall of 1915. The various items of expense were as follows:

Attorney Fees for drafting petition	$50.00
Engineer and helpers	38.19
Advertising	50.00
Excavating new ditch and repairing old ditch	990.88
Old ditch used by drainage district	463.50
Three Commissioners, one day	15.00
Clerk, one day	5.00
Total	$1,612.57

Results. The secretary of the Tillamook Drainage District writes that they have found the new law adequate and practical. The increased crop yields have returned at least half the total cost of the district during the first year. As the cost was only about $3.00 an acre, the expense was handled on a cash basis without issuing bonds. Several owners in the district have completed their field drainage by supplementary underdrains since the outlets have been provided.

Drainage District Bonds. The new district drainage law provides that bonds may be issued to distribute the expense of providing outlet ditches over a period of twenty years, during which time the increase in yield from drainage should be abundant to provide profits for retiring the bonds. Two districts organized along the lower Columbia have issued bonds and have found a ready sale for them. Good bond attorneys state that the law provides for a good bond. In the central states, drainage district bonds are regarded as good investments and in places are said to sell above par. It is important that the law be carefully followed if this is to be the case. Drainage district bonds are said to be the most attractive where the land in the district is owned by those who live on the lands and develop them rather than where they are held for colonization purposes in corporate ownership. Usually the total amount of bonds is small in proportion to the aggregate appraised value of land in a drainage district, but it is well to get practical assurance that the benefits will exceed the total cost of drainage. The total indebtedness for the district for all other purposes including drainage, should not become burdensome to the district. The short community ditches in much of the white land sections can be be paid for on a cash basis without bonds if a rural credit measure or other legislation is enacted which will provide money at moderate interest rates.

State Aid. In localities where there are a number of drainage problems to be met, the Agricultural College makes a practice of sending a field man to make examinations and give a demonstration or advise the community publicly as to the means of securing drainage. Field work usually consists of subsoil and water-table examinations and the taking of some preliminary levels to determine the available fall or best possible outlet and the location and design of drains required. Where there are several hours of surveying to be done, it will usually be necessary to secure the services of a professional engineer. The College only aims to aid drainage enterprises in getting started right and on their feet without competing with private enterprise. Arrangement has been made with the U. S. Office of Drainage Investigations to cooperate in securing some preliminary data in sections of the state where the practice of drainage is entirely new. These investigations aim to determine the feasibility of the proposed drainage project from an engineering and agricultural standpoint. The results of such preliminary investigation will be the organization and development of feasible projects. To carry these projects through, a good attorney and a drainage engineer should be employed, as it will pay to have the work done right.

The State could well afford to extend investigations of the effect of underdrains in the marshy, alkaline and white lands as well as other wet lands of Oregon.

OPEN DITCHES

By T. A. H. Teeter, Professor of Drainage and Irrigation Engineering

The primary purpose of an open ditch is to furnish a channel sufficient to accommodate a flow that is too large for a covered conduit. In general, covered or tile drains are used for farm or field drainage, while open drains are used for outlets. Covered drains are now coming into use even for small outlets.

Open Ditches vs. Tile Drains. There are very few reasons why tile drains should not be used on the farm unit, **but there is a range of outlet sizes slightly larger than ordinary field drains where the choice between the open and the covered drain is not easily made.**

The covered drain requires no right of way and occupies no valuable land. When properly designed, it requires very little maintenance.

Open drains are unsightly, harbor noxious weeds, occupy valuable space, and increase the difficulties of cultivation by cutting the land into inconvenient shapes. They also require the construction of bridges and culverts, as well as more or less cleaning each year. With open ditches, however, there is no tile to buy and the original cost is less.

In deciding between an open ditch and a tile drain* we first calculate the original cost of say the open ditch, together with the value of the saving in tile and expense of maintenance. Compounding the net value of these at 5 percent for say thirty years, the average man's period of activity on a farm, the actual cost of the open ditch is obtained. Next, the cost of the tile drain may be arrived at by compounding the first cost at 5 percent for thirty years, then compounding the value of the crops grown over the tile for the same time, and subtracting these two. If this remainder is less than the cost of the open ditch, it pays to use tile, otherwise the open ditch is the more economical.

In making a choice, the consideration of the first cost alone is misleading, because the cost of a very few years' maintenance will more than pay the difference in first cost between the two types of drains. A slightly different method † follows for making a choice between open and closed drains. Suppose a covered drain of a capacity costing $1 a foot to construct, and an annual maintenance of 1 percent of the first cost. Twenty cents a foot must be added to yield, at 5 percent interest, an annual income of 1 cent a foot to pay for maintenance. This makes the total cost $1.20 a foot. An open ditch to carry the same outflow will cost say 25 cents a foot for right of way, 30 cents a foot for excavation, and 10 cents a foot for inlets, flumes, bridges, culverts, fences, etc. It is reasonable to assume the annual maintenance at 10 percent of the exca-

*Day, W. H., Farm Drainage Operations, Bull. 175, Ontario Dept. Agriculture, p. 50—1914.
†Hart, R. A., Drainage of Irrigated Land, p. 8, Bulletin 190, U. S. Dept. Agriculture, 1915.

Figure 36. Open Lateral in Peat—Clatskanie.

vation cost, therefore 60 cents a foot must be added to yield an income of 3 cents a foot (figured at 5 percent), which gives a total of $1:25 a foot.

In this case the covered drain is to be preferred from the standpoint of first cost. A larger drain, however, would show in favor of the open ditch.

Practice in the humid regions is leaning more toward the covered drain. Tile having an inside diameter of 3 feet are not uncommon, while larger sizes are sometimes employed. ** Until quite recently, very little tile over 12 inches in diameter had been used; in fact, few of our Oregon local factories make larger than 16-inch tile. Conservative estimates based on present prices and conditions show that in Oregon it would be economical to use 12- to 16-inch tile, rather than the open channel of the same capacity; while improvement of methods, increase of land and crop values, and the decrease in the cost of materials that are now being witnessed, make it seem reasonable to predict that very shortly larger sizes as used in eastern practice will be adopted. The economical size will depend on the distance from the factory and upon shipping facilities.

The Surface Run. Some expensive tile drainage systems have been partial failures because they have not had the aid of the open ditch in the form of an inexpensive surface run. Such a ditch, 2 ft. deep and 10 ft. wide at the top, has been made with a road grader for 25 cents a rod. ††

Ditches such as this should be seeded down to grass to avoid erosion, waste of land, and inconvenience in cultivation. They may be constructed above a tile drain to carry off surplus surface water. They may also be used as the eave troughs to prevent water from hills getting into pot-holes which have no outlet. On the other hand, shallow ditches do not drain to a sufficient depth and when used alone are not successful except in sandy land.

Location of Open Ditches. The location of the open ditch should follow the general course of natural drainage as nearly as possible with due regard to alignment. In the location of the outlet ditches careful consideration should be given to the size and slope of the entire drainage area, so that the completed plan when carried out will be efficient and economical. No fixed rules can be laid down for location, but in any case a careful study of local conditions is essential.

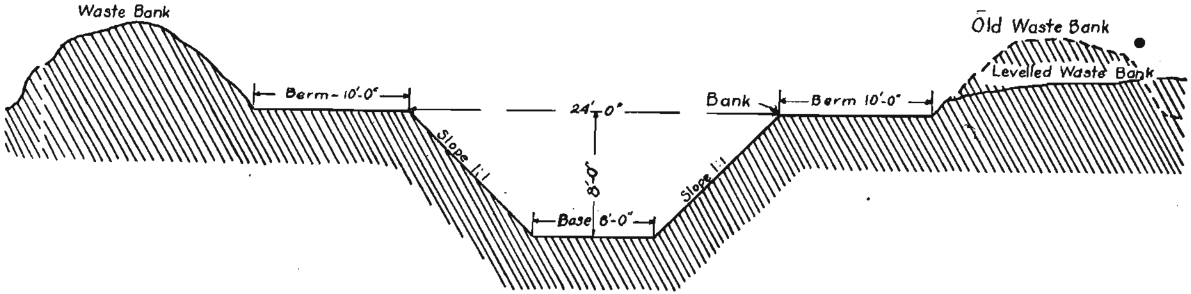
In the location of open ditches, the following general points and their conflicting arguments should be kept in mind:

1. The value of straight courses and gradual curves to stream flow;
2. The desirability of locating drains along property lines wherever possible;
3. The damages to farms by ditches cutting off small inaccessible corners of fields or extending across them in angling or irregular directions;
4. The economy of traversing natural depressions; and,
5. The injurious effect of unstable or caving soils on ditch construction and maintenance.

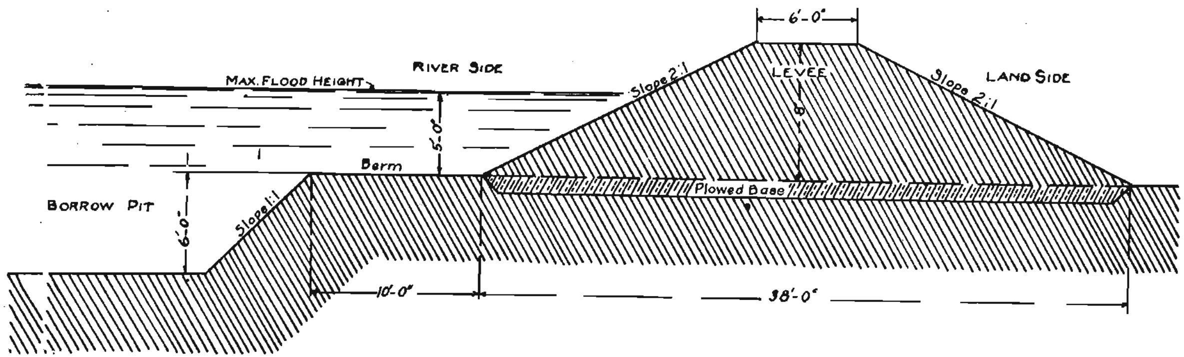
Before locating an open drain, an engineer should go over the entire route

**Smith, A. G., Tile Drainage on the Farm, p. 8, Farmers' Bulletin 524, 1913.

††Jones, E. R., The Right Drain for the Right Place, p. 7. Bull. 229, Univ. Wisconsin Agricultural Exp. Sta., 1913.



Typical Cross Section for Open Ditch



Typical Cross Section for 8-ft. Levee

Figure 37. Cross Section of Outlet Ditch and of Levee.

of natural drainage, investigating and comparing possible locations, and lining out tentative channels with lath and poles, later measuring and locating the line more accurately. This inspection will often disclose the possibility of draining to different outlets or shortening the line by cut-offs, and will necessitate a number of trial locations.

Treatment. Outlet systems require treatment different from that given lateral canals or small ditches intended to accomplish farm drainage directly. The former must usually follow the natural depressions and water courses, while the latter must be located with strict regard to the source of the drainage water, as is the case with tile drains. Wherever practicable, small open lateral ditches should extend along the highways, as the roadway is thus drained and less right of way will be required. Furthermore, the waste banks can be thrown into the roadway and crowned, making an excellent thoroughfare where roads would ordinarily be impassable during wet seasons.

Alignment and Curvature. All ditches should be as straight as possible and at the same time conform to the general topography of the adjacent country. Short sharp turns in the channel cause the moving water to come violently in contact with the bank, causing erosion, undermining, and subsequent caving of the banks. Caving greatly reduces the capacity of the canal. The sharpness of the curves should depend on the size of the stream, stability of the earth, and the velocity of the water; but the straighter the ditch, the cheaper its maintenance will be.

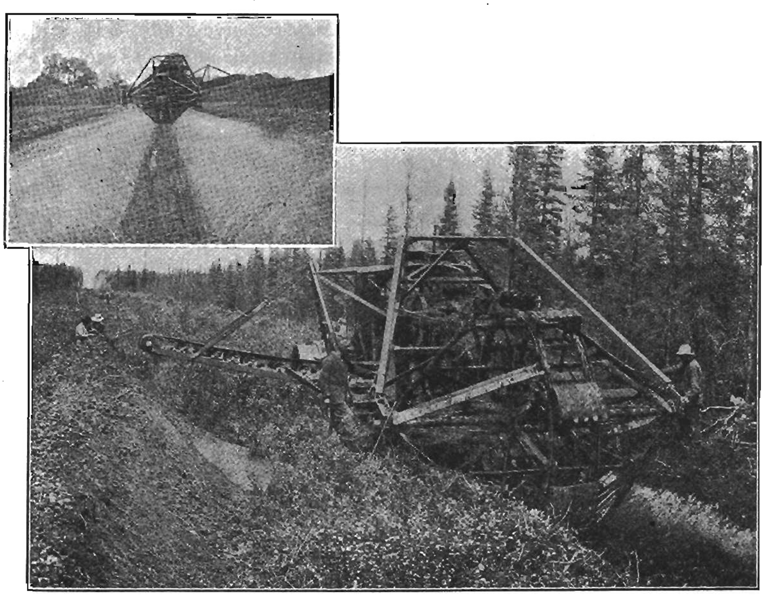


Figure 38. Wheel Excavator for Making Sloping Ditch Banks.

The proper curvature to give ditches when they are deflected from a straight line is a matter that requires careful attention. The adjustment of curvature to velocity of flow should be such that the banks will not require artificial protection. The relation of bank erosion to curvature of the ditch and velocity of flow is intricate, owing to the variation in stability of different kinds of earth when subjected to action of flowing water. How short a curve may be used in large ditches such as are constructed for drainage districts, without causing the banks to cave or wash, cannot be stated with mathematical exactness. In the following discussion the "degree of curve" is the angle enclosed at the center of the circle by a 100-foot length of curve; e. g., in a one-degree curve, 100 feet of curve subtends an angle of 1 degree at the center of the circle of which the curve forms a part. Elliot * gives the following general values:

For ditches with minimum bottom width of 6 feet and maximum grade of 2 feet to the mile, use 20-degree curve (radius 288 feet).

For ditches with a bottom width of 6 to 20 feet and grade of 3 to 6 feet to the mile, use 12-degree curve (radius 478 feet).

For larger ditches and greater fall, or for ditches with the dimensions given but with greater fall than indicated, 6- to 12-degree curves are used, according to the particular conditions.

Grades. Nature to a large extent fixes the fall or grade of a ditch. Natural channels are in general longer than artificial channels, due to the unnecessary curves in the former. It therefore often happens that nature does not provide enough fall for the natural channel. When artificially straightened, the channel may be so shortened as to cause an excessive grade. It is always necessary to make the artificial ditch conform in grade and cross section to the fall provided by nature.

But to decide what will constitute a satisfactory grade involves a consideration not only of the requirements of the ditch, but also of the nature of the earth. The grade should be as uniform as practicable. It may vary from 6 inches to the mile to 5 feet to the mile, where gravity ditches are used, or below 3 inches to the mile, when pumps are used. Ditches in some soils with grades above 3 feet to the mile are more difficult to keep in repair on account of the erosion caused by the rapid flow of water. In white land comparatively steep grades are permissible.

In flat country, all the fall available should be used in the design of the ditch to make the ditch as nearly self cleaning as possible. In heavy soils ditches with a fall of four feet to the mile can be considered self-cleaning, and large ditches will clean themselves on flatter grades. When flat grades are used with small ditches, an increased maintenance cost must be expected because there will be a tendency for the ditch to silt up. For this reason such flat grades as 6 inches to the mile, although often satisfactory, cannot be recommended.

Shape of Ditch Cross Section. The resistance which any channel offers to the flow of water depends on three factors: (1) the slope of the ditch (which governs the velocity of the water); (2) the roughness of the surface with which

*Elliott, C. G., Engineering for Land Drainage, p. 217, 2nd Ed , 1913.

the water comes in contact; and (3) the ratio of the area of the water cross section to the length of "wetted perimeter" or bottom and side bounding line of the water cross section. Nature determines the first two factors but the designer controls the third to a large extent. The larger the value of this ratio (area: wetted perimeter), the more water will flow in the ditch. This ratio, within practical limits of ditch construction, is greater for narrow deep ditches than for wide shallow ditches, and therefore the narrow deep ditch is more desirable.

Channels having vertical sides offer less resistance to flow than any other form. Where the fall is slight, therefore, and it is desirable to get the greatest ditch capacity with the least excavation, the ditch should be made deep and as nearly a rectangle or half square as possible. But earth will not stand vertically without a retaining wall, therefore absolutely rectangular ditches are impractical for drainage purposes. Fig. 37 shows a proper cross section for an open ditch.

Side Slopes. The rate of side slopes for open ditches depends on stability of the soil, though the method of excavation should be given some consideration. The angle at which the banks will stand depends on the fluidity of the soil when mixed with water, and unless this angle is maintained, caving is certain to result. On the other hand, since the tendency is for the water to widen the bottom to form a U-shaped ditch, it is not wise to make the side slopes too flat, as all excess soil in the lower corners will erode and silt up the ditch at other points. Again, if the slope is too steep, the upper banks will erode into the stream and partly fill the ditch.

Ordinary white land soil will stand with a slope of 1 foot horizontal to 1 vertical, or 45 degrees. Sandy or loose loamy soils require flatter slopes of about 2 horizontal to 1 vertical, sometimes 3 horizontal to 1 vertical. Some kinds of peat will stand nearly vertical. (See Fig. 36). The action of the water always tends to widen the bottom of the ditch and make the sides more nearly vertical. Side slopes as ordinarily constructed by dredges are ½ to 1 or nearly vertical, because a floating dredge cannot conveniently give the final slope to the bank. Contractors frequently dig the ditch to the required top width and then allow the banks to cave down to the natural slope. This is not desirable because the final form the ditch will take can never be predicted, and the unregulated caving clogs the ditch. A machine which will give the banks their final slope is far more desirable than one which can leave nothing but a vertical bank. (See Fig. 38).

Size of Cross Section. It is necessary before construction work can begin to determine the size of the drainage channel. The two important factors in determining the size are:—(1) the grade of the channel, and (2) the amount of surface run-off. Each of these factors must be carefully considered in determining the necessary capacity. From the necessary capacity and the available grade, the size of ditch can be computed. Good judgment must be exercised in adjusting the size of ditches to different parts of the drainage area, since physical conditions of soil and soil surface must be considered for different localities as well as the effect of unusual local storms.

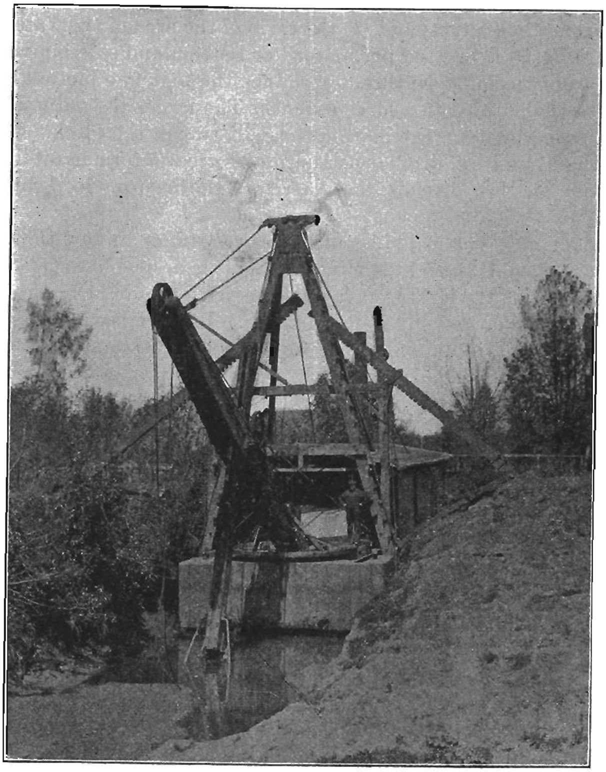


Figure 39. Floating Dredge—Lake Labish.

Bottom Widths. The base width of a ditch is of particular importance. It, together with the grade and depth, controls the capacity of the ditch. Because of aggravating filling action in ditches serving drainage areas from 1000 to 4000 acres, the minimum base width of **main ditches** should not be less than 8 feet and this is especially true where floating dredges are used, because they cannot operate in a narrower channel. *Contractors securing ditches of narrower base width will excavate to the proper top width with the wider base thus leaving side slopes too steep. It is therefore better, where dipper dredges are used, to figure on this base width in the first place and give the ditch the proper design for it.

In ditches for larger drainage areas, the bottom widths are determined by the capacity required.

Small ditches should never have a bottom width of less than 2 feet, else they cannot be easily cleaned with team and scraper, and where the fall is less than

*Parsons. J. L., "Land Drainage," p. 44; 1st Ed., 1915.

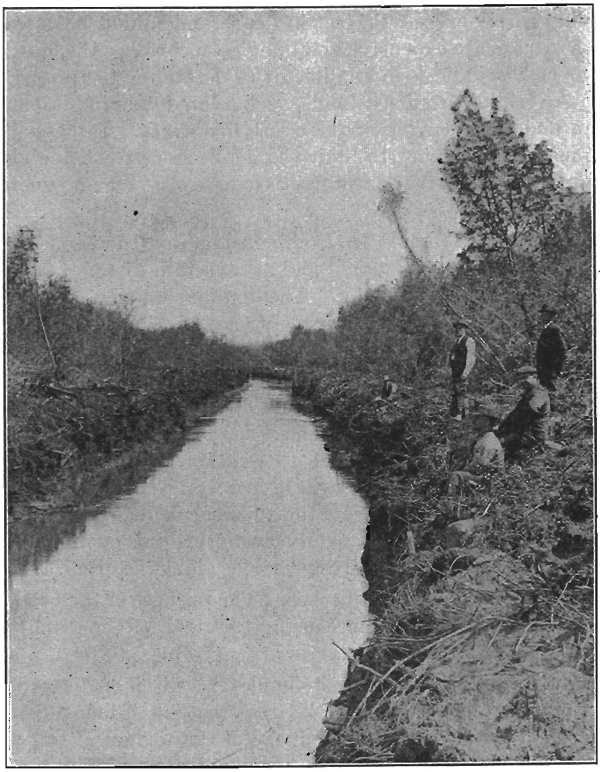


Figure 40. Open Ditch—Lake Labish.

3 feet to the mile, the base width should be at least 3 feet. It is impracticable to make narrower ditches or clean them except by hand labor. Where the fall is 10 feet to the mile or greater, any form of ditch will be self-cleaning, and protective devices to prevent erosion will often be necessary.

Depths. The depth must always be sufficient to provide ample outlet facilities for the lowest laterals, with 2 or 3 feet extra depth to provide for the silting up of the main canal which always takes place to that depth during the first few years after construction. The topography of the land through which a ditch passes largely governs the depth it must have. Since greater depths produce greater velocities, a deep channel is more apt to be selfcleaning.

Shallow ditches with wide bottoms are adaptable only for surface runs to carry off the surplus surface water during flood periods. In order to prove effective as an outlet for a tile drain, and be reasonably permanent, an open ditch should never be constructed to a depth of less than 6 to 7 feet. This excludes the planning and construction of capstan or cableplow ditches because capstan ditches rarely exceed 2½ feet in depth and cannot be constructed to grade. Such ditches are expensive and bunglesome, to say the least.

In sand or peat soils, it is more difficult to determine the proper minimum depth. Sand overlaid with denser soils, such as are found in Malheur County, is apt to run and cause caving of the overlying strata. In cases of such instability, it may be necessary to limit the depth so as to keep above the unstable stratum, or to construct a protective device such as a cunette to hold the sliding banks.

Waste Banks and Berms. In ditch construction the earth excavated is piled in a ridge parallel to the bank, and at a certain distance from it. This pile of earth is called the wastebank. The distance from the toe of the pile to the top of the bank is called the **berm**. (See Fig. 37).

Waste banks are an inconvenience in the satisfactory cultivation of the adjacent fields. The excavated material, if thrown up by a dredge, is deposited in a wet and plastic condition, and on drying becomes very hard and tough. The waste-banks for this reason are very hard to level down and cultivate before the banks have a chance to weather, but for convenience and appearance waste-banks should always be partly leveled. Waste-banks also act as a levee and prevent water from the adjacent field getting into the ditch. This objectional feature must be overcome by leaving openings through or under the waste-bank at the natural depressions along the ditch.

A clean berm is essential to all ditches. The purpose of the berm is to keep the weight of the waste-bank from causing the bank of the ditch to cave in. The following quotation * will illustrate:

"The weight per lineal foot of waste-bank for a ditch of 20 feet base, 1 to 1 slopes and 20 feet in depth, equals 1,481 lbs., wet earth being figured at 100 lbs. per cubic foot. As the line of cleavage of the wedges of soil which tend to cave from the sides of any trench is always of curved shape, if the waste-banks were deposited outside the surface extremity of this cleavage line, their sliding effect upon the ditch banks would be entirely prevented."

The proper width of berm depends therefore on the stability of the soil. Since ordinary ditching machines cannot remove the waste farther than necessary to leave a clear berm of 6 to 8 feet, it is better to specify these widths and such side slopes as will insure against caving of the banks when the weight of the waste-bank is considered. In case of very large, deep ditches, or in soft marsh, a clean berm of 8 to 12 feet should be specified, depending on the stability of the soil.

The berms should be seeded and sodded to help hold the ditch bank from caving.

Safe Velocity of Flow in Ditches. Ditches must be made as nearly self cleaning as possible, but this necessitates increasing the velocity of flow to the limit of safety when the water carries any quantity of silt. The safe velocity is the greatest velocity at which it is safe to let water flow in a ditch without causing erosion or washing of the banks. Kent's Mechanical

*Parsons J. L., Land Drainage, p. 43, 1915.

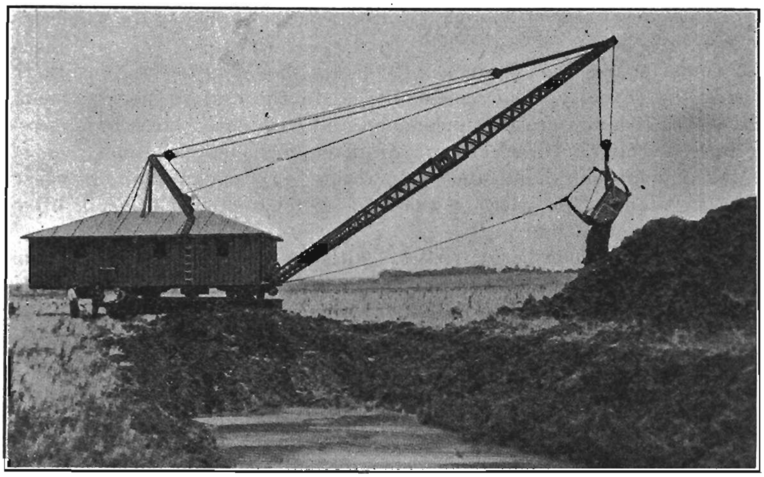


Figure 41. Drag-line Scraper Excavator.

Engineer's Pocket Book gives the following table of safe velocities in various soils:

Pure sand	1.1 ft. per second.
Sandy soil 15% clay	1.2 " " "
Sandy loam 40% clay	1.8 " " "
Loamy soil 65% clay	3.0 " " "
Clay loam 85% clay	4.8 " " "
Agricultural clay 95% clay	6.2 " " "
Clay	7.35 " " "

Velocities depend not only on the fall but also on the depth and shape of the ditch, as well as the roughness of the material of which it is constructed.

Character of Drainage Area. The character of the drainage area affects the rate of runoff and therefore influences the size of the ditch. A broad, flat drainage area will drain more slowly than an area of the same size but with steeper slope. In the latter case there is more water to be handled because there is less time for percolation, and a shorter time in which to move it than in the former case. This necessitates a much larger ditch in the latter case.

Broad, flat areas require larger ditches for the same area than long, narrow, flat areas because in the former case the time of concentration of runoff is the same for all points while in the latter case the concentration period for the lower end has passed long before the flood water from the upper end comes down.

Amount of Runoff. The amount of runoff is given as some fraction of an inch depth of water flowing off in 24 hours. This is called the "drainage coefficient." A drainage coefficient of ½ inch in 24 hours indicates that the ditches must carry off ½ inch of water from the surface of the whole drainage area in 24 hours.

A runoff of less than ½ inch in 24 hours should never be considered in figuring the capacity of any open ditch. In the eastern states runoffs of 6 inches in 24 hours are not uncommon and with small areas it may reach one inch an hour. In selecting a drainage coefficient, one must consider: (1) the amount of rainfall and temperature, (2) topography, (3) size and shape of watershed, (4) slope of the land, (5) character of the soil, (6) vegetation and cultivation.

Rainfall and Temperature. Localities having large annual rainfall have correspondingly large 24-hour storm periods. Localities having warm climates generally need fully as much drainage capacity as cold climates, the rainfalls being equal, for although the evaporation is greater, the violence of single storms is also usually greater in warm climates.

Topography. Level areas require smaller coefficients than undulating, hilly areas, because they absorb more water and the movement of the latter through the soil and over the surface is slower and more uniform.

The Size and Shape. The ratio of drainage to rainfall is in general smaller for large areas than for small ones, due to the fact that the rainfall is seldom uniform over a large area, and also because the flood portion of the lower area may be drained off before the flood water of the upper areas can get down to the lower part.

Character and Culture of the Land. Undulating or rolling territory with hard surface-like meadows gives a higher runoff than cultivated lands. If hilly lands are terraced or underdrained the coefficient will be less.

Evaporation and Transpiration of Plants. Careful experiments in France, Russia and India show that at the end of the growing season the water table in wooded tracts is from 2 to 12 feet lower than in the open tracts adjoining. Forestry experts estimate that 40% of the summer rainfall is caught by the leaves and again evaporated in wooded districts.

CONSTRUCTION.

Hand and Team Work. For ditches of small depth where the material is dry and the ground firm enough to support a team, team and scraper work can be done very economically when the amount of earth to be removed does not exceed 30,000 cubic yards. The earth is first plowed and then removed with wheel or slip scrapers.

In the irrigated section, or where the soil is water-logged, team work is in general not feasible because of the miry condition of the soil, and machine work must be resorted to.

Excavating Machines. Ditches of greater size than 30,000 cubic yards are more economically dug by dredges. The latter are of two types:

1. Floating dredges.
2. Dry-land dredges.

The former has its machinery mounted on a barge with the engine in the rear, turntable and digging machinery in front. The excavator consists of a large dipper and boom or grab bucket ranging in capacity from one-half to three cubic yards or more. The dipper type works much as the ordinary steam shovel, except that the dipper is longer and has greater range. Floating dredges are adaptable to very wet land, too soft to support heavy machinery. Fig. 39 shows a floating dredge with bank spuds in operation on the Lake Labish district.

Dry land excavators are of many types. With this type the work must begin at the outlet and proceed upward to keep the land drained under the machinery. Nearly all types have booms and turntables, the essential difference being in the type of bucket which may be a drag bucket, resembling a slip scraper; a clam shell; or an orange-peel bucket. There is also a templet or elevator and bucket type, as well as a wheel type, both of which give very smooth side slopes. (See Fig. 38.)

The selection of the type of machine for ditch work depends on the local conditions and in general should be left to the contractor or engineer. The men upon whom the responsibility of correct design and proper execution of the construction work usually devolves are seldom qualified by either experience or knowledge for the selection of the proper type of machinery to dig the particular ditch of which they have charge. This is especially true of county and district drainage commissioners, and often true of local engineers. Anyone contemplating the construction of a large open ditch should familarize himself with the government publications on this subject.*

The floating dipper dredge (See Fig. 39) is the type of excavating machine most used. Where many stumps are to be encountered, it is by far the most efficient type of machine. In wet land where the ditches have a cross section of 100 to 1,200 square feet, no other type of excavator will equal it for cheapness of construction. It is not adapted to levee construction because of its short reach. These dredges are made in capacities of ½ cubic yard to 4 or 5 cubic yards, but the most common sizes are 1 to 2 cubic yards. They cost from $5,000 up, the cost increasing rapidly with the size of bucket. To insure enough water to float it, this type should be operated downstream.

The Orange Peel and Clam Shell Dredges are adapted to certain types of soil where the material is soft and caves readily, such as the muck of southern Louisiana. They are not adapted to soil where stumps are encountered. When provided with a long boom they are well adapted to levee construction.

The Drag Line Excavator has a bucket which operates like a slip scraper. It is constantly increasing in favor for drainage work, and is especially adapted for large ditches and levee work, where the ground will support the machine. It is also suitable for ditch cleaning, and ditch banks can be more easily sloped with this type than with the other bucket or dipper types of dredge.

The Templet Type of Excavator has a single bucket which moves along a guide frame shaped to the desired cross section of ditch. The whole machine

*Wright, J. O., "Excavating Machinery Used for Digging Ditches and Building Levees;" Circular 74, U. S. Dept. of Agri.;
Yarnell, D. I., "Excavating Machinery Used in Land Drainage"; Bulletin 300, U. S. Dept. of Agriculture;
Yarnell, D. I., "Trenching Machinery Used for the Construction of Trenches for Tile Drains;" Farmers' Bulletin 698.

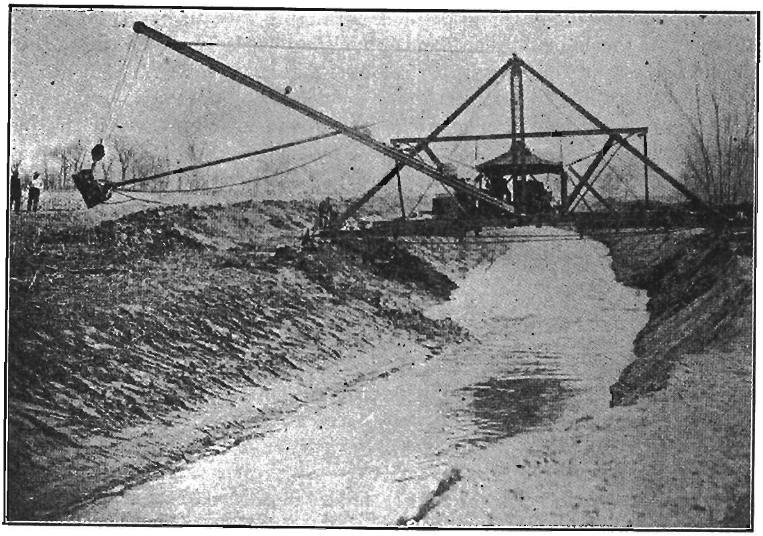


Figure 42. Dry Land Dipper Excavator.

is mounted on caterpillar wheels or a track. It cuts a superior ditch under favorable conditions, but it cannot handle rock, stumps, or very hard earth.

The Wheel Type of Excavator (See Fig. 38) has an excavating wheel on the rear of the machine which revolves on anti-friction wheels just outside the run of the main wheel. To the outer rim of the large wheel buckets are fastened, which, as the wheel revolves, cut slices of earth from the end of the ditch. With the addition of side knives, the wheel will cut a sloping ditch, the earth from the sides falling into the buckets. The ditches cut by this machine because of their perfect bank slopes are superior in hydraulic efficiency to those cut by most of the other excavators.

The Hydraulic or Centrifugal Dredge is not suited to open ditch construction. Small types can be used successfully for cleaning old ditches. With the use of slope boards it has been found successful for levee construction.

Costs of Machine Work. The cost of open ditch work is figured by the cubic yard. Usually the greater the yardage to be removed, the less the cost for each cubic yard. On large jobs dredge work is cheaper than team and scraper work, which costs 10 to 20 cents a cubic yard, while on small jobs the opposite is true because the cost of building or moving a dredge is quite high.

The cost for each yard for dredge work varies from as low as 5 or 6 cents on large jobs to 12 or 15 cents on small jobs. This fact shows the wisdom of co-operation and the organization of as much territory as possible under one head.

The following costs for each cubic yard are compiled for different machines described in the U. S. D. A. Bulletin 300.

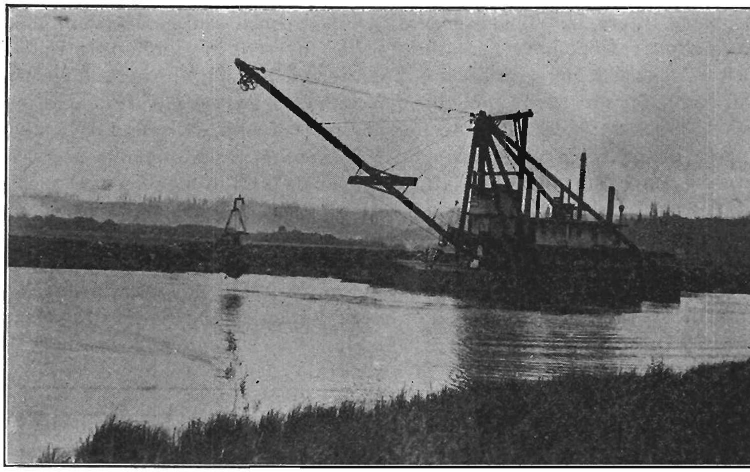


Fig. 43. Orange-peel Dredge, Dyking on the Lower Columbia.

TABLE XII. COST OF MACHINE EXCAVATION

Size and Type of Machine	Length miles	Top Width ft.	Bottom Width ft.	Depth ft.	Slopes	Width of Berm	Cost per cu. yd.
¼ Yd. floating dipper dredge......	3¾	22–26	....	6–10	1–1	8	$.0847
1¼ Yd. floating dipper dredge......	....	30	....	5– 6	....	....	.0221
1¼ Yd. floating dipper dredge......	3	25	18	8	....	....	.41
1 Yd. floating dipper dredge.......		18	....	12	½–1	....	.0512
2 Yd. drag line (Rotary)............	....	....	4–22	3–12	1–1	....	.1164
2 Yd. rotary drag line..............	....	....	4–22	3–12	1–1	8	.1273
1½ Yd. rotary drag line.............	....	....	4–22	3–12	1–1	8	.1512
*1 Yd. dry land dipper..............	....	18	4	6½	....	....	.1200
Templet excavator...................	1¼	....	24	3.5–7	1–1	15	.081
Wheel type..........................	165	4	2	4	....	....	.0682
Wheel type..........................	....	4½	20 in.	4½	....	....	.0793
1½ Yd. floating dipper dredge One year's work cleaning canal...	....	....	....	....	....	....	.058
2¼ Yd. rotary drag line 225,000 cu. yds in South Dakota...	....	....	....	....	....	....	.0521
1 Yd. dry land dipper grab bucket (Levee work)......................	10	6	....	7	2–1	....	.074

*Contractor neglecting depreciation.

Maintenance

A canal, to retain its efficiency, must be well maintained. Twice each year (more often if necessary) vegetation should be removed from the channel and banks, and such material as has fallen into the channel taken out. Any damaged places must be repaired to prevent further trouble. Tumbleweeds are a source of much annoyance, for they cannot be kept out of drainage canals. They soon form serious obstructions which must be removed at frequent intervals. This is generally done by men equipped with forks and rakes. Cultivation, however, seems to be effective in eliminating the nuisance. Another serious problem is "blow sand," which, during a high wind, may completely obstruct a canal in a few hours. The very nature of a drainage ditch makes maintenance difficult and costly; therefore, every endeavor should be made, during construction, to reduce the amount of maintenance necessary. Since the annual cost of maintaining open canals is often 10 per cent of the first cost, the need for correct design and careful construction is apparent.

Protective Devices for Open Canals. Checks. The usual flow in most drainage ditches is not sufficient to cause serious erosion, but occasional floods may increase the flow to a point that undesirable erosive velocities are attained. In such canals a check or over-fall dam can be placed with a small sluiceway through the lower part. This sluiceway will allow the ordinary flow to pass unchecked but excessive floods will be checked, the depth of flow increased, and the flow maintained at a safe velocity.

Cunettes.* Some soils when in a wet state are semi-fluid. In this condition the ditch banks will not stand unsupported. The banks can be held in place by installing a "cunette," which consists of driving piles at intervals of a few feet along the edges of the ditch bottom and building a waterway of plank in the bottom of the ditch between the piles.

Bridges and Flumes. Irrigating streams should be carried across drain ditches in well-built flumes or pipe lines of a capacity such as will insure their safety and permanence, as much damage can be caused by letting an irrigation ditch into a drainage ditch. When the grades are on the same level, one must be siphoned under the other.

Culverts are not satisfactory in drainage ditches as they are apt to clog and wash out. Good bridges are far more desirable and should be installed at all crossings. A clearance of 2 feet or more is necessary to prevent debris and floating weeds catching and thus obstructing the channel. No one should be permitted to dam or obstruct a channel in any way.

Ditch Inlets. There is an established tendency for surface waters to wash openings in the ditch banks and cut ditches along the water courses. The silt is carried from these ditches and deposited in the main channel. This can be remedied usually by bringing the surface water to the canal through a pipe inlet, but even this may have a tendency to wash out, in which case it is necessary to bring it in through a ditch whose grade line connects with the grade line of the main ditch by a gradual incline to prevent erosion. No over-fall should be permitted into any ditch. If flat grades are impossible, drops should be installed. The ditch inlet should be put in place before the ditch is constructed to permit continuous deposit of the waste banks once construction is begun. Lateral drains should be so located that the water will be discharged in the same direction as that of the flow in the main ditch.

Erosion. Injury by washing or erosion occurs:

First, by direct wearing of banks and bottom through action of the water which carries the particles down stream, and

Second, by action of water on the soft understratum thus undermining the

*Hart R. A.. Bulletin 190, U. S. Dept. of Agriculture.

bank structure and allowing the bank to cave. The erosive action varies as the square of the velocity; that is, if two streams have velocities of 2 and 3 feet to the second respectively, their erosive power will be as 4 is to 9. But velocity varies as the square root of the fall. Therefore a stream with 4 feet of fall to the mile will have twice as much erosive power as a stream whose fall is 1 foot to the mile.

Erosion may be diminished by making the channel wider, thus increasing the wetted perimeter and decreasing the ratio of area of cross section to "wetted perimeter" which has the effect of increasing the resistance to flow and diminishing the velocity.

Keeping the channel smooth and clean will prevent erosion because the velocity will be uniform. In large canals, dams and dikes may be constructed to decrease the fall and divert the current from the ditch banks.

Character of Flow. We have already learned that for a given quantity of water and a specified velocity, the size of the cross section is determined. Yet it is possible to vary the shape of this cross section within certain limits. During the dry-weather flow the velocity must be sufficient to keep vegetation from growing in the ditch and subsequent deposits of silt on the bottom, which would of course eventually fill or stop the ditch. It is therefore necessary to make the bottom of the ditch narrow so that depth of flow will be increased, will cover the bottom, and have sufficient velocity to keep down the aquatic plants. In a 10-foot ditch with a fall of 3 feet to the mile, an increase in depth from 2 to 8 feet increases the velocity of flow 45%. Ditches with wide bottoms should not be used except where there is no dry-weather flow. In this case the bottom can be mowed with a mowing machine. The ditch banks should also be mowed twice a year else weeds and bushes will soon stop up the ditch.

Curvature and Direction of Flow. The alignment and curvature of ditches greatly influences the maintenance cost. At sharp curves the current tends to travel in a straight path, therefore it runs into the bank on the outside of the curve. The section of the curve first struck receives the greatest force and therefore erodes or washes away faster than the rest of the bank. For this reason the upstream end of a curve should be "eased off" or made of longer and longer radius until it becomes a straight line so that the water will take the bend gradually and not wash into the outer bank.

Uniform Rate of Flow Throughout the Ditch Is Essential. All water carries silt in suspension. Since its carrying capacity varies with the velocity of flow, if the velocity is decreased some of the silt will be dropped and a bar will form, obstructing the channel.

Ditch Cleaning. Ditch cleaning is an expensive form of maintenance. The wet miry condition of stream beds makes hand or team and scraper work almost impossible. On the other hand, the amount of material to be removed is so small as to make heavy machinery impracticable because of the great expense of moving the machines. Cleaning old ditches therefore, may cost as high as 50 cents per cubic yard where the first cost may have been less than 10 cents. Hence, the necessity of properly designing the ditches in the first place to make them self cleaning, cannot be over emphasized.

Recently, hydraulic or centrifugal dredges of small size with cutting wheels have been designed which clean old ditches quite economically.*

Fencing Ditches. A large open ditch should always be fenced. If stock are permitted to graze on the ditch banks, they will, by their continued tramping, cause the ditch banks gradually to cave into the ditch and in time so completely fill it that its utility as a drainage ditch will be destroyed. This danger can be overcome in one way only, that is by keeping the stock off the ditch bank. All crossings should be bridged because fording also has a tendency to fill the channel and cause silt to be washed down and deposited in some undesirable place. It is a wrong impression, though a very popular one, that a ditch once constructed is there for all time. Only by a careful oversight and protection will it remain efficient.

The Cost of Open Ditches. A ditch in Wisconsin, 6 feet wide at bottom, 7 feet deep, 20 feet wide on top (6x7x20), costs $1,600 a mile when there are three or more miles to be dug. A single mile costs $2,500 or more.†

Earth excavation is figured at so much for each cubic yard and the more dirt to be removed, the less will be the cost of each cubic yard. The cost may vary anywhere between 5 cents and 20 cents, depending upon the size of the job, the machinery used, the ability of the contractor, and the character of the excavation.

When figuring on an acreage basis, a distinction must be made between farm drainage and outlet systems. The latter are intended only to afford outlet facilities to farm drainage systems; seldom are they designed to accomplish drainage directly without tile. Farm drainage systems presuppose that drainage outlets exist or that artificial outlets will be available. It is impossible to build an open ditch, therefore, that will not drain some land without tile, and this, of course, reduces the cost of farm drainage in the vicinity.

The cost of open-ditch systems may vary from $3 an acre to $15 an acre. As a rule, in the latter case very little farm drainage is necessary, and taking both farm drains and open ditches into consideration, the system may prove more economical than one costing much less but requiring more farm drainage.

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*Yarnell, D. L., Excavating Machinery, p. 36, Bulletin 300, U. S. Dept. of Agr., 1915.

†Jones, E. R., The Right Drain in the Right Place, Univ. Wisconsin Agriculture Exp. Sta. Bulletin 229, 1913.