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# Twenty-five Years of Supplemental Irrigation Investigations in Willamette Valley

Agricultural Experiment Station
Oregon State Agricultural College
CORVALLIS

# TABLE OF CONTENTS

## SUMMARY


1. Results of twenty-five years' experiments with supplemental irrigation in the Wlilamette Valley are summarized herein to meet the increasing need for information on methods, cost, and value of irrigation in this Valley.

2. The normal rainfall for the three summer months here is only 1.90 inches. The normal rainfall May 1 to October 1 is 5.43 inches, while the loss from an evaporation tank is 26.85 inches. Mean weather conditions for the 25-year period of this investigation were practically normal. The summer climate is similar to that at Baker or LaGrande.

3. Soils best suited to supplemental irrigation here are free-working and neither too sticky nor too coarse. Sandy loam of the Chehalis and Newberg soil series in the river bottom and lighter soils of the Valley floor, such as Willamette loam or silt loam, are suitable for irrigation. Soil and ground-water surveys of the Valley indicate that more than one-half million acres of naturally drained and free-working soil are well situated and suitable for irrigation for diversified crops, while nearly another half million acres with less perfect drainage are fairly suitable for irrigation for pasture or forage crops.

4. Crops found to give best response to supplemental irrigation here are the small fruits and truck crops, those crops grown for intensive dairying such as pasture and late cuttings of legume crops, or row crops that make maximum growth late in season, such as roots and corn. Potatoes and beans are cash crops that give large returns from small amounts of irrigation. Interest is increasing in irrigation (1) for ladino clover pastures for economic sustained production for dairy animals, and (2) for finishing lambs, as well as (3) for late growing or intensive crops such as vegetables and small fruits.

5. The Willamette drainage system affords a large potential water supply for gravity and pump irrigation. Under large areas of river-bottom land and part of the main Valley floor, water can be developed by means of wells tapping the gravel substratum. This water is usually of good quality.

6. Pumps of the simple, horizontal, centrifugal type will be suitable for many situations in this Valley. Any good standard make with guaranteed efficient performance for the conditions should prove satisfactory. A number four or four-inch centrifugal pump will discharge about a cubic foot per second or 450 gallons per minute under heads up to 70 feet. One cubic foot of water per second will cover an acre

## SUMMARY—*Continued*

one inch deep in one hour and this quantity is called an acre-inch. The turbine type of pump has been improved in recent years and is suitable for driven wells or locations where water level fluctuates greatly.

7. Motive Power. An electric motor with direct connection with the pump is a most satisfactory source of power as it avoids loss in belting and requires minimum attention. Any difference in cost between use of distillate and electricity, where available, as a source of energy is more than made up by saving in attendance where the electric power can be employed. With small plants the labor saved may be greater than the total fuel bill.

8. During a 25-year period, figuring water at the maximum price of one dollar an acre-inch, an average depth of 6.44 inches has yielded an average net gain in profit from irrigation of $8.80 per acre (Table IV). The economic limit of lift irrigation will vary with (a) height and value of crop increase, (b) quantity of water required, (c) amount of lift, (d) skill and economy of the irrigator, (e) cost of energy, and other factors. Data indicate that in the Willamette Valley it should pay to pump about 25 to 40 feet for pasture, alfalfa or clover, and more than twice this height for potatoes or berries (Table VII).

9. The crop-producing power of water, based on net use under good modern methods of farming and giving maximum net profit each season averages approximately:

6.0 inches per ton of alfalfa hay
5.0 inches per 10 bushels of beans
7.0 inches per 100 bushels of potatoes
4.0 inches per 10 bushels of grain.

10. Efficient irrigation farming is essential to success with pumped water. Crop rotation with manure each rotation and with supplemental irrigation has more than doubled the yield and profit per acre-inch and has cut in two the water cost per pound of dry matter (Table VI). It has increased the nitrogen content and capacity of the soil to hold nutrient bases such as calcium and potassium in nearly available form, or has increased the nutrient supplying power of the soil. Good fertility renders sufficient the least amount of water per unit crop.

11. The farmer who plans to pump for supplemental irrigation should start early, make a filing in the State Engineer's Office on the water to be utilized, level the land before seeding to perennial crops, have the well tested out with a used pump, and have permanent pumping equipment installed and in operation at the beginning of the dry season or earlier.

# Twenty-five Years of Supplemental Irrigation Investigations in Willamette Valley

By

W. L. POWERS*

FREQUENT recurrence of unusually dry summers in the Willamette Valley and the development of more intensive agriculture emphasize the importance or advantages of supplemental irrigation to afford green pastures (a) for finishing lambs, (b) to sustain production in dairy animals, and (c) to utilize fully the long growing season for intensive or later crops such as vegetables and small fruits.

The normal rainfall for the three summer months at Corvallis is only 1.90 inches or is lower than in some well-known irrigated sections. For the period May 1 to October 1 it is 5.43 inches. The mean rainfall at Corvallis for the 25-year period, 1907 to 1932, covered by these investigations, has been 5.23 inches or 0.2 inch below normal. The mean temperature for the period was 0.5° F. above normal. Evaporation from a weather bureau pattern tank May 1 to October 1 has averaged 26.615 inches for the period 1910 to 1931.

Experiments to determine the value of supplemental irrigation in Western Oregon were undertaken by the Oregon Agricultural Experiment Station in 1907. The United States Office of Irrigation Investigations cooperated for three years.† The plan of study was then extended to determine the economic time, amount, and frequency of irrigation for soil moisture control, maximum net profit, and minimum water cost per unit of dry matter produced. Studies of the effects of irrigation on soil and crops also were added. During the past six years studies with irrigated pastures and of the effect of irrigation on major berry crops have been made. A groundwater survey of the Willamette Valley has been carried out with the cooperation of the United States Geological Survey. Irrigation from deep wells has been successfully installed with the aid of a revolving fund furnished by interested business men.

A series of bulletins have been issued from time to time reporting results. On account of the extensive interest developed, these are nearly all out of print.‡ The object of the present report is to summarize the essential information on supplemental irrigation in the Willamette Valley obtained during the past twenty-five years and put it into readily available form so as to meet the heavy demand for information.

*The writer is indebted to Professor M. R. Lewis for reading the manuscript and contributing numerous helpful suggestions.

†Stover, A. P., Office of Experiment Stations Bulletin 226 (1910).

‡Oregon Agricultural Experiment Station Bulletins 122, 160, 161, 173, 189, 235, 264, 277, and Station Circular 57.

Some 5,000 acres in the Willamette Valley are now irrigated according to recent census figures. The records of the State Engineer's Office show that filings January 1, 1928, to June, 1932, number 395 including irrigation use with 1,548 second-feet involved.

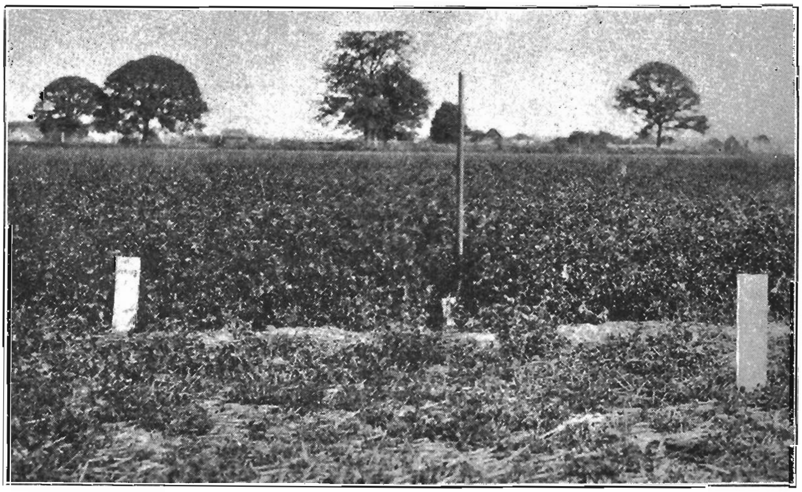

Figure 1. Irrigated alfalfa, fourth cutting.

The earlier experiments were developed on the hypothesis that if irrigation of staple field crops with pumped water would pay, gravity irrigation from neighboring streams certainly would pay and where used with intensive dairy and horticultural crops should yield even larger returns.

**Advantages of supplemental irrigation** for free-working naturally-drained Willamette Valley soils are as follows:

(1) Irrigation controls soil moisture and overcomes drought.
(2) Provides green pasture and green feed late in the summer.
(3) Saves the clover stand and makes a cutting the first season.
(4) Makes double cropping possible, such as late crops after early crops.
(5) Aids the beneficial bacterial and chemical activities in the soil.
(6) Improves quality and aids control of crop pests and diseases especially of vegetables and berries.
(7) Increases efficiency of soil moisture during the best growing weather.
(8) Aids in deep or early fall plowing and intensive cropping.
(9) Softens clods and dissolves plant food.
(10) If properly planned where feasible it pays in increased yields, net profits, and productive values. Irrigation under Willamette Valley conditions has usually decreased the unit cost of production.

**Soils best suited** to supplemental irrigation in the Willamette Valley are those that are naturally drained and free working without being either too heavy and sticky or too coarse and sieve-like. The sandy loam soils occurring along the Willamette and other stream bottoms—that is, soils belonging to the Newberg and Chehalis series—and the lighter types of soils on the Valley floor, including Willamette loam and silt loam, are suitable for irrigation.

Soil surveys of the Willamette Valley recently completed indicate that more than one-half million acres of the Valley are well suited to supplemental irrigation and diversified crops and that more than 400,000 acres additional are fairly suitable for irrigation for pasture and forage crops (Table I).

TABLE I. WILLAMETTE VALLEY SOILS SUSCEPTIBLE OF IMPROVEMENT BY DRAINAGE OR IRRIGATION

Estimates Based on Area Covered by Soil Surveys Outside the National Forests.

| Region | Total area | Wet land | | Irrigable | |
|---|---|---|---|---|---|
| | | Poor drainage | Imperfect drainage | Good irrigable | Fair irrigable |
| | *Acres* | *Acres* | *Acres* | *Acres* | *Acres* |
| Eugene area | 830,720 | 87,800 | 35,968 | 106,368 | 40,832 |
| Linn | 977,920 | 142,160 | 84,052 | 113,664 | 71,616 |
| Benton | 414,720 | 28,416 | 26,432 | 48,832 | 35,008 |
| Marion | 542,080 | 49,921 | 100,720 | 131,520 | 42,674 |
| Polk | 476,160 | 41,472 | 36,480 | 42,752 | 28,352 |
| Yamhill | 445,440 | 36,096 | 25,568 | 53,504 | 54,720 |
| Clackamas | 623,360 | 27,453 | 63,424 | 89,704 | 61,440 |
| Washington | 467,840 | 28,480 | 31,952 | 92,160 | 56,592 |
| Multnomah | 209,920 | 24,832 | 2,496 | 61,496 | 28,160 |
| Total | 4,988,160 | 466,630 | 407,092 | 740,000 | 419,394 |

This does not mean that at present water can be supplied economically for all of the soils listed above as suitable for supplemental irrigation. It is estimated that nearly 1,000,000 acres need tiling, and that more than 400,000 acres additional need some tiling and supplemental irrigation for the highest development.

The potential tonnage and returns from feasible supplemental irrigation are enormous. The cost of irrigation for these occupied lands is comparatively low while public improvement and means of transportation are already at hand.

**Usable soil water capacity.** Table II shows the usable soil water capacity in acre-inches per foot depth for the chief classes of soils.

TABLE II. USABLE WATER RETAINING CAPACITY OF SOIL CLASSES

| Soil class | Field water capacity. Depth per foot soil (approximate) |
|---|---|
| | *Inches* |
| Fine sand | 1 |
| Medium sandy loam | 1¼ |
| Fine sandy loam | 1½ |
| Silt loam | 1¾ |
| Silty clay loam | 2 |
| Peat | 3 to 4 |

**Root zone** studies show that most of the feeding roots of ordinary field crops are in the surface two or three feet of soil and that the greater part of the removal of moisture by plants occurs from this zone. For example, alfalfa growing on deep sandy loam in the Imperial Valley was found to have 26.93 percent of its feeding roots in the first foot.* Cooperative irrigation experiments with pears in the Medford section show 64 percent of moisture obtained from the first two feet.† The subsoil in heavy soils of the Willamette Valley is always moist and irrigation water should be applied sparingly in order to avoid saturation of the subsoil.

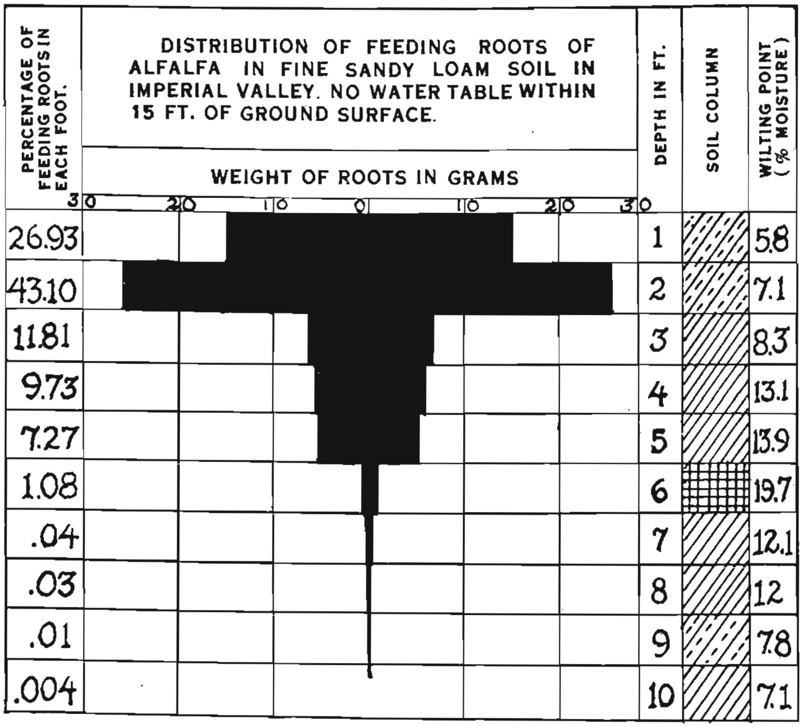


Figure 2. Root systems of alfalfa.

The aim in irrigation should be to maintain usable moisture in most of the root zone until late in the growing season. The object is to get the highest possible efficiency out of every acre-inch of water received or provided for the crop.

Water should be measured and applied according to the water capacity of the root zone. Detailed information is available elsewhere.‡ A weir table is appended for convenience (Table XII).

*Packard, Walter E. *Irrigation of Alfalfa in Imperial Valley;* Calif. Expt. Sta. Bul. 284.
†Work, Arch. *Second Progress Report* (unpublished), Cooperative Investigations, U. S. Bureau of Agricultural Engineering and Oregon Agricultural Experiment Station.
‡Powers, W. L. *Measurement of Irrigation Water,* Oregon State Agricultural College Extension Service Circular 4.

**Crops** found to give best response to supplemental irrigation here are the truck crops; certain small fruits; those crops grown for intensive dairying, such as late cuttings of legume crops; late pastures; or row crops that make a maximum growth late in the season, such as roots and corn. Potatoes and beans are cash crops giving large returns with a small amount of supplemental irrigation and are likely to pay for proper irrigation. Clover seed yields may be substantially increased by one irrigation. Tree fruits and nuts appear to benefit from irrigation on droughty soil.

**Water supply.** The water available for irrigation in this Valley is generally of good quality. Its total run-off indicates a potential water supply of some fifteen acre-feet a year for the irrigable area. Ground water which occurs in the gravel substratum under the river-bottom soils and in places under the main Valley floor, such as between the Pudding and Willamette rivers, can be tapped by means of wells. In many places perennial tributaries of the Willamette may be diverted by gravity to irrigable areas.

Water rights which must be established are initiated by filing an application upon forms provided by the State Engineer's office. It will be necessary to describe the point of diversion or pumping by giving distance and direction from a legal land subdivision corner and approximate location and area of land to be served. The equivalent of a cubic foot per second continuous flow for each 80 acres is commonly allowed.

**Average net use** for the past two decades on Willamette silt loam at Corvallis has been 6.5 inches depth a season (Table III), ranging from 3.35 inches for beans to nearly 12 inches for alfalfa and other mown meadow. Ladino clover and grass pasture on Amity and Wapato silty clay loam soil seem to require approximately 24 inches depth a season.

Sandy loam of the second bottom or Chehalis soil series seems to require 12 to 18 inches depth an acre a season for cultivated crops such as potatoes and berries, while 18 to 24 inches appears to be needed for hay meadows according to 6 years' results on bottom land on the Experiment Farm one mile east of Corvallis.

TABLE III. AVERAGE QUANTITY OF WATER GIVING MAXIMUM NET PROFIT PER ACRE

| Crop | Years in average | Irrigation | Total use | Yield | Water per pound dry matter |
|---|---|---|---|---|---|
| | *Years* | *Inches* | *Inches* | *Tons or Bu.* | *Lb.* |
| Alfalfa | 16 | 9.5 | 20.13 | 5.134 | 511 |
| Red clover | 17 | 7.9 | 17.90 | 5.547 | 504 |
| Grass (mown) | 5 | 11.2 | 20.62 | 4.780 | 657 |
| Potatoes | 19 | 4.5 | 15.94 | 234.5 | 760 |
| Corn (silage) | 19 | 5.5 | 11.70 | 9.236 | 577 |
| Beets | 8 | 5.3 | 11.38 | 16.556 | 521 |
| Beans | 19 | 3.6 | 8.57 | 20.48 | 1563 |

**Most profitable amount of irrigation.** The average amount of water giving maximum net profit has been obtained by tabulating (Table III) from water variation trials the record of the plot each season giving maximum net profit per acre. The averages show the highest probable use under good modern methods of farming. The tendency is for the maximum profit to be realized with a little more water than the quantity giving maximum net return per acre-inch and with a little less than used in producing the maximum yield (Figure 3). Frequently the amount of irrigation giving maximum net profit per acre has also given maximum yield and maximum net profit per acre-inch.

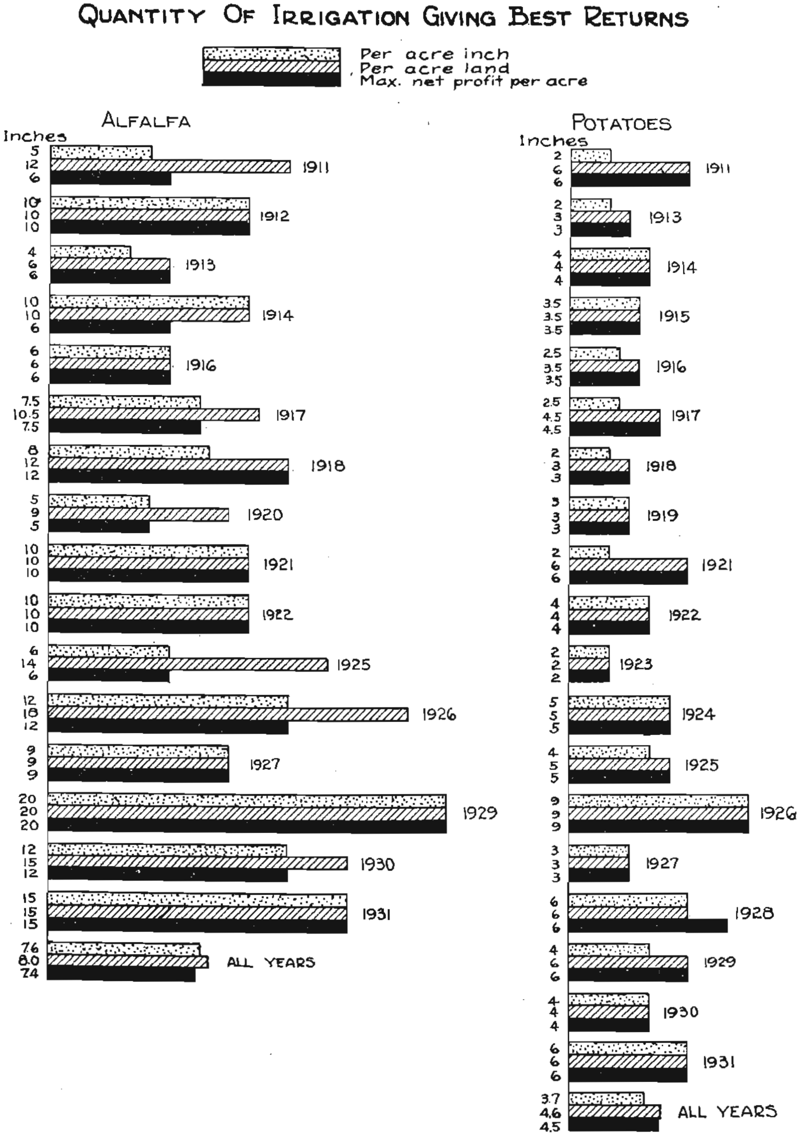


Figure 3. Quantity of irrigation giving best returns.

The quantity of soil, rain, and irrigation water used has been regularly determined and pounds of water per pound of dry matter or water cost computed. Irrigation and rainfall for the season are measured. The loss in soil water between crop emergence and harvest is computed from soil moisture determinations at these times. Moisture determinations are made on crop samples collected when yield weights are taken.

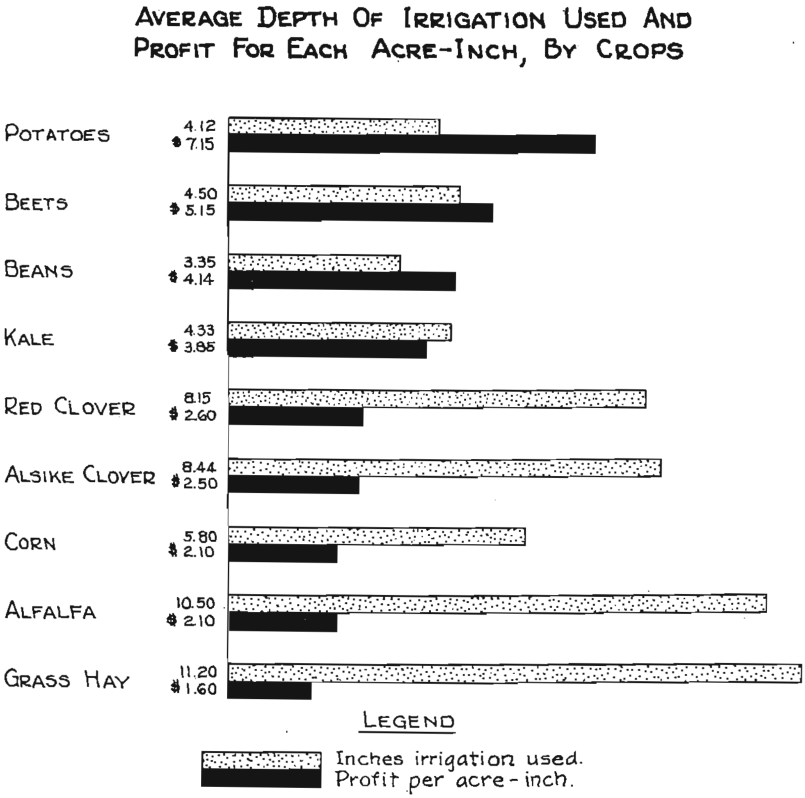


Figure 4. Average depth of irrigation used and profit for each acre-inch.

**The crop-producing power of water.** The water cost and other data given (Table III) by crops for plots giving highest net profit per acre with good modern methods of field practice form a basis for estimating the highest probable economic net duty or efficiency of water. The net economic water requirement here based on two decades of experiments under good conditions is approximately:

6 inches per 1 ton of hay
6 inches per 10 tons of beets
4 inches per 10 bushels of grain
7 inches per 100 bushels of potatoes
5 inches per 10 bushels of beans.

Water requirement will fluctuate somewhat with seasonal and soil conditions as shown in Figure 4. With efficient irrigation during the best growing weather the water requirement of the increase in the crop may be lower than that of the crop as a whole.

**Efficient design** of an irrigation system is necessary to realize the highest possible returns. The majority of irrigators in the Valley depend upon a farm irrigation pumping plant for water. The pumping plant gives an independent source of water. Over-irrigation with pump irrigation is improbable since every acre-inch represents a direct cash outlay. The Extension Specialist in Soils is available to assist in designing farm irrigation plants as time permits. Requests may be made through the county agents who group requests and schedule visits. The size of the power unit will depend on the lift, including friction and the size of stream required. Flexibility, or ability to perform with reasonable efficiency under modified conditions, is a prime consideration. The Experiment Station has pioneered in irrigation by pumping and in well-irrigation development. Small farm plants are less apt to be carefully engineered and a concise statement of results of experiments and experience will be briefly summarized here.

**Cost of a small pumping plant**, an important consideration in design, includes—

(a) First cost: power unit, pump, pipe and valves, shelter, and in some cases a well and distribution structures.
(b) Operating expenses: labor, fuel, or electric energy, lubricating oil, and repair.
(c) Fixed charges: interest on first cost and depreciation.
(d) Total annual cost: (b) plus (c).

The cost of pumped water increases with the height of lift and is frequently expressed in cost per acre-foot per foot of lift. With a well-designed pumping plant with a moderate lift operating nearly to capacity the cost delivered at the pump may run 15 to 30 cents per foot-acre-foot. The higher figure for a 24-foot lift would be $7.20 an acre-foot or 60 cents an acre-inch.

**Economic capacity.** With surface irrigation and no sprinkling the smaller plants should be large enough to provide an efficient "irrigating head" or size of stream. Providing at least one-half cubic foot of water per second (225 gallons per minute) for furrow irrigation or a cubic foot per second for flooding methods is desirable for the saving in time or labor cost. For larger installations the first cost is of relatively greater importance. Especially with electric power the size should be held down and operated long hours and regularly to secure the minimum cost per acre or acre-foot. This is illustrated by the following:

| | | Total annual cost per foot-acre-foot | | | |
|---|---|---|---|---|---|
| | First cost | 20 acre-foot run | 40 acre-foot run | 60 acre-foot run | 90 acre-foot run |
| Plant No. 1: West Experiment Station Farm | $ 733.02 | $0.54 | $0.38 | ........ | ........ |
| Plant No. 2: East Experiment Station Farm | 2000.00 | ........ | ........ | $0.24 | $0.19 |

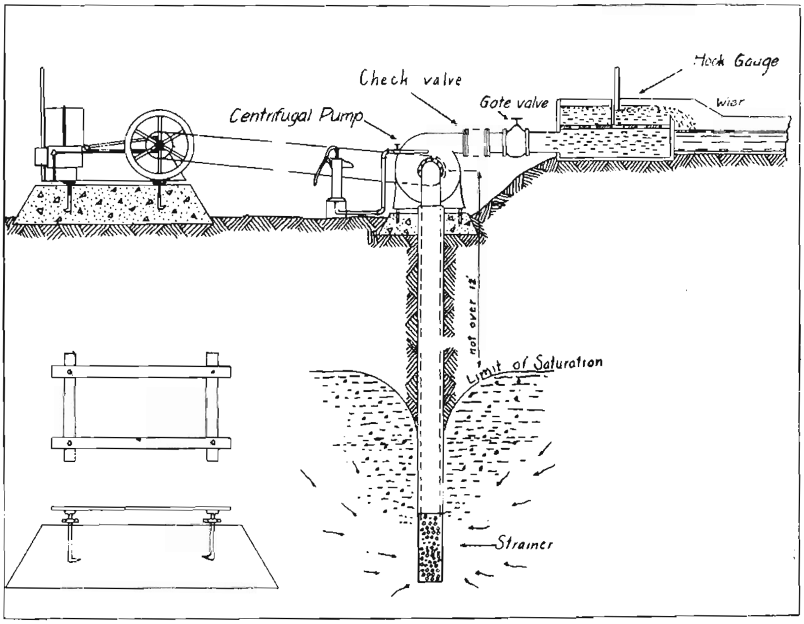


Figure 5. Design for belt-driven gasoline plant.

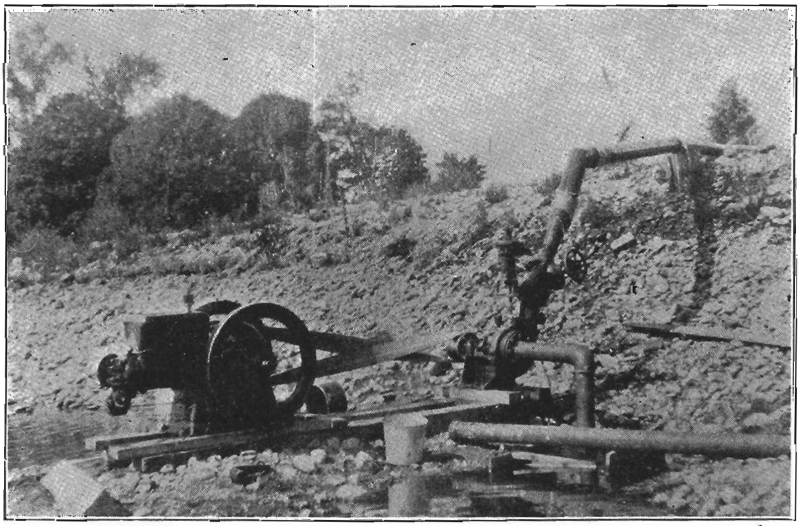

Figure 6. Small gasoline outfit.

To obtain power at the lower available rates an electric unit should be operated at least 24 ten-hour days per month while connected. Under most electric-power schedules the cost per unit of energy will become progressively lower the more nearly continuously the plant is operated. In computing the cost, value, and profit from irrigation (Table V) the maximum cost shown above (54 cents per foot-acre-foot) was found to be equivalent to 91 cents per acre-inch for the existing conditions.

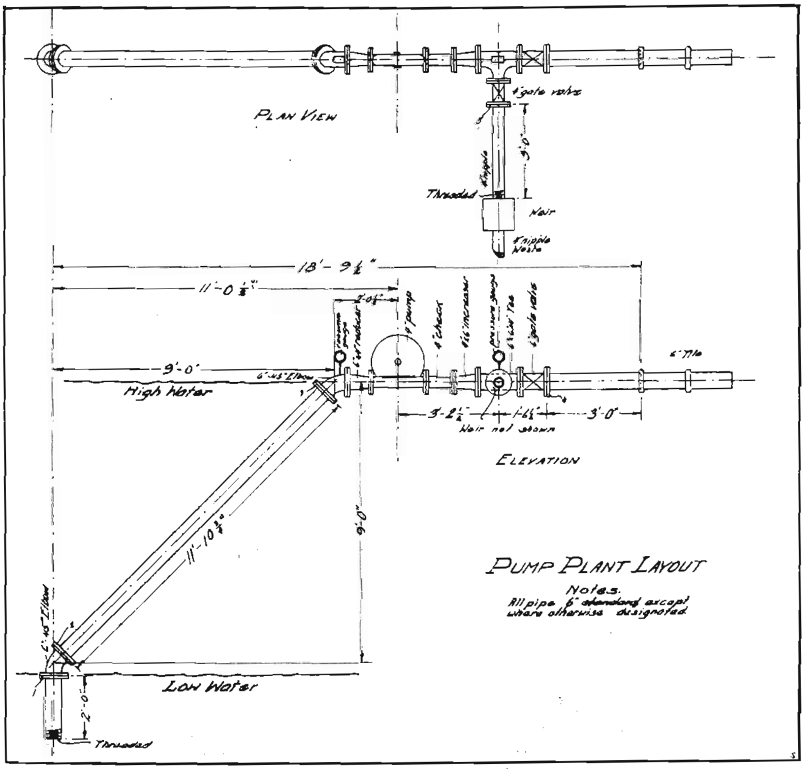


Figure 7. Design of Oak Creek electric pumping plant, Oregon Agricultural Experiment Station.

The all-crop summary, Table IV, has been prepared by comparing the average yield from various amounts of irrigation each year on Willamette and Amity silty clay loam with that of the dry plots. During the first decade of the experiment all dry plots as well as those in water-variation trials were in duplicate. Alfalfa, clover and other mown meadows received less than a foot depth of irrigation a season and were increased in yield approximately two tons per acre. Potatoes and beans are cash crops of low irrigation requirement and have paid very well for irrigation (Figure 4). With expensive pumped water it is important to have some such late-growing cash crops. The beans, alsike clover and grass were grown on gray brown silty clay loam of the Amity series.

TABLE IV. TWENTY-FIVE YEARS OF SUPPLEMENTAL IRRIGATION INVESTIGATIONS, ALL-CROP SUMMARY, AVERAGE OF ALL TRIALS

Oregon Agricultural Experiment Station—Department of Soils

| Crop | Period of trial | Average irrigation | Yield per acre: Dry | Yield per acre: Irrigated | Yield per acre: Gain per acre | Yield per acre: Gain per acre-inch | Increase from irrigation: Cash gain per acre | Increase from irrigation: Cash gain per acre-inch | Net profit per acre, Whole crop: Dry | Net profit per acre, Whole crop: Irrigated | Net profit per acre: Gain in net profit irrigated over dry | Water per pound of dry matter: Dry | Water per pound of dry matter: Irrigated |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | *Years* | *Inches* | *Tons or Bushels* | | *Tons or Bushels* | | | | | | | *Lb.* | *Lb.* |
| Alfalfa | 1909-32 | 10.50 | 3.62 | 5.83 | 2.21 | .21 | $22.10 | $ 2.10 | $21.20 | $28.38 | $ 7.18 | 774 | 618 |
| Red clover | 1908-32 | 8.15 | 4.17 | 6.25 | 2.08 | .26 | 20.80 | 2.60 | 26.70 | 35.19 | 8.49 | 570 | 598 |
| Alsike | 1914-32 | 8.44 | 1.92 | 4.01 | 2.09 | .25 | 20.90 | 2.50 | 4.20 | 12.48 | 8.28 | 773 | 646 |
| Grass | 1915-24 | 11.20 | 3.33 | 5.13 | 1.80 | .16 | 18.00 | 1.60 | 18.30 | 21.50 | 3.20 | 522 | 467 |
| Potatoes | 1907-32 | 4.12 | 134.00 | 192.92 | 58.92 | 14.30 | 29.46 | 7.15 | 27.00 | 45.27 | 18.27 | 722 | 799 |
| Beans | 1911-32 | 3.35 | 10.32 | 15.23 | 4.91 | 1.47 | 14.73 | 4.41 | 10.96 | 21.87 | 10.91 | 2301 | 2439 |
| Corn | 1907-32 | 5.80 | 6.47 | 8.93 | 2.46 | .42 | 12.30 | 2.10 | 12.35 | 13.93 | 1.58 | 554 | 598 |
| Kale | 1911-14 | 4.33 | 10.61 | 13.95 | 3.34 | .77 | 16.70 | 3.85 | 33.05 | 38.74 | 5.69 | 945 | 937 |
| Beets | 1908-14 | 4.50 | 10.98 | 15.61 | 4.63 | 1.03 | 23.15 | 5.15 | 34.90 | 44.29 | 9.39 | 876 | 573 |
| Fiber flax | 1927-32 | 4.00 | 1.68 | 2.36 | .68 | .17 | 20.40 | 5.10 | 10.40 | 25.44 | 15.04 | ........ | ........ |
| General averages | ............ | 6.44 | ........ | ........ | ........ | ........ | 19.85 | 3.66 | 19.91 | 28.71 | 8.80 | ........ | ........ |

Crop Values (1931) used: Hay $10 per ton; corn, kale, and beets $5 per ton; potatoes 50¢ per bushel; beans $3 per bushel; flax $30 per ton. Cost of production dry alfalfa, clover and grass meadow figured at $15 per acre; corn, kale, beets, and beans at $20, and potatoes and flax at $40. Water at the maximum value of $1 an acre-inch. A charge of $2.00 per ton or 20¢ per hundredweight or 12¢ a bushel is made for harvesting the increase due to irrigation.

All crops on the average are shown to have paid for irrigation when a maximum charge is made for water and conservative prices are used for products. The average use of 6.44 inches at $1 per acre inch has made more than 100 percent return, or an average of $8.80. The water cost per unit of dry matter is frequently lower with efficient irrigation to provide moisture during the best growing weather. Irrigation has decreased the percentage of small potatoes as shown in Figure 8.

**Irrigated sheep pastures.** Irrigated ladino clover and grasses have been studied in cooperation with the Department of Animal Husbandry beginning 1925. Since detailed results are to be reported elsewhere, only a summarized statement follows:

1. A total depth of approximately 24 inches of irrigation water a season, applied in 4 or 5 irrigations, is needed to keep pasture in a flush, highly productive condition.

2. Ladino clover has proved superior and returned 3,090 sheep days grazing an acre, during the 1931 season, whereas during six years' trials other pasture mixtures, including white clover and blue-grass, have given a maximum of 2,650 sheep days. Ladino is not likely to get too coarse for grazing.

3. Excellent irrigated sheep pasture can be provided at a cost of less than one cent per head per day.

4. Nitrogenous fertilizer or manure has increased growth and apparently the protein content of herbage, yet either the nitrogenous fertilizer or the manure tends to encourage grasses at the expense of clovers. Superphosphate and lime, on the other hand, tend to encourage the growth of clovers with similar increases in yield.

5. Carefully regulated rotation grazing is necessary to clean up grasses during the peak of the season.

**Irrigated dairy pastures** on Wapato silty clay loam have been under trial by the Dairy Husbandry department of the Oregon Agricultural Experiment Station for some four seasons. Results have been reported in detail elsewhere.* These experiments as well as the results on numerous farms show that irrigated ladino clover will carry from three to four cows per acre for six months out of the year. This means a net profit of some $35 to $45 per acre or a decreased unit cost of production of butter-fat, which enables the dairyman of this section to compete on very favorable terms with other dairy sections.

**Irrigation of field crops on river-bottom land.** Five years of experimentation on Chehalis loam on the East College Farm indicate that results will vary with the crop, that gains up to 100 percent are possible from irrigation, and that the irrigation requirement is 12 to 24 inches in depth per season. Proper irrigation has doubled the yield of potatoes. The yield of unirrigated plots averaged 98.9 bushels while three four-inch irrigations increased the yield to 208.3 bushels or a gain of 109.4 bushels an acre.

**Irrigated Pastures for Dairy Cattle,* Oregon Agricultural Experiment Station Bulletin 264.

**Irrigation of berries on river-bottom soil.** A detailed report of five years' study of berry irrigation on bottom land has been made* and shows that, with the exception of the Ettersburg 121 strawberry, production of small-fruit crops under irrigation proved to be more profitable than production without irrigation. The yield was increased 50 to 100 percent or more, in some cases, with an increased size and quality of fruit. It was found possible to plant some varieties of strawberries in summer after harvesting early spring crops.

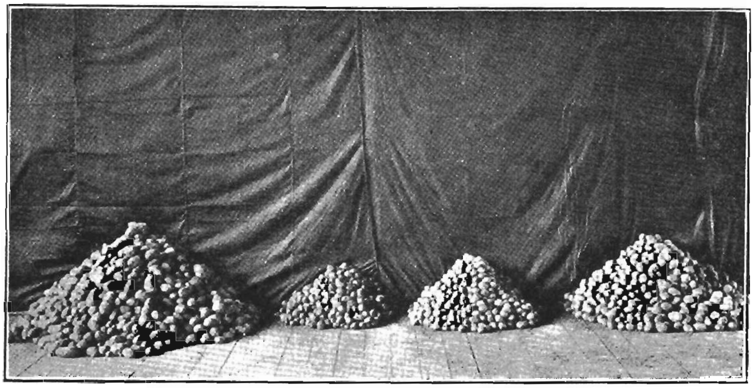

Figure 8. Irrigation increases size and marketability of potatoes. *At left:* Large and small potatoes with irrigation. *At right:* Large and small potatoes without irrigation.

**Irrigation of vegetable crops** has been studied for many years by Professor A. G. B. Bouquet, who advises that the truck crops responding well to irrigation include celery, cabbage, tomatoes, squash, cauliflower, sweet corn, carrots, and beets. According to J. A. Holt, secretary-manager of the Eugene Fruit Growers Association, certain varieties of vegetables are not accepted for canning unless irrigated. Mr. Holt supplied the comparative yields showns in Table V.

TABLE V. VEGETABLE YIELDS WITH VS. WITHOUT IRRIGATION

| Crop | Treatment | Average yield | Percentage of increase |
|---|---|---|---|
| | | *Tons* | % |
| Beets, 4-year average | Non-irrigated | 3.2 | ...... |
| Beets, 4-year average | Irrigated | 7.8 | 144 |
| Carrots, 4-year average | Non-irrigated | 12.2 | ...... |
| Carrots, 4-year average | Irrigated | 36.0 | 195 |
| Beans, Brown Ky. Wonder, 1926 only | Non-irrigated | 2364 lb. | ...... |
| | Irrigated | 10426 | 341 |
| Beans, Refugee, 1926 only | Non-irrigated | 803 | ...... |
| | Irrigated | 4289 | 434 |

**Relation of soil fertility to economic irrigation.** Good fertility renders efficient the smallest amount of water per unit of crop produced. In experiments at Corvallis on Willamette silty loam, extending over nearly two decades, the fundamental importance of soil-building practices in irrigation

*Schuster, C. E.; Besse, R. S.; Rygg, G. L.; Powers, W. L., *Effect of Irrigation on Major Berry Crops*, Oregon Agricultural Experiment Station Bulletin 277, 1931.

Figure 9. White beans with irrigation, rotation, and manure, yield 36.66 bushels per acre, 1928.

farming has been strikingly demonstrated. In this experiment barley, alsike clover, and beans have been grown in a three-year rotation in comparison with continuous cropping to beans. Part of the plots have received 10 tons of manure each rotation and duplicate plots have been provided without irrigation. During the first 6 rotations the gain from irrigation with continuous bean crop farming was 1.55 bushels per acre. With rotation and irrigation the gain was 7.52 bushels. With rotation and manure the gain was 12.38 bushels. The average gain in net profit from irrigation

Figure 10. White beans, fifteenth crop without rotation. Yield 4.83 bushels per acre, 1928.

was $2.38; with irrigation and rotation the gain was $23.17; and with rotation and manure it was $40.08. The gain per acre-inch with irrigation was $0.76 with continuous cropping; $7.72 with irrigation and rotation; and $13.36 with irrigation, rotation, and manure. The water requirement per pound of dry matter was cut in two by the soil-building treatments.

This striking gain in yield and net profit is explained by chemical analyses which show that rotation increased the total nitrogen per acre to plow depth 380 pounds. Rotation and manure increased it 788 pounds. The organic carbon was increased about 10 times this much and the organic matter about 20 times this much. The increase in humidified organic matter increases the soil's capacity to hold nutrients such as calcium and potassium in nearly available (exchange) form. It increases the nitrifying and nutrient-supplying power of the soil. This results in improved water capacity, a richer soil medium, and a reduced water or irrigation requirement. "The richer the soup the less required." Supplemental irrigation, soil building, and efficient, profitable use of water go hand in hand.

TABLE VI. RELATION OF SOIL BUILDING TO ECONOMIC IRRIGATION
Oregon Agricultural Experiment Station
Beans—18-Year Average

| Treatment | Irrigation | Yield | | Net profit | | | Water used per pound dry matter |
|---|---|---|---|---|---|---|---|
| | | Per acre | Gain | Average per acre | Gain by irrigation and rotation | Per acre-inch | |
| | *Inches* | *Bushels* | *Bushels* | | | *Inches* | *Lb.* |
| *Dry* | | | | | | | |
| Continuous | .. | 7.14 | ........ | $ 5.70 | ........ | ........ | 2,849 |
| Rotation | .. | 10.17 | 3.03 | 16.25 | $10.55 | ........ | 2,284 |
| Rotation and Manure | .. | 13.49 | 6.35 | 27.80 | 22.10 | ........ | 1,771 |
| *Irrigation* | | | | | | | |
| Continuous | 3. | 8.69 | 1.55 | 8.08 | 2.38 | .76 | 3,579 |
| Rotation | 3. | 14.66 | 7.52 | 28.87 | 23.17 | 7.72 | 2,245 |
| Rotation and Manure | 3. | 19.25 | 12.38 | 45.78 | 40.08 | 13.36 | 1,492 |

**The economic limit for irrigation by pumping** will depend on a number of factors, the chief of which are (1) lift, (2) price of energy, (3) amount of water required, (4) increase of yield due to irrigation, (5) value of the crop increase, (6) skill and economy of the irrigator.

Power cost varies almost directly with the lift; fixed charges increase somewhat, while cost of applying water does not change therewith. Hence the total cost of water applied to the crop increases more slowly than the lift. Since the draw-down in a well may increase more rapidly for larger quantities pumped, the economic capacity will usually be less than the maximum yield.

If a profit of $2.00 an acre is realized from an increase of 1 ton due to irrigation of alfalfa when worth $10.00 a ton, then with a price drop to $8.00 the economic limit would be reached for the conditions.

If irrigation of a heavy soil gave a net increase in profit of $2.00 an acre where the cost of water was 25 cents an acre-inch, there would be no profit in irrigating adjacent sandy soil that required 8 inches more water if no greater yield response was obtained. That it should pay to lift water 30 to 40 feet for alfalfa and perhaps twice this distance for intensive cash crops is indicated in Table VII.

TABLE VII. PROFIT FROM PUMPING FOR DIFFERENT LIFTS AND CROPS WHEN TOTAL ANNUAL COST OF IRRIGATION IS 50¢ PER ACRE-FOOT PER FOOT OF LIFT*

| Crop | Water applied | Increase from irrigation | Net value per bushel or ton | Net value of increase | Dollars net profit | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 20-ft. lift | 30-ft. lift | 40-ft. lift | 60-ft. lift |
| | *In.* | | | | | | | |
| Alfalfa | 15 | 2.00 T. | $ 8.00 T. | $16.00 | $3.50 | -$1.75 | -$9.00 | -$21.50 |
| | | | 10.00 T. | 20.00 | 7.50 | 1.25 | -5.00 | -17.50 |
| | | | 12.00 T. | 24.00 | 11.50 | 5.25 | -1.00 | -13.50 |
| Potatoes | 9 | 50.00 bu. | .60 bu. | 30.00 | 22.50 | 18.75 | 15.00 | 7.50 |
| | | | .90 bu. | 45.00 | 37.50 | 33.75 | 30.00 | 22.50 |
| Berries | 12 | 1.00 T. | 80.00 T. | 80.00 | 70.00 | 65.00 | 60.00 | 50.00 |

*In practice the total annual cost will not increase as fast as the lift.

The figures in Table VII are based on quantities of water and increases in crop yields induced thereby which experiment and observation have shown to be reasonable. Importance of irrigating some cash crops of low water requirement is demonstrated from the data in Table VII as well as in Figure 4.

**Wells** for irrigation under Willamette Valley conditions as described in more detail elsewhere* may be (1) standard casing or (2) stovepipe casing. In either case the well should be carefully located to insure adequate water and convenience in distribution. If no well "logs" are available in the locality, a small test hole will be advisable.

The standard casing may be started from the surface or in a well pit dug to the water level. Where encountered at moderate depth, casing 4 to 10 inches in diameter, depending on size of pump, should extend to the bottom of the water-bearing stratum in order to secure the least possible draw-down of the water-table about the well when pumping. The second type may be installed in alluvial deposits by experienced drillers using standard or special equipment. Such wells are 14 to 26 inches in diameter and are started with a well ring and one or two extra thicknesses of 10- to 16-gauge riveted or welded steel pipe. The two courses of pipe forming the casing are arranged so as to break joints and are dented with a pick or preferably are torch welded in spots to hold the column together. Such a well is suitable for receiving the deep-well turbine type of pump and is more easily installed and perforated in the larger sizes than the standard casing. An accurate log of the well should be kept and the casing thoroughly perforated throughout the water-bearing strata.

**Pumps.** The centrifugal pump is most suitable for large quantities of water and moderate lifts. Such pumps may be operated by a vertical or a horizontal shaft. The horizontal-shaft type is preferable where natural conditions or a shallow pit will permit its use. The approximate capacity

*Powers, W. L., *The Economic Limit of Pumping for Irrigation*, Ore. Ag. Exp. Sta. Bul. 235, 1928.

of a centrifugal pump is shown in Table VIII. Different pumps are designed for different conditions and it is advisable to study characteristic and efficiency curves and get a pump that will be guaranteed as to performance under the conditions at hand.

Deep-well turbine pumps may be installed in bored or drilled wells 6 inches or more in diameter. The outside diameter of the bowls should be at least two inches less than the inside diameter of the well casing. The bowls are submerged and the motor or pulley is at the top of the pump shaft above the ground surface. This type of pump is thus suitable for irrigation where the level of the water shows considerable fluctuation.

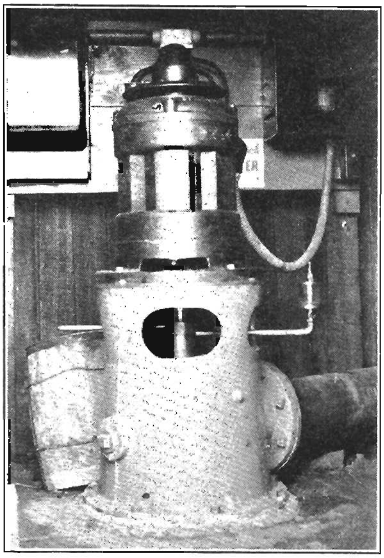

Figure 11. Direct-connected motor on No. 10 turbine yields 750 g.p.m.

**Suction and discharge pipes** must be air tight and should be at least 50 percent greater in diameter than the pump to reduce friction. The size of long discharge pipes should be determined by a study of the cost of power required to overcome the friction heads shown in Table IX. When pumping from an open stream a screen should be provided in the intake channel. Few turns and large radius elbows should be used. The suction end should be submerged 3 feet or more for the larger sizes. Flanged connections are desirable for four-inch pipe or larger. A gate valve and for high lifts a check valve should also be placed just above the pump for protection and to close the pipe for priming. Piping should be supported or anchored to avoid strain on the pump. If concrete or other rigid pipe is used for lifts of more than a few feet a stand-pipe, air chamber, or quick-acting release valve should be provided to avoid water hammer.

**Motive power** should be carefully selected for the conditions. Where electric power can be obtained at reasonable cost, it is very desirable as it requires little attendance. A motor direct-connected to the pump saves loss of power in belting. With belt drive the speed of pump can be adjusted by changes in the size of pulleys and the proper sizes should be chosen. The power unit should be on an adjustable base with slide rails to permit tightening. A starting device will often be needed with a motor as well as fuses, switch, and an overload release. Compact magnetic starters with overload and undervoltage protection are now available for the new "across-the-line" motors. Two hundred and twenty volt, three-phase motors are usually used. The oil level should be kept fairly constant.

Distillate or crude oil engine power is fairly reliable in the hands of a man of fair mechanical ability. In selecting a new engine a throttling type is desirable. A magneto is more reliable than dry cells. Ease of getting re-

TABLE VIII-A. APPROXIMATE CAPACITY AND COST OF A CENTRIFUGAL PUMPING UNIT

| Gallons per minute | Size of pump | Weight | Head | Horse-power | Cost (Portland) |
|---|---|---|---|---|---|
| | *Inches* | *Lb.* | *Feet* | | |
| 20 | 1 | 100 | 80 | 1 | $132.00 |
| 25 | 1 | 240 | 100 | 3 | 154.00 |
| 50 to 100 | 1¼ | 290 | 100 | 5 | 170.00 |
| 150 | 1½ | 370 | 100 | 7½ | 195.00 |
| 200 | 2 | 650 | 100 | 10 | 280.00 |
| 300 to 400 | 3 | 480 | 20 | 5 | 227.00 |
| 300 | 3 | 480 | 40 | 5 | 227.00 |
| 300 | 3 | 600 | 60 | 7½ | 260.00 |
| 500 | 4 | 640 | 20 | 7½ | 276.00 |
| 500 | 4 | 786 | 40 | 10 | 303.00 |
| 500 | 4 | 875 | 60 | 15 | 335.00 |
| 700 | 5 | 690 | 20 | 7½ | 305.00 |
| 700 | 5 | 920 | 40 | 15 | 363.00 |
| 700 | 5 | 920 | 55 | 15 | 363.00 |
| 900 | 5 | 920 | 20 | 15 | 363.00 |
| 900 | 5 | 1,025 | 40 | 20 | 407.00 |
| 900 | 5 | 1,085 | 60 | 25 | 438.00 |

TABLE VIII-B. APPROXIMATE COST OF TURBINE PUMPING UNITS

| Size of pump | Gallons per minute | Head | Speed and horse-power required | Weight | Price, belted | Price, motor-driven with motor and starter |
|---|---|---|---|---|---|---|
| *Inches* | | *Feet* | | *Lb.* | | |
| 8—1 stage | 300 | 40 | 7½, 1,800-1,750 | 1,700 | $480.00 | $ 550.00 |
| 10—2 stage | 500 | 40 | 10, 1,200-1,160 | 2,100 | 625.00 | 725.00 |
| 12—1 stage | 750 | 40 | 15, 1,800-1,750 | 2,600 | 650.00 | 800.00 |
| 12—4 stage | 950 | 40 | 20, 1,200-1,160 | 3,200 | 750.00 | 1,060.00 |
| 14—2 stage | 1,200 | 40 | 25, 1,200-1,160 | 3,500 | 800.00 | 1,150.00 |
| 14—1 stage | 1,500 | 40 | 25, 1,800-1,750 | 3,300 | 725.00 | 1,000.00 |

pairs and replacements should be considered. Where irrigation is required for only a short time during the season and a tractor is available the latter is often an economical source of power. Irrigation pumping may help to carry the overhead cost of the tractor under such conditions. Pumping machinery should be protected from the weather by a plain, small, fireproof house, provided with ventilation and light.

**Calculation of power required.** A horse-power will lift a cubic foot of water 8.8 feet per second (or lift 33,000 pounds one foot per minute), and is then called a water horse-power. To the apparent vertical lift must be added the friction head for the length of pipe used, including friction head due to elbows and other fittings, and an allowance of 1.5 feet for entrance and velocity head. The friction value for straight iron pipe is given in Table IX. The pressure in pounds per square inch corresponding to head of water in feet may be found by multiplying values of the latter by 0.434. Suppose one cubic foot per second is to be delivered with a total lift including "friction head" of 22 feet. Dividing by 8.8 gives 2.5 water horse-power. Assuming 50 percent efficiency it will be seen that a 5 horse-power unit will be needed.

**Installation.** The foundation for the pumping unit should be made strong enough to hold against belt strain, weight of pipes, water column in

TABLE IX. LOSS OF HEAD IN FEET DUE TO FRICTION IN VARIOUS SIZES OF SMOOTH, STRAIGHT IRON PIPE FOR EVERY 100 FEET USED

The friction losses for wood pipe will be less than those for iron pipe given in this table.*

| Gallons per minute | Size of pipe | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1-in. | 2-in. | 3-in. | 4-in. | 5-in. | 6-in. | 7-in. | 8-in. | 9-in. | 10-in. | 12-in. |
| 5 | 1.9 | .09 | .01 | ....... | ....... | ....... | ....... | ....... | ....... | ....... | ....... |
| 10 | 7.3 | .28 | .05 | ....... | ....... | ....... | ....... | ....... | ....... | ....... | ....... |
| 15 | 16.1 | .57 | .09 | .02 | ....... | ....... | ....... | ....... | ....... | ....... | ....... |
| 20 | 28.0 | .96 | .13 | .03 | .01 | ....... | ....... | ....... | ....... | ....... | ....... |
| 25 | 43.7 | 1.70 | .23 | .05 | .02 | .01 | ....... | ....... | ....... | ....... | ....... |
| 30 | 63.2 | 2.10 | .30 | .07 | .03 | .01 | ....... | ....... | ....... | ....... | ....... |
| 35 | 85.1 | 2.70 | .39 | .11 | .04 | .02 | ....... | ....... | ....... | ....... | ....... |
| 40 | ....... | 3.70 | .53 | .14 | .05 | .02 | ....... | ....... | ....... | ....... | ....... |
| 45 | ....... | 4.60 | .64 | .16 | .07 | .02 | ....... | ....... | ....... | ....... | ....... |
| 50 | ....... | 5.60 | .80 | .20 | .09 | .03 | .01 | .01 | ....... | ....... | ....... |
| 60 | ....... | 8.00 | 1.20 | .30 | .11 | .05 | .01 | .01 | ....... | ....... | ....... |
| 70 | ....... | 11.00 | 1.40 | .44 | .16 | .06 | .02 | .01 | ....... | ....... | ....... |
| 75 | ....... | 12.20 | 1.70 | .48 | .17 | .07 | .02 | .02 | ....... | ....... | ....... |
| 80 | ....... | 14.50 | 2.00 | .53 | .18 | .07 | .03 | .02 | ....... | ....... | ....... |
| 90 | ....... | 17.90 | 2.50 | .60 | .21 | .09 | .04 | .02 | ....... | ....... | ....... |
| 100 | ....... | 21.70 | 2.90 | .74 | .27 | .11 | .05 | .03 | .01 | .01 | ....... |
| 125 | ....... | 34.30 | 4.60 | 1.20 | .39 | .16 | .07 | .04 | .02 | .01 | ....... |
| 150 | ....... | 48.80 | 6.50 | 1.60 | .57 | .23 | .09 | .06 | .03 | .02 | .01 |
| 175 | ....... | 64.60 | 8.60 | 2.10 | .78 | .30 | .11 | .07 | .04 | .03 | .01 |
| 200 | ....... | 86.20 | 11.50 | 2.80 | .96 | .39 | .16 | .10 | .05 | .04 | .02 |
| 250 | ....... | ....... | 17.70 | 4.30 | 1.50 | .60 | .28 | .15 | .09 | .05 | .02 |
| 300 | ....... | ....... | 25.70 | 6.20 | 2.10 | .85 | .39 | .21 | .11 | .07 | .03 |
| 350 | ....... | ....... | 34.90 | 8.40 | 2.90 | 1.10 | .53 | .28 | .16 | .10 | .04 |
| 400 | ....... | ....... | 44.90 | 10.90 | 3.70 | 1.50 | .69 | .37 | .21 | .13 | .05 |
| 450 | ....... | ....... | 57.50 | 13.80 | 4.60 | 1.80 | .85 | .43 | .25 | .15 | .06 |
| 500 | ....... | ....... | 70.80 | 17.10 | 5.50 | 2.30 | 1.00 | .56 | .32 | .20 | .08 |
| 750 | ....... | ....... | ....... | 38.70 | 13.50 | 5.10 | 2.30 | 1.40 | .69 | .41 | .18 |
| 1,000 | ....... | ....... | ....... | 68.40 | 22.00 | 9.00 | 4.10 | 2.20 | 1.20 | .73 | .30 |
| 1,250 | ....... | ....... | ....... | ....... | 37.50 | 13.80 | 6.60 | 3.70 | 1.90 | 1.10 | .46 |
| 1,500 | ....... | ....... | ....... | ....... | 49.50 | 19.80 | 10.40 | 5.00 | 2.70 | 1.60 | .66 |
| 1,800 | ....... | ....... | ....... | ....... | 73.60 | 28.80 | 13.60 | 6.90 | 4.00 | 2.30 | .94 |
| 2,000 | ....... | ....... | ....... | ....... | 88.00 | 35.60 | 16.40 | 8.50 | 4.80 | 2.80 | 1.20 |
| 3,000 | ....... | ....... | ....... | ....... | ....... | 81.00 | 36.90 | 19.80 | 10.80 | 6.30 | 2.60 |

*After table by O. W. Waller, Washington State College Bulletin.

pipes, and vibration. A method of locating bolts in a concrete base to conform to base holes of pumping unit is shown in Figure 7. Where pump and motor are not on a solid base, care must be given to alignment to avoid noise and heating when operated. This is corrected by wedges and is facilitated by use of a steel testing gauge. After the unit is level in both directions as tested by a carpenter's level, the bolt-nuts beneath can be set with cement. Use a belt about 20 feet long to give weight and reduce slippage with a belt-drive set-up. Multiple V belt drives have recently been developed that are very satisfactory and will operate in small spaces.

**Priming and operation.** A direct-connected pump driven by a three-phase motor should be started carefully to be sure that it turns in the proper direction; if not, two of the connecting wires should be changed. The gate valve on the discharge side should be closed for priming and opened gradually after the pump is operating at full speed. No damage will result from partly closing the valve to reduce the irrigation head, but the power required to lift a given quantity of water will be increased.

Suction results from creating a partial vacuum, which is then filled with water by atmospheric pressure. A pitcher pump of good size, attached to the jacket of the main pump by means of a short length of pipe, may be used to pump out the air in priming as shown in Figure 5. A globe valve in the connecting pipe will be needed to close the line after priming.

Air leakage, reduced speed of pump, or obstructions in the suction pump or runner are common causes of failure of the pump to work properly. Lack of lubrication or poor alignment may cause heating.

**Distribution of water** will be facilitated by careful leveling before planting. A distribution system should be planned that will carry water within 200 or 300 feet of any point, this being a suitable distance to carry water over the surface. Water may be distributed through temporary earthen ditches or flumes from the high point. Carrying capacities for small earth laterals are given in Table X.

TABLE X. CARRYING CAPACITY IN SECOND-FEET OF EARTH DITCHES

Bottom width 1.25 to 3 feet with side slope 1 to 1½ and with water 3 to 15 inches deep.

| Width | Depth of water | | | | |
|---|---|---|---|---|---|
| | 3 inches | 6 inches | 9 inches | 12 inches | 15 inches |
| *Fall 1 foot per 1000 feet* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft.* | *Sec.-ft.* |
| 1.25 | 0.19 | 0.72 | 1.66 | ...... | ...... |
| 1.50 | 0.22 | 0.96 | 1.91 | ...... | ...... |
| 2.00 | ...... | 1.19 | 2.35 | 4.20 | ...... |
| 3.00 | ...... | ...... | 3.38 | 5.85 | 9.15 |
| *Fall 0.5 foot per 1000 feet* | | | | | |
| 2.00 | ...... | 0.84 | 1.66 | 2.98 | ...... |
| 3.00 | ...... | ...... | 2.34 | 4.05 | 6.35 |

The body of the table gives the flow in second-feet in ditches with different grades and depths of water. Example: A stream 9 inches deep in a ditch 3.0 feet wide with a grade of 1 foot per 1,000 feet delivers 3.38 cubic-feet per second. Pumped water is often distributed by means of underground pipes. The discharge pipe may lead through a vibration-deadening joint directly into underground concrete irrigation pipe. The concrete pipes are laid in line on a nearly uniform grade and banded at the joints to render them water tight, using rich cement grout. Fresh-slacked lime water increases tenacity and hastens setting. Rich cement grout may be painted inside the joint and the pipe with a long brush after each length is placed. Capacity of concrete pipe lines is indicated in Table XI.

Surface distribution on smooth land may be by means of strip borders with solid-seeded crops or in furrows for row crops. Pastures and meadows on smooth soil where a good-sized stream is available for flooding should be fitted for the border method of irrigation. Strong back-furrows are thrown up running directly down the slope and 20 to 30 feet apart. The interior is made level cross-wise and flat at the head, so that when water is turned into the strip a substantial gate at the top of the strip will spread out and flow down through in a thin sheet.

**Spray irrigation** is especially in favor for undulating bottom land and small-sized irrigating streams. It requires little attendance and is economical in use of water. Design will vary with water supply, area, and capital at hand. A high-speed centrifugal pump connected to an electric motor by

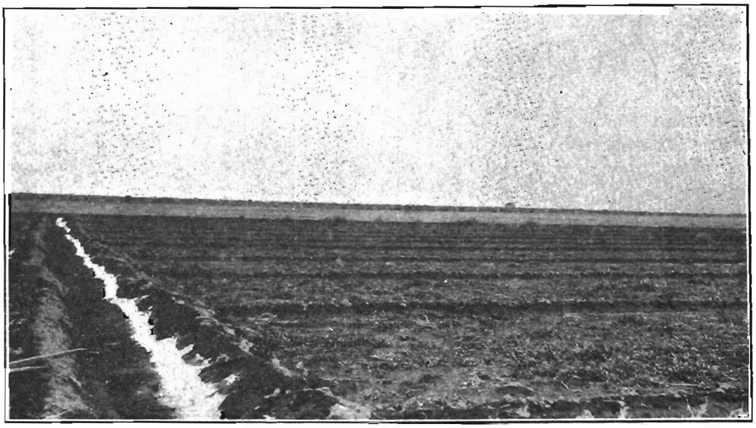

Figure 12. Strip-border irrigation, Harney Branch Experiment Station.

a V-belt drive is a desirable type of pumping unit. A $1\frac{1}{2}$-inch pump and 5 horse-power motor with a vertical lift of approximately 20 feet should deliver some 90 gallons per minute or one-fifth cubic foot per second under pressure of 35 pounds per square inch and should apply the equivalent of one inch rainfall to two acres in a 10-hour day. This will supply 1,800 feet of overhead delivery lines of sprinklers serving approximately two acres at one time. Nozzles are spaced four feet and lines are 50 feet apart. Use of second-hand pipe for distributaries may reduce cost. Mains are of iron pipe and may be underground across the center of the field with 2-inch risers for delivery to spray lines. Revolving sprinklers with portable hose give promise of a fairly even distribution system at a cost of \$75 to \$100 an acre.

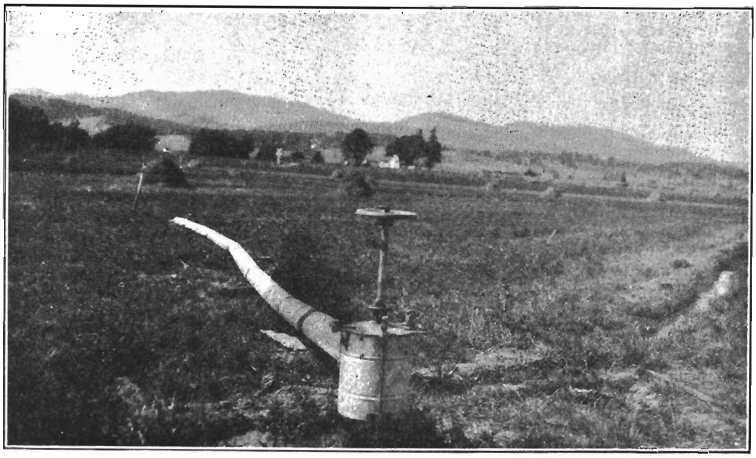

Figure 13. Portable hydrant and distribution pipe.

TABLE XI. ESTIMATING THE CAPACITY OF MODERN CONCRETE PIPE LINES* MADE BY DRY-MIXTURE PROCESS†

H = Friction head.

For example, 2 second-feet of water, the equivalent of 80 miner's inches measured under a 6-inch pressure, or of 100 miner's inches measured under a 4-inch pressure, or of 898 gallons per minute, will be conveyed by a 12-inch pipe, with a velocity of 2.55 feet per second with a loss of head (grade) of 3.04 feet for each 1,000 feet of pipe.

| Second-feet | Gallons per minute | Inside diameter, in inches and corresponding area, A, in square feet | | | | | |
|---|---|---|---|---|---|---|---|
| | | 6 A=0.196 H | 8 A=0.349 H | 10 A=0.545 H | 12 A=0.785 H | 14 A=1.069 H | 16 A=1.396 H |
| | | *Ft.* | *Ft.* | *Ft.* | *Ft.* | *Ft.* | *Ft.* |
| 0.1 ...... | 45 | 0.28 | 0.07 | .......... | .......... | .......... | .......... |
| .2 ...... | 90 | 1.06 | .15 | .......... | .......... | .......... | .......... |
| .3 ...... | 135 | 2.60 | .57 | .......... | .......... | .......... | .......... |
| .4 ...... | 180 | 4.61 | 1.00 | .......... | .......... | .......... | .......... |
| .5 ...... | 225 | 7.24 | 1.58 | .......... | .......... | .......... | .......... |
| .6 ...... | 270 | 10.40 | 2.30 | 0.71 | 0.27 | .......... | .......... |
| .7 ...... | 315 | 14.00 | 3.15 | .96 | .37 | .......... | .......... |
| .8 ...... | 360 | 18.40 | 4.07 | 1.26 | .48 | 0.22 | .......... |
| .9 ...... | 405 | 23.40 | 5.16 | 1.60 | .61 | .27 | .......... |
| 1.0 ...... | 449 | 28.80 | 6.38 | 1.96 | .75 | .34 | .......... |
| 1.2 ...... | 539 | 42.00 | 9.15 | 2.84 | 1.09 | .48 | 0.24 |
| 1.4 ...... | 629 | 56.00 | 12.50 | 3.88 | 1.48 | .66 | .33 |
| 1.6 ...... | 719 | 74.00 | 16.30 | 5.07 | 1.95 | .84 | .43 |
| 1.8 ...... | 809 | 93.00 | 20.70 | 6.46 | 2.44 | 1.09 | .54 |
| 2.0 ...... | 898 | 105.00 | 25.40 | 7.95 | 3.04 | 1.35 | .67 |
| 2.2 ...... | 988 | 140.00 | 30.80 | 9.50 | 3.66 | 1.63 | .82 |
| 2.4 ...... | 1,089 | 165.00 | 36.50 | 11.40 | 4.37 | 1.93 | .97 |
| 2.6 ...... | 1,168 | .......... | 43.00 | 13.30 | 5.11 | 2.28 | 1.13 |
| 2.8 ...... | 1,258 | .......... | 50.00 | 15.50 | 5.92 | 2.64 | 1.30 |
| 3.0 ...... | 1,348 | .......... | 57.30 | 17.80 | 6.81 | 3.04 | 1.50 |
| 3.2 ...... | 1,438 | .......... | 65.30 | 20.20 | 7.74 | 3.44 | 1.71 |
| 3.4 ...... | 1,528 | .......... | 73.50 | 22.80 | 8.77 | 3.90 | 1.94 |

*Scobey, Fred C., *Flow of Water in Concrete Pipe.* U. S. Dept. of Agric. Tech. Bul. 852, 1920.

†This is the table that should be used in the design of pipe lines made from units 2 to 3 feet long, as ordinarily made by hand in the pipe yards of the Pacific Coast states.

Figue 14. Small portable weir.

TABLE XII. DISCHARGE OF STANDARD* CIPOLETTI AND STANDARD SUPPRESSED RECTANGULAR WEIRS IN CUBIC FEET PER SECOND

| Head depth | Head depth | Width of weir | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1.0 ft. | 1.5 ft. | 2.0 ft. | 2.5 ft. | 3.0 ft. | 4.0 ft. |
| *Inches* | *Feet* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* | *Cu. ft.* |
| 2½ | .20 | .30 | .45 | .60 | .75 | .90 | 1.20 |
| | .21 | .32 | .49 | .65 | .81 | .97 | 1.30 |
| | .22 | .35 | .52 | .69 | .87 | 1.04 | 1.39 |
| 2¾ | .23 | .37 | .56 | .74 | .93 | 1.11 | 1.48 |
| | .24 | .40 | .59 | .79 | .99 | 1.19 | 1.58 |
| 3 | .25 | .42 | .63 | .84 | 1.05 | 1.26 | 1.68 |
| | .26 | .45 | .67 | .89 | 1.11 | 1.34 | 1.78 |
| 3¼ | .27 | .47 | .71 | .94 | 1.18 | 1.42 | 1.89 |
| | .28 | .50 | .75 | 1.00 | 1.25 | 1.50 | 1.99 |
| 3½ | .29 | .53 | .79 | 1.05 | 1.32 | 1.58 | 2.10 |
| | .30 | .55 | .83 | 1.11 | 1.39 | 1.66 | 2.21 |
| 3¾ | .31 | .58 | .87 | 1.16 | 1.45 | 1.74 | 2.32 |
| | .32 | .61 | .91 | 1.22 | 1.53 | 1.83 | 2.44 |
| 4 | .33 | .64 | .96 | 1.28 | 1.60 | 1.91 | 2.56 |
| | .34 | .67 | 1.00 | 1.33 | 1.69 | 2.00 | 2.67 |
| 4¼ | .35 | .70 | 1.05 | 1.39 | 1.74 | 2.09 | 2.79 |
| | .36 | .73 | 1.09 | 1.45 | 1.82 | 2.18 | 2.91 |
| 4½ | .37 | .76 | 1.14 | 1.52 | 1.90 | 2.27 | 3.03 |
| | .38 | .79 | 1.18 | 1.58 | 1.98 | 2.37 | 3.15 |
| | .39 | .82 | 1.23 | 1.64 | 2.05 | 2.46 | 3.28 |
| 4¾ | .40 | .85 | 1.28 | 1.70 | 2.13 | 2.56 | 3.41 |
| | .41 | .88 | 1.33 | 1.77 | 2.21 | 2.65 | 3.53 |
| 5 | .42 | .92 | 1.37 | 1.83 | 2.29 | 2.75 | 3.66 |
| | .43 | .95 | 1.42 | 1.90 | 2.38 | 2.85 | 3.80 |
| 5¼ | .44 | .98 | 1.47 | 1.97 | 2.46 | 2.95 | 3.93 |
| | .45 | 1.02 | 1.52 | 2.03 | 2.54 | 3.05 | 4.06 |
| 5½ | .46 | 1.05 | 1.58 | 2.10 | 2.63 | 3.15 | 4.20 |
| | .47 | 1.09 | 1.63 | 2.17 | 2.71 | 3.25 | 4.34 |
| 5¾ | .48 | 1.12 | 1.68 | 2.24 | 2.80 | 3.36 | 4.48 |
| | .49 | 1.16 | 1.73 | 2.31 | 2.89 | 3.46 | 4.62 |
| 6 | .50 | 1.19 | 1.79 | 2.38 | 2.98 | 3.57 | 4.76 |
| | .51 | 1.23 | 1.84 | 2.45 | 3.07 | 3.68 | 4.90 |
| 6¼ | .52 | 1.26 | 1.89 | 2.52 | 3.16 | 3.79 | 5.05 |
| | .53 | 1.30 | 1.95 | 2.60 | 3.25 | 3.90 | 5.20 |
| 6½ | .54 | 1.34 | 2.00 | 2.67 | 3.34 | 4.01 | 5.34 |
| | .55 | 1.37 | 2.06 | 2.75 | 3.44 | 4.12 | 5.49 |
| 6¾ | .56 | 1.41 | 2.12 | 2.82 | 3.53 | 4.23 | 5.64 |
| | .57 | 1.45 | 2.17 | 2.90 | 3.63 | 4.35 | 5.79 |
| 7 | .58 | 1.49 | 2.23 | 2.97 | 3.72 | 4.46 | 5.95 |
| | .59 | 1.53 | 2.29 | 3.05 | 3.82 | 4.58 | 6.10 |
| 7¼ | .60 | 1.57 | 2.35 | 3.13 | 3.91 | 4.69 | 6.26 |
| | .61 | 1.60 | 2.41 | 3.21 | 4.01 | 4.81 | 6.42 |
| 7½ | .62 | 1.64 | 2.47 | 3.29 | 4.11 | 4.93 | 6.57 |
| | .63 | 1.68 | 2.53 | 3.37 | 4.21 | 5.05 | 6.73 |
| | .64 | 1.72 | 2.59 | 3.45 | 4.31 | 5.17 | 6.89 |
| 7¾ | .65 | 1.76 | 2.65 | 3.53 | 4.41 | 5.29 | 7.06 |
| | .66 | 1.81 | 2.71 | 3.61 | 4.52 | 5.42 | 7.22 |
| 8 | .67 | 1.85 | 2.77 | 3.69 | 4.62 | 5.54 | 7.38 |
| | .68 | 1.89 | 2.83 | 3.81 | 4.72 | 5.66 | 7.55 |
| 8¼ | .69 | 1.93 | 2.89 | 3.89 | 4.83 | 5.79 | 7.72 |
| | .70 | 1.97 | 2.95 | 3.98 | 4.93 | 5.92 | 7.89 |
| 8½ | .71 | 2.01 | 3.02 | 4.06 | 5.04 | 6.04 | 8.06 |
| | .72 | ...... | 3.08 | 4.15 | 5.14 | 6.17 | 8.23 |
| 8¾ | .73 | ...... | 3.15 | 4.24 | 5.25 | 6.30 | 8.40 |
| | .74 | ...... | 3.21 | 4.33 | 5.36 | 6.43 | 8.57 |
| 9 | .75 | ...... | 3.28 | 4.41 | 5.47 | 6.56 | 8.75 |
| | .76 | ...... | ...... | 4.51 | 5.58 | 6.69 | 8.92 |
| 9¼ | .77 | ...... | ...... | 4.60 | 5.69 | 6.82 | 9.10 |
| | .78 | ...... | ...... | 4.69 | 5.80 | 6.96 | 9.28 |
| 9½ | .79 | ...... | ...... | 4.78 | 5.91 | 7.09 | 9.46 |
| | .80 | ...... | ...... | 4.87 | 6.03 | 7.23 | 9.64 |
| 9¾ | .81 | ...... | ...... | 4.96 | 6.14 | 7.36 | 9.82 |
| | .82 | ...... | ...... | 5.05 | 6.25 | 7.50 | 10.00 |

*Cipoletti weir has side slopes of 1:4. A suppressed weir is one in which weir is same width as channel of approach.

The body of the table gives the flow in second-feet when given depths of water flow over weirs of various widths. A circular on Water Measurement may be obtained upon application to Soils Department, Oregon Agricultural Experiment Station.

TABLE XIII. TABLE FOR CONVERTING LOSS ON 100 GRAMS OF MOIST SOIL TO PERCENTAGE DRY WEIGHT
(Applicable to any other unit or material)

| Loss | Percentage dry weight | Loss | Percentage dry weight | Loss | Percentage dry weight | Loss | Percentage dry weight | Loss | Percentage dry weight |
|---|---|---|---|---|---|---|---|---|---|
| 1.0.... | 1.0 | 2.0.... | 2.04 | 3.0.... | 3.1 | 4.0.... | 4.2 | 5.0.... | 5.3 |
| .... | .... | .1.... | .... | .1.... | .2 | .1.... | .3 | .1.... | .4 |
| .... | .... | .2.... | .... | .2.... | .3 | .2.... | .4 | .2.... | .5 |
| .... | .... | .3.... | .... | .3.... | .4 | .3.... | .5 | .3.... | .6 |
| .... | .... | .4.... | .... | .4.... | .5 | .4.... | .6 | .4.... | .7 |
| .... | .... | .5.... | .6 | .5.... | .6 | .5.... | .7 | .5.... | .8 |
| .... | .... | .6.... | .7 | .6.... | .7 | .6.... | .8 | .6.... | .9 |
| .... | .... | .7.... | .8 | .7.... | .8 | .7.... | .9 | .7.... | 6.0 |
| .... | .... | .8.... | .9 | .8.... | .9 | .8.... | 5.0 | .8.... | 6.2 |
| .... | .... | .9.... | 3.0 | .9.... | 4.1 | .9.... | 5.1 | .9.... | 6.3 |
| 6.0.... | 6.4 | 7.0.... | 7.5 | 8.0.... | 8.7 | 9.0.... | 9.9 | 10.0.... | 11.1 |
| .1.... | .5 | .1.... | .6 | .1.... | .8 | .1.... | 10.0 | .1.... | .2 |
| .2.... | .6 | .2.... | .8 | .2.... | .9 | .2.... | 10.1 | .2.... | .4 |
| .3.... | .7 | .3.... | .9 | .3.... | 9.0 | .3.... | .2 | .3.... | .5 |
| .4.... | .8 | .4.... | 8.0 | .4.... | .2 | .4.... | .4 | .4.... | .6 |
| .5.... | .9 | .5.... | .1 | .5.... | .3 | .5.... | .5 | .5.... | .7 |
| .6.... | 7.1 | .6.... | .2 | .6.... | .4 | .6.... | .6 | .6.... | .9 |
| .7.... | .2 | .7.... | .3 | .7.... | .5 | .7.... | .7 | .7.... | 12.0 |
| .8.... | .3 | .8.... | .5 | .8.... | .6 | .8.... | .9 | .8.... | .1 |
| .9.... | .4 | .9.... | .6 | .9.... | .8 | .9.... | 11.0 | .9.... | 12.2 |
| 11.0.... | 12.4 | 12.0.... | 13.6 | 13.0.... | 14.9 | 14.0.... | 16.3 | 15.0.... | 17.6 |
| .1.... | .5 | .1.... | .8 | .1.... | 15.1 | .1.... | .4 | .1.... | .8 |
| .2.... | .6 | .2.... | .9 | .2.... | .2 | .2.... | .5 | .2.... | .9 |
| .3.... | .7 | .3.... | 14.0 | .3.... | .3 | .3.... | .7 | .3.... | 18.1 |
| .4.... | .9 | .4.... | .2 | .4.... | .5 | .4.... | .8 | .4.... | .2 |
| .5.... | 13.0 | .5.... | .3 | .5.... | .6 | .5.... | 17.0 | .5.... | .3 |
| .6.... | .1 | .6.... | .4 | .6.... | .7 | .6.... | .1 | .6.... | .5 |
| .7.... | .2 | .7.... | .5 | .7.... | .9 | .7.... | .2 | .7.... | .6 |
| .8.... | .4 | .8.... | .7 | .8.... | 16.0 | .8.... | .4 | .8.... | .8 |
| .9.... | .5 | .9.... | .8 | .9.... | .1 | .9.... | .5 | .9.... | .9 |
| 16.0.... | 19.1 | 17.0.... | 20.5 | 18.0.... | 21.9 | 19.0.... | 23.4 | 20.0.... | 25.0 |
| .1.... | 19.2 | .1.... | .6 | .1.... | 22.1 | .1.... | .6 | .1.... | .1 |
| .2.... | .3 | .2.... | .7 | .2.... | .2 | .2.... | .7 | .2.... | .3 |
| .3.... | .4 | .3.... | .9 | .3.... | .3 | .3.... | .9 | .3.... | .4 |
| .4.... | .6 | .4.... | 21.0 | .4.... | .4 | .4.... | 24.0 | .4.... | .6 |
| .5.... | .7 | .5.... | .2 | .5.... | .6 | .5.... | .2 | .5.... | .7 |
| .6.... | .8 | .6.... | .3 | .6.... | .8 | .6.... | .3 | .6.... | .9 |
| .7.... | 20.0 | .7.... | .5 | .7.... | 23.0 | .7.... | .5 | .7.... | 26.1 |
| .8.... | .2 | .8.... | .6 | .8.... | .1 | .8.... | .6 | .8.... | .2 |
| .9.... | .4 | .9.... | .8 | .9.... | .3 | .9.... | .8 | .9.... | .4 |
| 21.0.... | 26.5 | 22.0.... | 28.2 | 23.0.... | 29.8 | 24.0.... | 31.5 | 25.0.... | 33.3 |
| .1.... | .7 | .1.... | .3 | .1.... | 30.0 | .1.... | .7 | .1.... | .5 |
| .2.... | .8 | .2.... | .5 | .2.... | .2 | .2.... | .9 | .2.... | .7 |
| .3.... | 27.0 | .3.... | .7 | .3.... | .3 | .3.... | 32.1 | .3.... | .9 |
| .4.... | .2 | .4.... | .8 | .4.... | .5 | .4.... | .2 | .4.... | 34.0 |
| .5.... | .3 | .5.... | 29.0 | .5.... | .7 | .5.... | .4 | .5.... | .2 |
| .6.... | .5 | .6.... | .1 | .6.... | .8 | .6.... | .6 | .6.... | .4 |
| .7.... | .7 | .7.... | .3 | .7.... | 31.0 | .7.... | .8 | .7.... | .6 |
| .8.... | .8 | .8.... | .5 | .8.... | .2 | .8.... | 33.0 | .8.... | .8 |
| .9.... | 28.0 | .9.... | .7 | .9.... | .4 | .9.... | .2 | .9.... | 35.0 |
| 26.0.... | 35.1 | 27.0.... | 37.0 | 28.0.... | 38.9 | 29.0.... | 40.8 | 30.0.... | 42.8 |
| .1.... | .3 | .1.... | .2 | .1.... | 39.1 | .1.... | .9 | .1.... | 43.0 |
| .2.... | .5 | .2.... | .4 | .2.... | .3 | .2.... | 41.2 | .2.... | .3 |
| .3.... | .7 | .3.... | .6 | .3.... | .5 | .3.... | .4 | .3.... | .5 |
| .4.... | .9 | .4.... | .7 | .4.... | .7 | .4.... | .6 | .4.... | .7 |
| .5.... | 36.1 | .5.... | .9 | .5.... | .9 | .5.... | .8 | .5.... | .9 |
| .6.... | .3 | .6.... | 38.1 | .6.... | 40.1 | .6.... | 42.0 | .6.... | 44.1 |
| .7.... | .4 | .7.... | .3 | .7.... | .2 | .7.... | .2 | .7.... | .3 |
| .8.... | .6 | .8.... | .5 | .8.... | .4 | .8.... | .4 | .8.... | .5 |
| .9.... | .8 | .9.... | .7 | .9.... | .6 | .9.... | .6 | .9.... | .7 |

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SB 270. Progress Report of the Irrigated 80-Acre Demonstration Farm at the Harney Branch Experiment Station.
SB 277. Effect of Irrigation on Major Berry Crops.
SB 299. Soils of Chehalis Series and Their Utilization.
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