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Irrigation and Duty of Water.

BY PROF. B. C. BUFFUM, B. S.

Bulletins will be sent free upon request. Address: Director Experiment Station, Laramie, Wyo.
Wyoming Agricultural Experiment Station.

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IRRIGATION.

B. C. BUFFUM, B. S.

The importance of irrigation in our state does not need more than a passing comment. The subject has brought out so much discussion and fruitful study in the last few years that a casual observer might think some new and great discovery had been made. In fact new discoveries in methods and effects are being made and our knowledge is vastly increasing upon this subject, which, in theory and practice, is as old as civilization itself. All this is being brought about by necessity, that mother of all good things in our advancement—the necessity of utilizing that vast expanse of territory known as the arid region for the location of homes, and homes which shall be self-supporting to the westward-moving population who seek them. Even though it were not a necessity that this region support a larger population, our invigorating atmosphere, large per cent. of sunshine and healthful climate would in time demand the attention of home-seekers.

The arid region comprises all that portion of the United States lying west of the 97th meridian west of Greenwich, except a comparatively narrow strip along the Pacific coast and those parts of states or comparatively small areas which are called semi-arid or sub-humid. The term arid indicates land where practically no profitable tilling of the soil can be done without the artificial application of water. Wyoming is almost centrally located
in this region and is termed arid. In 1889 our state had over two million acres of farm and pasture land which was irrigated. Its population increased from 20,789 in 1880 to 60,589 in 1890. It needs a larger home supply of farm and garden produce to supply more cheaply this population and keep this large amount of wealth within our own borders. This makes irrigation to reclaim and make productive the soil, of prime importance.

The subject matter of this bulletin is largely compiled from other authors, with such additional material as has been suggested by observation and experiment. The results in "Duty of Water" are from experiments on the Laramie and Wheatland Experiment Farms.

AGRICULTURAL POSSIBILITIES.

Outside of the mineral resources we must not lose sight of the fact that stock-growing is, and naturally will always be one of the most remunerative industries in Wyoming. In Census Bulletin No. 107 we find the following statement:

"The agricultural land in Wyoming lies at the highest altitude of that of any state in the Union, nearly one-half the total area being above 6,500 feet and probably less than one per cent. below 4,000 feet."

In some classifications those lands and plateaus above 6,000 feet are rated "pasture lands." As a rule, being supplied with abundant nutritious grasses and forage plants, which in this region have the peculiar property of curing naturally without losing their nutritious qualities, such lands are eminently fitted for grazing. In addition to this, although Wyoming has a water supply as good or better than other arid states, there are, in comparison with the land for which there is water, large areas which
can never be reclaimed by irrigation but which will form a feeding ground for the stock from the adjoining ranches or farms.

Several years experimenting has proved that this elevated land, to at least a little over 7,000 feet altitude, which can be brought under the influence of irrigation, is abundantly productive when planted to the forage and more important farm and garden crops. All of the cereals, root crops and the more hardy garden vegetables and fruits are eminently successful. It therefore happens, with the increase of population, that the large stock ranges are being converted into smaller farms where pure farming and stock-raising are combined, both reaching a greater degree of excellence.

The state contains moreover large areas of land under 5,000 feet altitude where agriculture and horticulture are as successful as in adjoining states where irrigation is practiced, said lands being located in the eastern, northern and west-central portions. Along the eastern border the plains do not differ materially from those in Nebraska. Here, according to the Progress Report on Irrigation, issued by the United States Department in 1890, the amount of land under ditch in one year increased 100 per cent., from 75,000 to 150,000 acres. The seasons are long, climate mild and crops are correspondingly successful. In the west-central portion the land below 5,000 feet consists of valleys and table lands along the Wind and Big Horn rivers and their tributaries. Heretofore farming on an extensive scale in this region has only been prevented by the lack of transportation facilities. The best district in the state for farming is probably in the northern part. Here along the Powder river and its tributaries
and farther north along the Tongue river the elevation is as low as 3,500 feet. These streams all flow north and east from the Big Horn mountains, which are high and broad, forming a large catchment area which furnishes a good supply of water. The mountains being so high, 8,000 to 10,000 feet, and the adjoining valleys so low the streams are clear and cold the larger part of the year, and in flood time they bring down the soil of the mountains, forming rich alluvial deposits along their valleys. The low altitude makes the climate warm, and the seasons are long enough for nearly all crops. Many ditches have been taken from the streams in this region, and the land is already coming into a high state of cultivation.

In the northeast corner of the state irrigation is not practiced to any considerable extent, but crops are raised with more or less success. In favorable seasons the yields are large, but besides crops being made certain every year they would be greatly increased, I venture to say doubled, by irrigation. However, the conditions in this section are peculiar, especially in the hilly or mountainous part. The annual precipitation is greater than in other parts of the state, being a little over seventeen inches. This alone, other things being equal, would not be sufficient. From traveling over this ground I am convinced that the success with which crops are raised in the more favorably located valleys is not due to the precipitation during the growing season alone, but to a vast natural system of sub-irrigation or seepage irrigation. The mountains are not of great height, the tallest being about 6,000 feet elevation, but are quite abrupt. The valleys are broad and level and usually devoid of timber, while the mountain tops and sides well down to the valleys are generally cov-
Irrigation.

...ered with pine, oak, boxelder, willows and other trees and shrubs. They consequently act as storage reservoirs, catching the water through the winter which supplies the many springs and keeps up the supply of surface water which is found at no considerable depths by digging wells in the valleys. By capillary action this water is continually brought to the surface supplying the roots of plants.

EFFECTS OF WATER ON LAND.

The effects of water on the land may be placed under two heads—chemical and physical. These can be only briefly mentioned. The principal chemical effects are:

1. Supplying fertilizers, contained in the water, to the land.
2. Changing the chemical composition of the plant foods already in the soil.
3. Dissolving and preparing food material for absorption and assimilation by plants.
4. Deposition of beneficial or injurious salts. Its physical effects are, briefly:
   1. Softening hard soils, putting them in proper condition to be worked.
   2. Freezing and thawing, thus disintegrating hard particles, making soils finer in texture. Where the water is properly applied the above combined effects tend continually to improve the land. Without any other treatment crops are often taken from land year after year without any apparent diminution.

INCREASED VALUE OF LANDS.

F. H. Newell, of the United States Geological Survey, in speaking of Wyoming, tersely says:

"Land in this state, as in all parts of the arid region, has no value without water, but the area of arable land being almost boundless agricultural development is restrained only by the uncertainty of obtaining water."
In the same report* is given the following data:

"The average first cost of water right is $3.62 per acre. The average cost of preparing the soil for cultivation, clearing off sage brush, etc., including purchase price of the land, is $9.48 per acre. The average present value of the irrigated land in the state, including buildings, is $31.40, showing an apparent profit, less cost of buildings, of $18.30 per acre. The average annual cost of water per acre is $0.44, which, deducted from the average annual product, leaves an average annual return of $7.81 per acre."

The average value of water rights per acre was placed at $8.69 in 1890. This data, combined with the fact that in 1890 91.73 per cent. of all the crops raised were for forage, and that irrigation and farming are still in their infancy, a little over 59 per cent. only of the farms being irrigated, will fairly represent the value of water to the land. As this is for the whole state it will be readily seen that the increased value in those portions lying at low altitudes would be much greater. In Colorado, for example, improved land with permanent water right is worth $40 to $150 per acre.

**AMOUNT OF LAND IRRIGATED.**

In order to get a better idea of the scope of irrigation in Wyoming, the following statements are inserted:

In the engineer's report for 1889 the total amount of land irrigated was placed a little over 2,000,000 acres. A large portion of this was irrigated meadow or pasture land. In 1890 the census report places the irrigated area in crops, not including grass lands, at 229,676 acres. The amount of land reclaimable by irrigation is placed at 12,-

*Census Bulletin No. 107.
000,000 acres. It is probable that these figures are approximately correct.

**WYOMING’S WATER SUPPLY.**

**RAINFALL.**—Our records of precipitation are by no means complete for the whole state. However, records have been kept in different localities for a number of years, from which a close estimate may be made. In round numbers the amount varies from 10 to 17 inches, averaging for the state a little less than 12 inches.* The average near the 105th meridian, Cheyenne, is 9.96 inches, of which 6.56 inches falls during the growing months, viz. : May, June, July and August.† It is evident that without other supply practically no vegetation could be supported, and when we remember that irrigation is extensively practiced where the precipitation is as high as 40 inches per annum the insufficiency of our supply from this source is apparent. No records have as yet been kept of precipitation upon our mountain ranges. We know that the amount is much greater at those high altitudes. From sixteen years observations on Pike’s Peak, Colo., the average annual precipitation was 28.65 inches, while for the adjoining plains region it was not more than one-half that amount.‡

It is to our mountain ranges we owe the fact that so much of the land is reclaimable. Heavy snows in the mountains are harbingers of good crops the coming season and a cause of rejoicing among the farmers.

Wyoming being well supplied with large mountain ranges her water supply has been the source of favorable comment. F. H. Newell says: "The water supply of

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*Engineer’s Report, 1889.
†Progress Report on Irrigation in United States, part I., page 130.
‡Irrigation and Water Storage in the Arid Regions, pages 259 and 267.
the state, as a whole, is remarkably good, since there is perhaps a larger proportion of perennial streams of notable size than in any other part of the west." The principal streams are the North Platte, Big Horn, Green, Bear, Snake, Powder, Tongue, Belle Fourche and Cheyenne rivers with their many tributaries. The water from these large rivers has not yet been utilized to any great extent, the principal farming being done along their tributaries on account of the greater ease with which the water is diverted from them.

But little attention has yet been given to underground water supply for irrigation. There are several streams of considerable length with sandy or gravelly beds into which the water sinks and runs beneath the surface during the summer months.* With properly constructed works this underflow might be used to advantage.

A few artesian wells have been bored in different localities, from which good flows are obtained, those at Rawlins furnishing a large supply of water. In Crook county some of the settlers are anxious that the possibility of artesian wells for irrigating purposes be investigated. Large flows would be a valuable addition to their present water supply.

THEORY AND PRACTICE.

Irrigation as a science is well worthy the attention now being bestowed upon it. Theory and practice must go hand in hand, for without a knowledge of the science the artisan labors under many disadvantages. The idea that "any one with common sense can irrigate" has been almost as prevalent as the idea that any one can farm.

*Hat creek, Lance creek and other tributaries of the Cheyenne river in Weston county are examples.
Without any reference to the success of the operation they may be true. In old irrigation districts where its practice has been brought to a high degree of excellence, experienced irrigators are eagerly sought, and demand high wages.

So much depends upon the proper application of water that its practice often results in failure, unless it has received careful consideration and study. The amount of water a crop should receive, the time in its development to irrigate to obtain best results, the methods of applying water to different crops together with that skill in accurate and economical manipulation which comes through practice and experience, are some of the important considerations. The following suggestions are made with the hope that they may be of benefit to some who are not already well informed upon the subjects treated.

**OVER IRRIGATION.**

The extravagant and wasteful use of water should be most carefully guarded against by every irrigator. Over irrigation is one of the first and most serious mistakes made by the early settler. This is not a strange circumstance. Coming as he does from regions where irrigation is not practiced, the available literature upon the subject being so limited, he has been obliged to glean the greater part of his knowledge from the school of experience. The first settlers, comparatively few in number, find an abundant supply of water at hand, and not feeling the necessity of economising, pour it upon the land as a rule in greater quantities than is needed.

The evils of putting too much water on the land are many. It is difficult to determine which of these detrimental effects is of greatest importance. In the first place
quantities of water are used which might go to reclaim and make productive other arid land. As the agricultural wealth of the state is only limited by the amount of land which can be irrigated, this is an important consideration. In the second place large amounts of water may produce chemical and physical changes in the soil, causing it to become less productive. By changing the land to an alkali plat or swampy condition it is often left a public nuisance and worse than valueless. Too much washing of light soils may take out useful chemicals. Heavy soils are more apt to become sour and cold if kept too wet. If the land is level and without drainage, as will be the case if the subsoil is clay or other impervious stratum, greater care will be necessary in irrigating. In alkali soils the injurious salts often increase on irrigated land to such an extent as to seriously injure or totally destroy the vegetation. This may be due to alkali in the subsoil being brought to the surface and left there by evaporation. Soils with little or no alkali may come to the same condition by these salts being supplied to them through the use of water which is strongly impregnated. Here again evaporation causes the alkali to accumulate upon the surface. In either case the least irrigation sufficient for a quickly maturing crop should be given.*

The third class of injuries from over irrigation, to which attention is called, are to the crops themselves. Probably the greater number of crops, including meadows, where water is plentiful, are more apt to be irrigated too much than not enough. This was forcibly brought to the writer's attention during the past summer, meadows being viewed from which many of the best and most nutritious

*For further information on this subject see Alkali Lands, Irrigation and Drainage in Their Mutual Relations, by E. W. Hilgard.
grasses had disappeared, having been actually drowned out, the more succulent water grasses, rushes and sedges taking their place. This is more often the case in mountain meadows where little water is needed, but the supply being abundant, it is turned on and left to run over the land for days and even weeks at a time. Growing crops should not be allowed to stand in water for any great length of time. It is thought best to apply water only when needed, and then a sufficient amount should be supplied in the shortest possible time. This allows the ground to quickly regain its normal temperature and condition, and the plants resume growth with renewed vigor. In Italy, Baird Smith concludes, that an amount of water that would form a layer four inches deep over the entire field is sufficient for an irrigation of a meadow.*

One meadow on Cooper creek was visited in June, 1892, where a large amount of water was made to bring about a beneficial effect. Though but indirectly connected with the subject it may be of interest. Much of the best meadow land had previously been so extensively covered with boulders of various sizes as to prevent any haying operations. By skilfully irrigating it, the force of their own specific gravity had caused them to sink beneath the surface, leaving the meadow smooth and in fine condition. Had the soil been different, however, it is likely injurious effects would have resulted. Being a light loam with almost perfect natural drainage, it required more moisture than ordinary soils, and soon regained its normal condition after the water was turned off.

At high altitudes unless the plants are in need of it, cold water seems to check growth and cause them to take

*Agriculture, Storer, volume 2, page 254.
on a sickly appearance. At the Laramie Experiment Farm, above 7,000 feet altitude, crops are more successful when the least water consistent with their requirements is applied.

WHEN TO IRRIGATE.

This problem needs more careful investigation in this country and would be a fit subject for a more complete set of experiments than it has received. Hellriegel carried on some experiments in Prussia to determine the time that plants need to be supplied with water. He found that the crops experimented upon did not commence to wilt until the amount of moisture in the soil was reduced to less than 16 per cent. He claims, however, that the wilting of the leaves does not indicate the time when the plant first needs water, as its growth may be seriously checked sometime before wilting occurs.* This probably depends somewhat upon the crop and surrounding conditions. The above experiments were carried on at a time when dry, hot winds were prevalent. As a rule the general appearance of the soil and crop is sufficient to the experienced irrigator. The indications of the time water is needed will vary with every kind of crop. The soil will appear dry, a check in the growth is noticed or wilting of the leaves takes place.

To secure the best results it is often necessary to supply sufficient moisture to the soil during certain periods of growth. The following suggestions are made treating each sort of crop separately:

Irrigation of the meadow—Grasses may be irrigated at almost any time during the season. Our best native hay grasses, the Blue Stems, (Agropyrrums), and Grama

*Agri., Storer, volume 2, page 252.
(Bouteloua), produce stems just underneath or at the surface of the ground. Wherever these underground stems or root stalks are broken other stems and leaves will grow. Where then these grasses are not thick enough a thorough harrowing in the spring before water is turned on answers the double purpose of breaking up the root stalks causing the sods to thicken up, increasing yield and leaving the ground in best condition for absorbing water. Native meadows should be supplied with comparatively large amounts of water in the spring before the stalks begin to shoot. No water should be given any hay crop for some length of time before it is to be cut. This allows the plants to store up larger amounts of nutrition, and the ground is firm, in good condition for cutting and curing the hay. Alfalfa and other clovers where more than one crop is to be harvested in the season, should be quickly and thoroughly irrigated soon after the previous crop has been removed. One irrigation is usually sufficient for each crop. The same treatment should be given native meadows which are to be used for pasture. The stubble is easy to irrigate, and it is just the time that the plants need moisture to enable them to put forth a new growth.

Cereals—It may be said of all crops of which the seed is planted, if there is not enough moisture in the soil to insure germination and growth as soon as planted, it should be irrigated long enough before planting time to allow the ground to regain a suitable working condition. Great care should be taken, especially with clay soils, not to work the ground when too wet. If stirred at this time there is danger of "puddling," as it is called, i. e., of destroying the tilth by driving out the air which is held between the soil particles. This is an argument in favor of
fall irrigation, the ground being thoroughly soaked after the crops have been harvested. If the ground is plowed as soon after as it becomes dry enough to work, there will usually be a sufficient amount of moisture retained to supply the early growth of crops in the spring.

Wheat needs the most water during its early period of growth. Just before heading if the ground does not contain enough moisture to last until the crop will mature, it should be irrigated, as water applied after the heads are formed is liable to induce rust.

Oats succeed best in cool, moist climates, and will probably stand more water than other cereals. To insure heavy crops they should be well supplied with moisture during the time of filling.

Corn being a plant which naturally thrives best in a warm soil, care must be taken in irrigating this crop. In this state it should not be irrigated until it plainly shows the need of water. The common rule is not to irrigate it until the leaves appear wilted in the morning. Though the leaves may curl during the day, as long as they come out bright and fresh in the morning, it is thought best not to supply more water. Corn roots lie near the surface, so deep irrigation is not necessary. The water should be run through the rows quickly and turned off. As soon as in a condition to work the surface should be cultivated to prevent rapid evaporation. On the Laramie Experiment Farm corn planted on land which had been thoroughly irrigated the year before, succeeded best where no water was given during its growth. The best time to irrigate corn is said to be during the period of tasseling.
Potatoes—Around Greeley, Colorado, where potatoes are so successfully raised, though they may appear to need water, the farmers are careful not to irrigate them until after the young tubers are set. The reason for this is obvious. When irrigated immediately before setting a greater number of potatoes will be formed than the plant can properly support, few of them becoming large enough for market. When the tubers are allowed to form first and irrigated afterwards, fewer potatoes will form in each hill, but a large crop of marketable tubers is the result. Keeping the ground mellow by thorough and deep cultivation is important. If the ground is dry irrigate some time before beginning to set. If kept too wet a large amount of tops and few potatoes will be produced.

Other Root Crops—Turnips, beets, carrots, etc., may be irrigated at any time, the only care necessary being to keep the ground mellow and in good tilth. Sugar beets should not be irrigated late in the season, as supplying water at this time will lower the per cent of sugar which they contain. Onions need a moist, rich soil with plenty surface cultivation and should never be too wet close to the bulbs.

Garden Vegetables—Cabbage and cauliflower need a large amount of water, and should be irrigated often during the season. Celery is also grateful for large amounts of water. It is said to continually need “wet feet.” Nearly all vegetables need more water than cereals and potatoes, though considerable judgment must be used in applying it. Pumpkins, melons and the like should be irrigated more or less often, depending upon the character of the soil. To ripen tomatoes as early as possible after the fruit is set, they should not be supplied with more water than is necessary to keep them alive.
Fruits—No crops are raised with more profit under the influence of irrigation than fruits. With it they are made to yield abundantly every year, and the profit is often great enough to excuse the use of the most expensive systems. By a supply of water at hand late frosts are often prevented doing any injury, and crops are secured even in unfavorable seasons.

Strawberries should be irrigated often after they are first set out, and every second or third day during the fruiting season. Raspberries and blackberries do not need irrigation so often, but the ground should be kept moist. An increased yield of raspberries may be obtained by irrigating after the earliest berries have been picked.

In the orchard sub-irrigation is the best, giving a continual supply of moisture when and where most needed. Late in the fall, before the water is turned out of the ditches, all fruits should be thoroughly irrigated to prevent the ground drying out during our dry winters. The roots of trees, growing deep in the soil, it takes much longer to irrigate them thoroughly from the surface than ordinary crops. After transplanting they require a much larger amount of water than after the roots are fully developed.

METHODS OF IRRIGATION.

The different methods of applying water to the land can be only briefly discussed. The one to be used will depend upon the kind of crop, character of the surface and sub-soil, and lay of the land, whether rough or smooth, steeply inclined or level. The value of the crop cultivated will also play an important part in deciding between the cheaper and more expensive systems. Through the kindness of J. S. Meyer, superintendent of the Lan-
der Experiment Farm, some information regarding irrigation in Fremont county has been furnished this department. Before speaking of each method separately the following extracts are inserted:

Letter from Mr. Meyer:—"The two methods used here are 'furrow irrigation' and 'flooding.' It is generally acknowledged that furrow irrigation is much better. From my own experience the 'marker' (similar to the one used in corn countries), is not a success, and should not be recommended. 'Ditchers' which have two shovels, making two ditches at a time, leaving them rough so that the water will soak rapidly into the soil, are preferable to the marker, which leaves the ground smooth and packed in places, allowing the water to run through so fast that it requires a long time to thoroughly wet the soil. On the Experiment Farm we use a single shovel-plow for ditching. This has two shovels, the smaller of which is right for spring ditching. We use the larger shovel on winter grain, where the ditches are made in the fall, as they are liable to close up during the winter if too small.

'Where the ground is steep it is better to have the ditches run parallel with the slope. Unless this can have the proper attention throughout the season, however, would prefer running the ditches up and down the hill, as the weight of the water is liable to cause breaks, in which case the furrows below will fill up and run over, damaging both ditches and crops. Where they can be watched the level irrigation is the best, for the ditches have little slope and the water running slowly through them is taken up more rapidly, and there is no waste of soil from washing. I know of no vegetables which will stand flooding."

Letter of E. A. Gustin to Mr. Meyer:—"We have
three systems of irrigation in use as follows: Irrigation by sakiehs,* Flooding and Sub-irrigation. To irrigate with "sakiehs," or small furrows, the water is taken at intervals according to flow of water and lay of land, from the laterals into sub-laterals, and from these distributed among the furrows equally, commencing at the upper end or inlet. Gauge the size of the inlets until all the water is consumed, regulating it so the progress in the furrows will be as even as possible. This system is best where the ground is sandy or rough with porous sub-soil.

*In irrigating by flooding the water is conducted to the highest part of the land in shallow furrows, and spread by means of outlets so arranged and regulated as to cover the land as evenly and quickly as possible.

"Sub-irrigation is used on light sandy or loam soils, which have clay or hard-pan sub-soil. The water is run in shallow furrows, which are from 60 feet to 200 feet apart, according to the nature of the soil, said furrows being as nearly level as possible. Fill the furrows with water and so regulate the flow that it will just supply the absorption and keep the furrows full. Let water run in the ditches all through the growing season if necessary. It will be found that as soon as the water strikes the sub-soil it will follow it, and the evaporation will bring sufficient moisture to the surface to keep the soil in good growing condition."†

FLOODING.

This method of applying water is sufficiently described above. Being the quickest and cheapest it is almost universally used for grass, meadows and

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*“Sakieh, a small irrigating brook.”
†This method is often called sub-irrigation, but to prevent confusion it is thought best to confine the term to its first significance. See sub-irrigation, page 22 of this bulletin.
grain crops. On those soils which bake and crack badly flooding is injurious, unless the plants stand close enough together to shade the ground well. Water coming directly against the crown is unfavorable to the growth of many plants. The writer has often noticed that millet, rye, oats and other crops will be larger and more thrifty a short distance from a ditch bank, where they receive all their moisture by seepage, than they will farther out in the field, where irrigated by flooding, though kept sufficiently moist. It is believed that with our conditions of soil and climate, flooding is never so favorable to the greater number of plants as is some method whereby the roots may be supplied with water from below without the crowns of the plants standing in the water or becoming too wet. However, as all other systems require more time and are more expensive the value of the crop cultivated, together with the facility and ease with which other methods can be used, will necessarily determine which is of greater advantage.

ROW, FURROW OR SEEPAGE IRRIGATION.

The methods in general use need no further description here than that given in the above extracts from letters where furrows, or "sakiehs," as they are sometimes called, are used. The Rill system (where the corn marker is used), is a modification of row irrigation. A roller so constructed that it will leave small furrows eighteen inches or two feet apart is sometimes used.* This method is not recommended for heavy or clay soils which pack badly, for, as stated above, the rows will be left hard and smooth. On light, porous soils it may often be used to advantage.

*Bulletin No. 28, South Dakota Experiment Station.
Except for meadows and grass lands, furrow or seepage irrigation, where it can be applied, has many advantages over flooding. In the absence of the more expensive sub-irrigation, it is necessary to use it for garden vegetables and other crops which are greatly injured by flooding.

**SUB-IRRIGATION.**

In the general acceptance of the term, sub-irrigation applies to that method in which water is supplied to the roots of plants by a system of pipes laid far enough below the plow not to interfere with working the land. Porous tiling, or iron or other pipes with openings at stated intervals, are used. The tiling has the advantage of furnishing drainage when there is too much water in the soil.

In Europe, according to Storer, this system has been successfully used on meadows. Besides the beneficial effects of applying water in this way the surface of the ground is left smooth and free from open ditches. The first cost being comparatively great, the system is little used in this country, except for trees and fruits, such crops as are more permanent and profitable enough to repay the expense. The first cost of laying a system of pipes has been estimated at $400 per acre. Upon first thought such an expense appears too great for any crop or land except the most valuable, but for the following reasons the future cost of irrigating is so materially reduced that the system is often practical under ordinary conditions: 1. It is a permanent improvement which requires little or no expense to keep in repair. 2. The trouble and expense of irrigating with it is reduced to a minimum. 3. No troublesome ditches are left on the land. 4. By a system of drainage being incorporated
with it the land is improved and a high degree of perfection in irrigating maintained. 5. It is the method of applying water generally most agreeable to crops. 6. It economizes water, less being needed than where other methods are used. No water is lost by evaporation or waste. The increased "duty" where sub-irrigation is used is an important factor in localities with limited water supply.

Sub-irrigation is most successfully used with soils of some consistency and where the sub-soil is not too porous.

AN EXPERIMENT.

To determine the value of sub-irrigation at our altitude a pipe was laid on the University grounds at Laramie in May, 1891. For a description that in the annual report of this department to the president of the Agricultural College for 1891 is copied, with slight changes, as follows:

"The pipe laid upon the campus extends across the west and north sides, a distance of about 900 feet. It is two inches in diameter and at distances of eight feet are pit-cocks giving apertures of one-eighth inch each. The size of the pipe is determined by the size and number of apertures. It should be large enough in cross section to carry sufficient water to supply all the openings in a given length when running at the same time. The pipe is of iron and laid fifteen to eighteen inches below the surface. Coarse gravel was placed next to it, and every pit-cock is surrounded by a box six inches square, perforated at the sides and bottom to allow the water to escape, and with a cover so the pit-cock can be reached and water shut off if any part of the ground gets too wet. To prevent freezing an opening with valve is left in the lowest
part of the pipe so the water can be drained off. Water running into the pipe at its highest end passes out at the apertures into the boxes, in the gravel along the pipe and through the soil to the roots of the plants. By regulating the size of the openings through the pit-cocks any desired degree of moisture can be obtained. A row of trees was set along each side of the pipe and cuttings of willow and barberry placed over it."

Although the subsoil is of a loose and gravelly nature, the results from this pipe have been most satisfactory for the two seasons it has been in use. It has caused no extra expense or trouble since laid, and but little water, comparatively, has been required to keep the ground in good condition. Not only have the trees along it thrived and made excellent growth, but the shrubs and grasses within its influence have shown beneficial effects to a marked degree. More water has been required, however, than would be needed with a clay or other impervious subsoil. It was because of our loose open subsoil that the openings were placed only eight feet apart. Where the conditions of soil are favorable the distance between them may be increased to twenty feet or more.

OTHER METHODS.

There are a few other forms of irrigation which are essentially but modifications of the above. In the Mexican system dykes or levees are thrown up around level plats of land. The water is turned in and left standing a short time, drawn off into an adjoining plat and so on until all are irrigated. It is a modification of flooding.

The barrel or wagon and tank method is but little used in this state. Its name indicates the method of procedure. As cumbersome and expensive as is this method of putting water on the land, it is often better than no irrigation. One of the botanical stations (forty acres in extent) in Antigua, one of the Leeward islands, is irrigated in this way, the water being dipped up from ponds, hauled to the station and poured into basins made around the base of each tree.
DUTY OF WATER.

Experiments were early inaugurated by the Station to determine the duty of water, i.e. the amount of land for which a certain quantity of water is sufficient to produce crops successfully. This may be expressed in three ways: 1. The volume of water used. 2. The average depth to which the amount used would cover the land. 3. The area which a continuous flow of one cubic foot per second through the irrigating season will irrigate. The last of these methods is most generally used, but all three are given in the table giving results of investigation by the Station. The duty varies greatly with different conditions. The more important conditions under which it will vary are taken from Flynn's Irrigation Canals as follows: 1. With the character and conditions of soil and subsoil. 2. Configuration of the land. 3. Depth of water line below the surface. 4. Rainfall, evaporation and temperature. 5. Method of application. 6. Length of time the land has been irrigated. 7. Kind of crop. 8. Experience of the irrigator. It is evident then that the duty determined in parts of Europe or even in an adjoining state where the investigation is being extensively carried out are of little practical value to Wyoming and space prevents quoting such duties here. The duty of water in this state must be determined by actual measurement. Means by which the water used can be measured with the greatest possible degree of accuracy is the first requisite in the investigation. These are: 1. A weir so constructed and placed that it will fill the necessary conditions of measure-
ment. 2. An instrument which will give a continuous record of the time and depth of water flowing over the weir.

The Cippoletti trapezoidal weir in which the sides are inclined at one-fourth horizontal to one vertical was adopted. In order to fill the conditions necessary for accurate measurement, large boxes six feet square and three feet deep were constructed. The water from the lateral runs into the rear end of the box and out over the weir which is placed in the forward end. A notch for the weir is made in the middle of a wide board which fits into the end of the box between cleats like a gate so it can easily be removed and a board with different length of weir used if needed. This is found convenient as the depth of the water flowing over the weir should not be less than three inches nor more than one-third its length. Then if a large flow is being used a long weir can be used and if only a small flow a shorter weir is substituted which will often overcome sources of error. Strips of galvanized iron are screwed on the side from which the water comes, leaving the sill or base of the weir 12, 18 or 24 inches long. This gives a sharp crest which is necessary.

This form of weir has two important advantages over the rectangular weir in which the sides are vertical. 1. In weirs of different lengths the discharges are proportional to the lengths, i.e. the amount flowing over a two foot weir will be twice that flowing over a one foot weir, with but a small error, the depth remaining the same. 2. The slope of the sides are such that no coefficient for end contractions need be used, which makes computations much easier. The formula for computing the quantity of water running over the trapezoidal weir is \( D = 3.33 \frac{3}{3} \ LH^\frac{3}{2} \) in which \( D \) equals discharge in cubic feet per second, \( L \)
equals length of weir in feet and $H$ equals the depth of water flowing over the weir in feet. (L. G. Carpenter in Bulletin No. 13 of the Colorado Station.)

In the rectangular weir there are two end contractions and the formula becomes $D = 3 \frac{3}{3} (L - .2H)H^2$ in

which the letters have the same value as above. (Francis' formula where the velocity of the water approaching the weir is very small.)

An instrument to give a continuous record of the time and depth of the water running over weir was kindly loaned the Station by the State Engineer. This was used at the Laramie farm and one of like pattern was purchased
Duty of Water.

and sent to Wheatland. The instrument is shown in Fig. 1. A line from a float in the water passes over a pulley at the top of the instrument and is fastened to the marking pen, so any variation in the depth of the water is marked on a paper placed around the cylinder. This cylinder is turned by clock work giving the time. Fig. 2 shows the instrument, weir and weir-box in use at the Laramie farm.

Fig. 3 represents a self-registering instrument of another pattern. The floats are shown as attached to the instrument and the weir-box with the water flowing over a trapezoidal weir are well represented. The dial above shows the manner in which the time and depth are registered. This is probably the simplest and cheapest instrument for its purpose yet constructed and no fault has been found with its work.

Irrigation is a business and should be conducted on business principles. The time is approaching when every ditch owner must have some means at hand for measuring the water to be used. This with some knowledge of the duty of water will enable him to avoid expensive errors.

The weir and self register for measurement is the most simple, accurate and effective method, and their adoption and use is urged.

DUTY.—In 1889 the then Territorial Engineer reported from experiments at Wheatland a duty of one cubic foot continuous flow per second, of 93.6 acres for oats and 229.5 acres for potatoes. In the appended table are given the results of the investigation which has been carried on by the Experiment Station. The mixed crops in 1891 were as follows: 6 acres native sod, 7 acres cereals, 3 acres root crops, 2 acres garden vegetables and 6 acres various crops. The land was new, it being its first year of cultivation. In 1892 it will be noticed that the duty for mixed crops is over twice as much. In fact from 8 acres which were irrigated in 1891 good yields were harvested the last season without any irrigation, the oats yielding from 17 to 35 bushels per acre. In addition to the large amount
<table>
<thead>
<tr>
<th>PLACE</th>
<th>Year</th>
<th>Crop</th>
<th>Area in acres</th>
<th>Yield per acre</th>
<th>Rainfall for 4 months-Inches</th>
<th>Date irrigated</th>
<th>Time water run over weir</th>
<th>Total amount of water used in cubic feet</th>
<th>Ave. flow for time used in cu. ft. per sec.</th>
<th>Ave. flow for season in cu. ft. per sec.</th>
<th>Ave. depth of irrigation water on land—inches</th>
<th>Duty of 1 cu. ft. continuous flow—acres</th>
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</thead>
<tbody>
<tr>
<td>Laramie Experiment Farm</td>
<td>1891</td>
<td>Mixed</td>
<td>24</td>
<td>6.16</td>
<td></td>
<td></td>
<td>1,083 34 2,667,288.75</td>
<td>.68249 25098 30.6 95.62</td>
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<tr>
<td>Wheatland Experiment Farm</td>
<td>1891</td>
<td>Oats</td>
<td>150</td>
<td>40 bu.</td>
<td>3.50</td>
<td>June 20 to July 12</td>
<td>459.57 9,507,073.47</td>
<td>5.7415 89459 17.4 167.69</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Laramie Experiment Farm</td>
<td>1892</td>
<td>Sugar beets and Rutabagas</td>
<td>2.727</td>
<td>8.6 tons. and 18 tons</td>
<td>6.99‡</td>
<td>June 16-17, Aug. 16, Sept. 22</td>
<td>113.36 97,973.24</td>
<td>.0395 0.0022 9.9 295.77</td>
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<td></td>
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<tr>
<td>Laramie Experiment Farm</td>
<td>1892</td>
<td>Corn</td>
<td>.75</td>
<td>Cut for fodder</td>
<td>6.99‡</td>
<td>July 20.</td>
<td>9 10,848.39</td>
<td>.33482 0.0102 4.0 735.29</td>
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<tr>
<td>Laramie Experiment Farm</td>
<td>1892</td>
<td>Cane and Dhoura</td>
<td>.625</td>
<td>6.99‡</td>
<td>July 23.</td>
<td>1 19,754.92</td>
<td>.9145 0.0186 8.7 336.02</td>
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<tr>
<td>Laramie Experiment Farm</td>
<td>1892</td>
<td>Peas and Beans</td>
<td>1.00</td>
<td>Peas, 7 bu.</td>
<td>6.99‡</td>
<td>June 5.</td>
<td>27.48 18,081.13</td>
<td>.1807 0.017 4.9 588.23</td>
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<tr>
<td>Laramie Experiment Farm</td>
<td>1892</td>
<td>Mixed</td>
<td>24</td>
<td>6.99‡</td>
<td></td>
<td></td>
<td>1,222 4,118,051.41</td>
<td>.2683 11108 13.5 216.06</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Four months of growing season—May, June, July and August.
‡Irrigating season—May, June, July and August.
†5.13 inches fell in May and June.
of water used last season the increased rainfall in May and June this year probably aided in increasing the duty. More complete experiments will be carried on in 1893.

SUMMARY.

1. The opportunity to construct large irrigation works to reclaim large tracts of land in Wyoming is excellent.

2. Over irrigation is pernicious and must be avoided.

3. Of the methods of irrigation, flooding is the most injurious to cultivated crops but the most economical method for grass lands and cereals. Row irrigation is recommended for all crops where it is convenient to apply it. Sub-irrigation is the most expensive but most favorable to the majority of crops. It works best on rather heavy soils with impervious sub-soils.

4. So far as determined in this state the duty of one cubic foot per second continuous flow varies from 93.6 to 735.3 acres.
NOTE.—To make the work of the Experiment Station upon the problems of irrigation of greater value to the public, the co-operation of farmers and ranchmen in furnishing reliable information and data regarding ditches and other irrigation works, samples of water, etc., are needed. Ditch owners and others who can do so are requested to assist by furnishing data of ditches, their location, size, length, fall, cost, when constructed, with estimated amount and value of land irrigated by them, and that of any irrigation works connected with the same, as flumes, dams, headgates, tunnels, reservoirs, etc. Persons expressing a willingness to furnish any such information will be supplied with blanks and envelopes for reply.

Irrigation water from any important ditches in the state will be analyzed free at the Experiment Station if samples are taken according to directions, which will be sent on request. The importance of the chemical analysis of irrigation water is shown on pages 4 and 12 of this Bulletin, and it is desired that the Bulletin to be issued upon the composition of Wyoming irrigation water be made as complete as possible. A few samples of the well waters and of the water supply of towns in different parts of the state are also wanted in order to determine their value for domestic and manufacturing purposes. Address,

DEPARTMENT OF IRRIGATION ENGINEERING,
AGRICULTURAL EXPERIMENT STATION,
Laramie, Wyoming.