UNIVERSITY OF IDAHO
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Irrigation of Hay and Pasture Crops in Idaho

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Joint contribution of the Department of Agricultural Engineering, Idaho Agricultural Experiment Station; and the Engineering and Watershed Planning Unit, Soil Conservation Service, U. S. Department of Agriculture.

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CENSUS figures show that, of 5.9 acre feet per acre diverted for irrigation from Idaho streams, only 1.7 acre feet are actually used by the crops. Most of the losses occur on farms where deep percolation and surface waste account for over one-half of the irrigation water that is diverted but not utilized by crops.

Some of the waste is unavoidable but efficiencies of water application can be greatly increased by using the conservation irrigation practices and methods described in this bulletin. Along with a saving of water will come other benefits such as increased yields and saving of fertilizer and manpower.

Idaho has a great variety of topographic, soil and climatic conditions. It is not always easy to determine irrigation methods, rates and amounts of irrigation water to apply under these various condition. This bulletin is intended to fill the need for a single publication to bring together all the data and facts relative to irrigation of forage crops in Idaho. It is a guide for technicians and farmers engaged in the planning of farm irrigation systems.

Irrigation of Hay and Pasture Crops In Idaho

VICTOR I. MYERS and DELL G. SHOCKLEY*

NEARLY two-thirds of the harvested cropland in Idaho is irrigated. A considerable portion of it is devoted to the production of hay and pasture crops. These crops include grasses, legumes, grass-legume mixtures and small grain. The importance of these forage crops in the irrigated areas of Idaho is indicated by the 1950 agricultural census, which shows that 1.1 million acres, or about 50 percent of the irrigated land in the state, was devoted to forage crop production. In addition, at least half of the irrigation water supply available in the state, and possibly as much as two-thirds, was used on these crops. Good crop yields are obtained and the production of forage crops is generally profitable. However, in many cases yields can be improved, water and labor requirements can be reduced and profits can be increased by the use of better crop management and irrigation practices.

The purpose of this bulletin is to provide information which can be used by technicians as a basis for designing and laying out sound conservation irrigation systems and in establishing effective and efficient water management practices on Idaho farms.

Recommended crop varieties and rates of seeding of forage crops for Idaho conditions can be obtained from county agents and Soil Conservation Service personnel.

SOIL AND ROOT ZONE DEPTH

To use soil moisture deficiency data effectively in timing applications of irrigation water, it is necessary to have a knowledge of the root growth characteristics of the plants in question. It is particularly important to be able to determine or estimate their effective root zone depths. Mature alfalfa plants grown on deep, well-drained soils under Idaho climatic conditions have an effective root zone depth of 5 or 6 feet. Small grains, most clovers and most of the higher-producing grasses have root zone depths of about 4 feet under favorable soil conditions. Ladino clover and some of the short, sod-forming grasses have root zone depths of only 2 to 2½ feet. The effective root zone depths of all these plants may be reduced by unfavorable profile conditions. Plants commonly root deeper in sandy and well-aerated soils than they do in clay and poorly aerated soils. In many areas the effective depth of soil is the factor limiting root development. Some soils have impervious layers at various depths which prevent penetra-

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tion of roots beyond that depth. Draughty open sand or underlying gravel strata also may limit root development. Another limiting factor in many Idaho areas is the presence of a high water table.

WHEN TO IRRIGATE FORAGE CROPS

Forage crops require a continuous supply of readily available soil moisture in order to maintain vigorous growth. Withholding moisture from plants at certain stages will not result in deeper root systems. The most extensive root systems develop under conditions where adequate moisture is available at all times. However, there are no demonstrated advantages in maintaining excessively high moisture levels, and a considerable amount of water can be wasted by such a practice.

The most reliable way to determine when to irrigate is to examine and measure, or estimate, the moisture in the soil throughout the crop root zone. Plant appearance, including color, is not a good index. Factors other than the availability of soil moisture often cause pronounced changes in the appearance of the crop. A darkening change in the color of forage crop plants may indicate the desirability of careful soil moisture examinations, but the color change alone should not be used to determine when to irrigate.

A study of the pattern of moisture extraction by irrigated crops, including forage crops, by Shockley[6] indicates a common pattern. Of the total moisture extracted from the soil by the crops, about 40 percent came from the upper quarter of the root zone, 30 percent from the second quarter, 20 percent from the third quarter and 10 percent from the bottom quarter. The same study indicates that, when all of the available moisture (field capacity to wilting point) has been removed from 20 to 30 percent of the root zone, the plants usually will be unable to obtain sufficient moisture from the remaining portion of the root zone to maintain rapid, vigorous growth during periods of high transpiration.

For most soils, then, irrigation will be needed by the time the available moisture has been used from the top fourth of the root zone. Assuming the amount used from the top fourth of the root zone is equal to about 40 percent of the total extraction from the full root zone, the total moisture that can be taken out of the profile will be about 2.5 times the available moisture holding capacity of the top fourth of the root zone. For a uniform soil, about 62.5 percent of the available moisture in the root zone will have been used by the time all of the available moisture has been removed from the top quarter of the root zone.

As removal of more than the above indicated portion of the total available moisture may cause undue stress in the plants and reduce the rate of growth, it generally is desirable to provide a safety factor of about one inch of moisture in the root zone. Therefore, forage plants usually should be irrigated just before all of the available moisture has been used from the top fourth of the root zone. For uniform-textured soils, this is equivalent to irrigating when 40 to 60 percent of the total available moisture in the root zone has been extracted. As a general guide, then, forage crops should be irrigated when about half of the available moisture in the root zone has been used.

Fall watering is an irrigation practice that will give good returns under field conditions where good drainage exists. Forage crops irrigated in the fall, and allowed to produce some top growth before freezing, store more food in their roots. This food is available for plant growth in early spring and generally results in hardier plants and in increased production. In areas of light winter precipitation, fall irrigation also avoids the necessity for early spring irrigations which cool the soil and retard plant growth. It has been observed at the Caldwell Branch Experiment Station, however, that severe winter losses result from applying water in the late fall to alfalfa that has been allowed to become dormant after the third cutting has been removed. New growth after fall irrigation may deplete food root reserves, making the plants less winter hardy.

Special attention must be given to the irrigation of new seedlings. Forage plantings generally are seeded shallower than 1 inch. Therefore, adequate moisture should be available in the root zone at the time of seeding so as to obviate the necessity of "irrigating up" the crop. Irrigating before or during seedling emergence frequently causes a crusting of the surface soil which interferes with stand establishment. Where moisture is available from natural precipitation it may not be necessary to irrigate until the plants have become well established. After the seedlings have emerged, new plantings require more frequent applications of irrigation water than are needed after the roots are more fully developed. However, as most forage plants develop extensive root zones in a relatively short time after emergence, the necessity for these frequent light applications seldom extends more than a few weeks.

Where plants with different root growth characteristics are grown together, it is necessary to irrigate so as to satisfy the requirements of the plants with the shallowest root zone. For example, a mixture of ladino clover with some deeper rooted legumes or grasses should be irrigated by the time about half of the available moisture in the upper 2 to 2½ feet of the profile has been extracted. When grasses or legumes are seeded with a companion crop of small grain, irrigations should be made so as to maintain favorable moisture conditions for the slower developing forage plants.

AMOUNT OF WATER TO APPLY

The net amount of moisture to be applied during an irrigation is that required to refill the root zone to its field capacity. If irrigation takes place when half of the available water stored in the root zone has been used, half of the total storage will need to be refilled. If the crop is irrigated at a time when less than half of the total available supply has been extracted, less than half will need to be added. The soil moisture deficiency in the root zone at the time of irrigation is the guiding criterion as to the net amount of water that should be applied. A greater amount of water will be of benefit only when required to leach salts out of the root zone. The gross amount required will, of course, be dependent upon the uniformity with which water can be distributed over the field. With adequately designed farm systems, adapted irrigation methods and reasonably careful water control, field application efficiencies of 60 to 70 percent, or higher, can be attained on mature forage crops. Light applications, sometimes required for the establishment of new seedings, usually are difficult to apply at these efficiencies, except when a sprinkler system is used. Small irrigating streams must be used to prevent erosion, and, under unfavorable conditions, efficiencies as low as 25 percent may be expected for these early irrigations.

The available moisture-holding characteristics of many Idaho soils have been determined by careful field and laboratory measurements. With these data, and careful examination of moisture conditions in the root zone profile prior to irrigation, the amount of water to be applied during an irrigation can be estimated with a high degree of accuracy. Where such data are not available, it may be possible to estimate available moisture-holding capacities on the basis of soil texture. Table 1 shows the general range of available moisture holding capacities in relation to soil texture.

Table 1.—General range of available moisture-holding capacities for average soil conditions

Soil texture	Available moisture
	In./Ft.
Coarse textured sands, fine sands and loamy sands.	0.75-1.0
Moderately coarse textured sandy loams and fine sandy loams.	1.0-1.5
Medium textured very fine sandy loams, loam, sandy clay loams and silt loams.	1.5-2.3
Moderately fine textured clay loams and silty clay loams.	1.75-2.5
Fine textured sandy clays, silty clays and clay.	1.6-2.5

FREQUENCY OF IRRIGATION

The frequency of irrigation is determined by the amount of readily available moisture that can be stored for plant use and the rate at which the plants use this stored water. The frequency is greatest, or the interval between irrigations is at a minimum, during the period of maximum consumptive use. For mature forage plants the maximum consumptive use usually will occur in July when the days are longest and the temperatures are highest. For short periods during this peak use season, average daily consumptive use rates may be materially higher than the average daily rate for the month.

Table 2 shows the monthly consumptive use of forage crops during July for all irrigated areas in the State, and Table 3 shows

Table 2—Average consumptive use for July in inches depth of water, for forage crops in Idaho—(3).

Area No.	Area	July consumptive use in inches	
		Alfalfa or clover	Grass pasture
1	Kootenai River	6.13	5.77
2	Pend Oreille River	6.02	5.67
3	Coeur d'Alene	6.25	5.89
4	St. Maries	6.15	5.78
5	Moscow	6.12	5.77
6	Lower Clearwater River	6.90	6.49
7	Upper Clearwater River	6.60	6.21
8	Camas Prairie	5.95	5.60
9	Lower Salmon River	6.89	6.48
10	Little Salmon River	5.62	5.29
11	Upper Weiser River	6.56	6.18
12	Lower Weiser River	6.84	6.44
13	Long Valley (N. Fk. Payette)	5.69	5.35
14	Squaw Creek	6.26	5.89
15	S. Fk. Payette River	6.25	5.88
16	Lower Payette River	6.60	6.21
17	Boise River	6.53	6.15
18	Bruneau-Snake River	6.88	6.48
19	Mountain Home	6.41	6.03
20	Upper Wood River	6.03	5.67
21	Middle Wood River	6.27	5.90
22	Lower Wood River	6.45	6.07
23	North Side	6.62	6.22
24	Twin Falls	6.38	6.01
25	Salmon Falls	6.28	5.92
26	Rupert-Burley	6.34	5.96
27	Goose Creek	6.25	5.88
28	Raft River	6.19	5.83
29	Malad	6.19	5.83
30	Bear Lake	5.94	5.58
31	Middle Bear River	5.94	5.58
32	Lower Bear River	6.15	5.79
33	Aberdeen-Springfield	6.20	5.83
34	American Falls	6.21	5.84
35	Pocatello-Fort Hall	6.24	5.88
36	Idaho Falls-Blackfoot	6.12	5.76
37	Teton River	5.56	5.22
38	Sugar-Idaho Falls	6.03	5.67
39	Henry's Fork	5.78	5.44
40	Dubois	6.25	5.89
41	Mud Lake	6.05	5.69
42	Lost River	6.02	5.67
43	Upper Salmon River	6.02	5.67
44	Middle Salmon River	6.13	5.76

the estimated average peak daily consumptive use rates for short periods of time, with the time periods represented by the net replaceable storage capacity of the root zone profile.

The frequency of irrigation for the peak use period (minimum interval between irrigations) can be determined by dividing the net moisture to be replaced at an irrigation by the peak consumptive use rate from Table 3. Irrigations are needed at this frequency only during the period of maximum consumptive use. During the cooler parts of the growing season, when consumptive use rates are lower, irrigations should be made at less frequent intervals.

Table 3—Average peak daily consumptive use rates for irrigation system design—(3).

Net depth of soil moisture to be replaced each irrigation	Peak monthly consumptive use—Inches				
	5.0	5.5	6.0	6.5	7.0
	Daily consumptive use design rate				
Inches	In./day	In./day	In./day	In./day	In./day
1.0	0.27	0.30	0.32	0.35	0.37
1.5	0.25	0.28	0.30	0.33	0.35
2.0	0.23	0.25	0.27	0.30	0.32
2.5	0.22	0.24	0.26	0.29	0.31
3.0	0.21	0.23	0.25	0.27	0.29
3.5	0.20	0.22	0.24	0.26	0.28
4.0	0.19	0.21	0.23	0.25	0.27
4.5	0.19	0.21	0.23	0.25	0.26
5.0	0.18	0.20	0.22	0.24	0.25
5.5	0.18	0.20	0.22	0.24	0.25
6.0	0.17	0.19	0.21	0.23	0.24

IRRIGATION METHODS FOR FORAGE CROPS

Corrugation Method

The corrugation method is a modified form of furrow irrigation. With this method, close growing crops are irrigated by small streams of water running down the slope in shallow furrows or "corrugations." The water soaks into the soil along the corrugations and spreads out into the area between corrugations. The corrugations are made after the field has been seeded and usually are run directly down the slope. The flow of water into each individual corrugation must be carefully controlled. Siphons or gated spiles may be used to regulate flows from the head ditch, or from small equalizing basins below the head ditch, into each corrugation. Gated surface pipe, also, is adapted for use in controlling flows. On the flatter lands openings cut in the lower bank of the equalizing basins and protected by canvas, burlap, paper or grass-sod may provide adequate control.

The corrugation method is well adapted for the irrigation of hay crops on steep or rough lands. It, also, may be used to establish pasture crops. However, since trampling by grazing stock plugs the small corrugations, pastures should be irrigated by some other method after grazing starts. Both hay and pasture crops often are irrigated with the corrugation method until the plants are well established and then are irrigated by the border or controlled flooding method. This scheme is particularly advantageous on soils that tend to bake and crust when they are flooded.

Figure 1.—Corrugations between border ridges are used for first irrigation on new alfalfa seeding. After the stand is established, the field will be irrigated by flooding the strips between the border ridges.

The corrugation method is adapted for the irrigation of most medium and fine textured soils. These soils have small pores that cause the water to spread laterally and wet the area between corrugations. Coarse textured sandy soils, though, have larger pores and the lateral movement of water is quite slow in relation to the vertical movement. Good water distribution on very coarse soils would require an impractically close spacing of corrugations. Soils that have high concentrations of salts, also, are not suited for corrugation irrigation. The capillary movement of water laterally from the corrugations will increase the salt concentrations in the unflooded areas between corrugations.

Where grass-legume hay crops are to be irrigated on stable soils, corrugations can be used successfully on slopes as steep as

8 percent. However, unstable soils (generally those having a high percentage of silt) are easily eroded, and, even when protected with a good grass-legume cover, may be seriously damaged on such steep slopes. On these soils the corrugation method should be limited to slopes of less than 6 percent. Where alfalfa is grown alone the corrugation method should be limited to slopes of less than 6 percent on the most stable soils, and to less than 4 percent on unstable soils.

The corrugation method is well adapted for the irrigation of forage crops on slopes as flat as 2 percent. Good water distribution can be secured on flatter slopes, but large corrugations will be needed to carry the required irrigating streams and the border method generally will be more advantageous.

On many fields little land preparation is required for successful irrigation with the corrugation method. Often new land can be cleared and put into production in one season. The corrugations are run directly down the prevailing land slope and usually very little cross leveling is required. Irrigation grades should be reasonably uniform. Undulating slopes should be avoided but grades may progressively steepen or flatten within the following design criteria:

> **Increasing Slopes.**—Steepest part of the run should not be more than twice as steep as the flattest part and the grade difference, also, should not exceed 2 feet per 100 feet.
>
> **Decreasing Slopes.**—Steepest part of the run should not be more than 1½ times the flattest slope and the grade difference, also, should not exceed 1 foot per 100 feet.

Cross slope should be limited to one-fourth of the grade in the direction of flow, or to 0.5 percent, whichever is smaller.

Successful irrigation with the corrugation method requires a good field layout and careful water control. Irrigation runs should be short enough so the maximum allowable irrigating streams will reach the lower end of the field in about one-fourth the time required to refill the root zone profile to field capacity. The irrigating streams that can be used must, of course, be limited to flows that will not cause erosion in the corrugations. On the flatter slopes the capacity of the corrugations may further limit the allowable stream size. If irrigating streams reach the lower end of the run in one-fourth of the time required to refill the soil profile, deep percolation losses usually can be held to less than 10 percent.

Maximum allowable non-erosive stream sizes may vary some between different soils, but slope has a more significant effect. In general, the safe corrugation streams for established forage crops will be indicated by the formula $Q = \frac{12.5}{S}$ where Q is the stream size in gallons per minute and S is the slope of the corrugation in percent. New seedings and re-corrugated fields may require smaller streams until the corrugations become stabilized.

After these initial irrigating streams reach the lower end of the field they will, of course, need to be reduced, or cut-back, to prevent excessive water loss from surface runoff.

The time required to refill the root zone profile is dependent upon the intake characteristics of the soil, the corrugation spacing, and the amount of moisture that must be replaced. The corrugations should be spaced close enough to assure adequate lateral spread of the moisture by the time the needed amount of water has been applied.

Corrugation spacing is dependent upon soil texture, soil profile characteristics, root zone depth and irrigation grade. In homogeneous medium- and fine-textured soils the wetted area from each corrugation will be roughly semi-circular in shape. Under such conditions, maximum corrugation spacing should be equal to about three-fourths of the crop root zone depth. Closer spacing may be needed when the profile is not homogeneous throughout the root zone depth. Coarser textured soils, also, will require closer spacing of corrugations, and spacing should be reduced on all soils as irrigation grades increase. Too, on some fine-textured soils it may be desirable to reduce corrugation spacing in order to shorten the time required to irrigate. Table 4 may be used as a general guide for corrugation spacing.

Table 4—General guide for corrugation spacing

Slope	Fine and medium textured soils	Moderately coarse textured soils
%	inches	inches
	2 foot root zone depth	
1-4	18-21	15
5-8	15-18	—
	4 foot root zone depth	
1-4	24-30	18
5-8	18-21	15

Different soils have different intake characteristics, but normally intake rates decrease with time, and the general shape of the intake curves can be expressed by the formula $I = KT^n$ where I is the intake rate of the soil after a given time, T is the time water has been on the surface of the soil, and K and n are empirical values dependent upon soil characteristics and soil moisture conditions at the time of irrigation. Corrugation intake rates usually are determined from inflow-outflow measurements and commonly are expressed in terms of gallons per minute per 100 feet of corrugation. These values can be converted to equivalent field intake rates by the following formula:

$$\text{Field Intake Rate (In./Hr.)} = \frac{\text{g.p.m. per 100 ft.} \times 11.55}{\text{corrugation spacing (inches)}},$$

where field intake rate is the rate at which water is absorbed into the soil as expressed in terms of acre-inches of water per acre per hour. The field intake rate curve can then be expressed by the formula $R = CT^n$ where R is the field intake rate and $C = \frac{11.55K}{\text{corrugation spacing in inches.}}$ If field intake rate is expressed in inches per hour and time in hours, the area under the curve to any time (T) will be equal to the depth of water absorbed by the soil (D). The area under the curve as determined by integration is: $D = \frac{C}{n+1} T^{n+1}$ This can be plotted as an accumulated intake curve, from which the time required to absorb any given depth of water can be obtained.

The factors required for the design of adequate corrugation irrigation systems can be summarized as follows:

1. Maximum allowable irrigating stream.
2. The rate at which this stream moves down the corrugation.
3. The amount of water required to refill the root zone profile.
4. The time required for the soil to absorb this needed amount of water.

A method for evaluating existing furrow and corrugation irrigation systems as a means of developing data for use in the design of other systems for similar site conditions is given in

Table 5—Maximum irrigating streams and maximum lengths of run for corrugations (1).

Slope	Maximum irrigating stream	Soil texture	Maximum length of run Depth of application—inches 2	 3	 4	 5
%	g.p.m.		feet	feet	feet	feet
1.0	12.5	Fine	475	600	675	775
		Medium	375	450	525	575
		Mod. coarse	225	275	325	—
2.0	6.2	Fine	325	400	475	525
		Medium	250	300	350	400
		Mod. coarse	150	200	225	—
3.0	4.2	Fine	275	325	375	425
		Medium	200	250	300	325
		Mod. coarse	125	150	175	—
4.0	3.1	Fine	225	275	325	350
		Medium	175	200	250	275
		Mod. coarse	100	125	150	—
5.0	2.5	Fine	200	250	275	325
		Medium	150	175	225	250
		Mod. coarse	—	100	125	—
6.0	2.1	Fine	175	225	250	275
		Medium	125	175	200	225
		Mod. coarse	—	100	125	—
7.0	1.8	Fine	175	200	225	250
		Medium	125	150	175	200
		Mod. coarse	—	100	100	—
8.0	1.6	Fine	150	200	225	250
		Medium	125	150	175	200
		Mod. coarse	—	—	100	—

Agriculture Handbook No. 82[4]. In cases where basic data are not available, Table 5 may be used as a general guide for corrugation system design.

Border Method

The border method of irrigation is a controlled way of flooding the surface of a field. The field is divided into strips between parallel ridges or "borders." The strips of land between adjacent borders should have no cross slope, but may have a grade in the direction of irrigation. In fact, under conditions of continuous flow delivery of small irrigating streams, common in Idaho, a slight irrigation grade often is desirable. Each strip is irrigated by advancing a sheet of water from one end to the other.

If irrigation stream sizes are properly adjusted for soil intake characteristics, required depth of application, slope of land and the border strip area, water can be uniformly distributed with very small losses to deep percolation or surface runoff. Labor costs usually are less for border irrigation than for any other method of irrigation.

The border method is adapted for the irrigation of forage crops on most soil types. However, it should not be used on heavy textured soils that tend to bake, unless natural precipitation or

Figure 2.—Border irrigation of alfalfa seeded with a companion crop of grain. Water is evenly spread over the entire width of the border strip. Ridges are well rounded and are large enough to prevent overtopping.

moisture applied by some other irrigation method, can be used to get the crops established. Corrugations, between the border ridges, or sprinklers are sometimes used for this purpose. Very coarse, sandy soils usually are not irrigated with the border method, because of the difficulty in maintaining border ridges of sufficient height to control the large irrigating streams required.

The border method is adapted for the irrigation of forage crops on all slopes from zero to at least 6 percent. However, stream sizes and lengths of run will need to be reduced as slopes increase, to provide uniform water distribution and prevent excessive erosion.

Careful land preparation is needed in order to obtain good water distribution with the border method. Irrigation grades should be reasonably uniform. Undulating slopes are not allowable, but irrigation grades may progressively steepen or flatten, if the steepest part of the run is not more than twice as steep as the flattest part. Very flat grades (0.0 to 0.2 percent) are desirable if relatively large irrigating streams can be delivered to the border strips. However, if stream sizes are limited, slightly steeper grades usually will permit efficient irrigation of longer runs. Some cross slope is allowable in field leveling, but individual border strips should be level transversely. Exactness in cross slope leveling of individual border strips is most important on the steeper slopes and the tighter soils. Under these conditions minor irregularities may prevent adequate coverage with the small irrigating streams that must be used.

Adequate border ridges are essential to successful border irrigation. The ridges must be high enough to confine the required irrigating stream, but they should not be so high they will not wet through enough to support crop growth. They should be constructed with flat side slopes, rounded tops and relatively broad bases to allow easy crossing with farm machinery and to prevent damage from trampling by stock. Border ridges used in irrigating steep slopes and tight soils may need to be only 3 or 4 inches high, with base widths of 18 to 24 inches. However, on flat slopes and coarse textured soils, ridges 8 inches or more in height, with base widths of 4 to 6 feet, may be required. Ridges always should be constructed with ample allowance for settling. As high ridges are difficult to construct and maintain, and are hard to cross with farming equipment, layouts requiring settled ridge heights in excess of 8 or 10 inches seldom are satisfactory. Disc ridgers, road graders or border drags are commonly used to build the smaller ridges. Earth for larger ridges often is moved into place in the field leveling operation, or in a special operation, by large scrapers working across the borders. Depressions in the border strip left by the disc ridger, or by other equipment used to construct the ridges, must be filled by dragging or planing. Crossing the border ridges with one or two of the initial tillage operations will help to settle and smooth them.

Uniform-efficient applications of water with the border method of irrigation are dependent upon the use of irrigation streams of the proper size for the slope, intake rate, and depth of application involved. The relationship of stream size to border strip area can best be expressed as a unit stream. A unit stream is the stream required for a border strip area 1 foot wide and 100 feet long. Curves have been developed that show the unit streams required for the application of various depths of water on soils

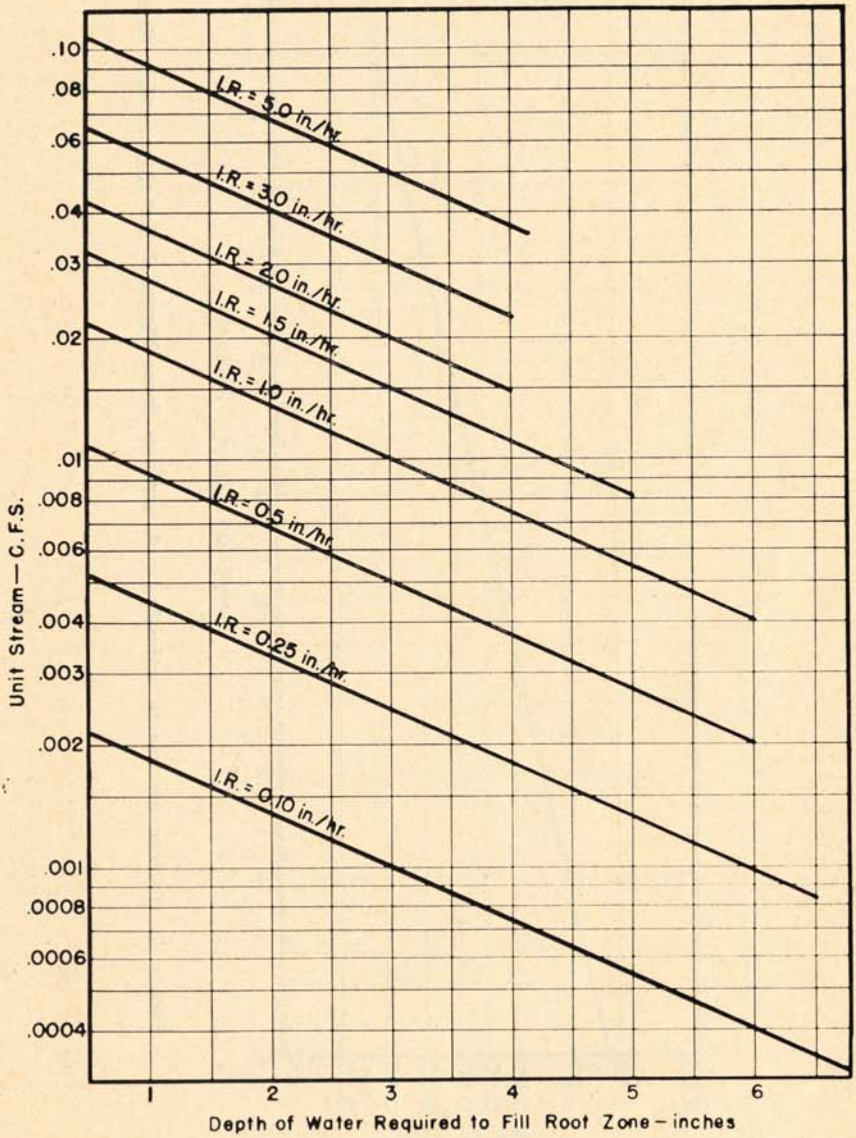

Figure 3. Unit streams for various depths of application on soils having different basic intake rates (I.R.) on an irrigation slope of 0.5 percent.

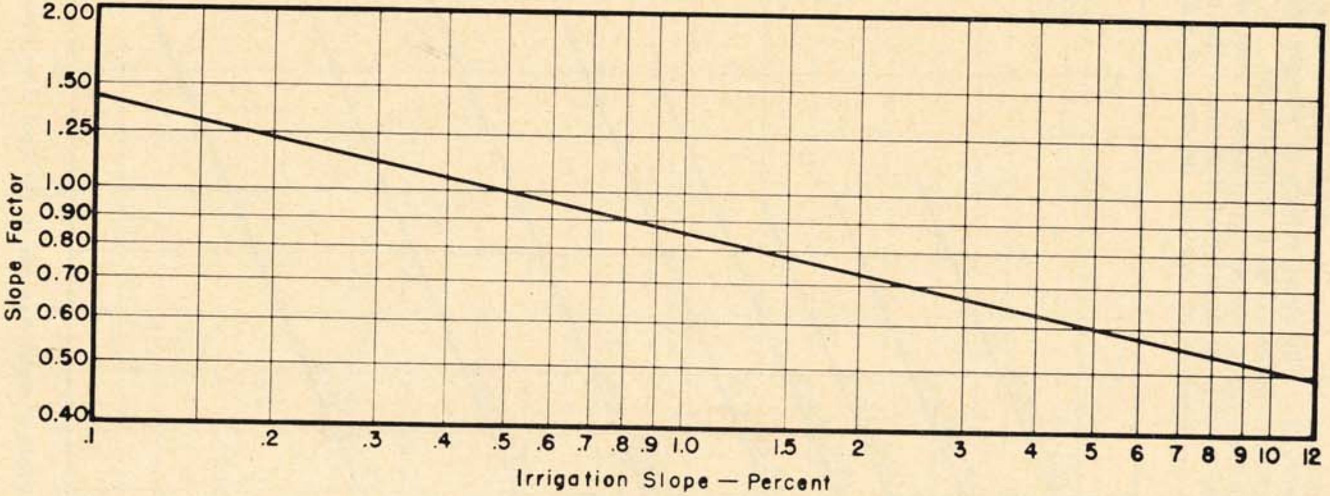

Figure 4. Factors for use in adjusting unit streams from Figure 3 for slopes other than 0.5%.

having different basic intake rates.[4] The basic intake rate is the final, nearly constant rate at which water will enter the soil after several hours of irrigation. Figure 3 shows these unit streams for slopes of approximately 0.5 percent. Unit streams for other slopes can be determined by multiplying the unit streams in Figure 3 by the slope factors shown in Figure 4.

The irrigation stream needed for an individual border strip can be determined by multiplying the required unit stream by the number of units in the border strip (width in feet x length in hundreds of feet). For example, a border strip 30 feet wide, 1000 feet long and requiring a unit stream of 0.004 c.f.s., would need an irrigating stream of about 1.2 c.f.s. (30 × 10 × 0.004).

For conditions where the available irrigating stream is limiting, the width or length of the border strip should be adjusted to provide a number of units equal to the available stream divided by the required unit stream. For example, if in the problem given above, the available irrigating stream was only 0.8 c.f.s., it would be sufficient for only 200 units (0.8 ÷ 0.004). Therefore, an adjustment in border strip length or width, or both, would be required. If the length is fixed, the width would need to be reduced to 20 feet. If the length is not fixed, strips 30 feet wide by 660 feet long could be irrigated. Strips 25 feet wide by 800 feet long also could be irrigated with this stream. On rotation crop land, border strip lengths often are fixed by the layout requirements for furrow irrigation of cultivated row crops.

On flat slopes the maximum length of run is governed by the capacity of the border strips to carry the needed irrigating streams. This capacity is limited by the height of border ridges that can feasibly be constructed and maintained. As a rule, on slopes under 0.3 percent it will not be feasible to use irrigating streams larger than about 0.15 c.f.s. per foot width of border strip, unless border ridges with settled heights of over 8 inches can be constructed and maintained.

On slopes steeper than about 0.3 percent, stream sizes and lengths of run may be limited by the erosion hazard. On fields without sod cover, erosion may be found to be significant if streams larger than indicated in Figure 5 are used. Where a dense sod cover has been established on stable soils, larger border streams may safely be used.

Field application efficiencies of at least 60 percent should be feasible for forage crops irrigated by the border method, and, under favorable conditions, efficiencies in excess of 70 percent should be expected.

The time of application required can be computed as follows:

$$T = \frac{D}{4.32Eq}$$

where:

T = Time water must be applied in hours.
D = Net depth of water application required in inches.
E = Estimated efficiency in percent.
q = Unit stream in c.f.s.

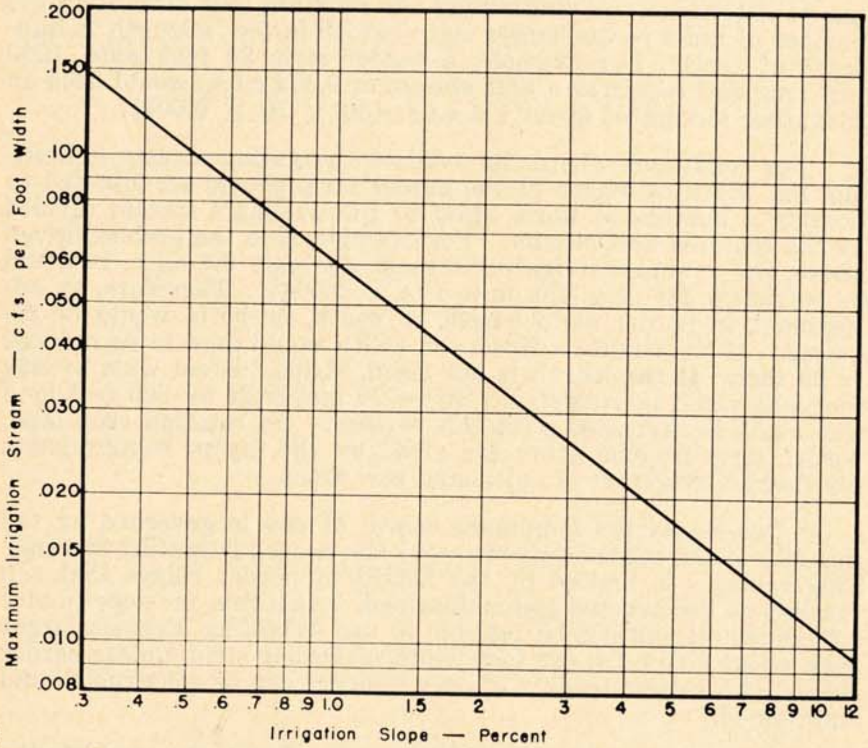

Figure 5. Maximum safe irrigation streams in c.f.s. per foot width for fields without sod protection.

Controlled Flooding Method

Controlled flooding is an efficient method of irrigating forage crops on lands having steep slopes, shallow soils or irregular topography. In this method, water is distributed from closely spaced head ditches that are run across the field nearly on the contour. In fact the method is sometimes called "contour ditch irrigation." The head ditches generally are constructed with a slope of less than 0.2 percent, and slopes of .05 to 0.1 percent usually are considered optimum.

The spacing of head ditches is dependent on the steepness of the field slope, the type of soil, the amount of water to be replaced and the configuration of the field surfaces. The ditches must be close enough together to maintain a reasonably uniform spread of water over the field surface, without excessive deep percolation losses or damage from erosion.

The configuration of the field surface usually is the most important factor, since smooth slopes, where the water has the least tendency to concentrate, generally can be irrigated better by other methods.

Because of the difficulty usually encountered in keeping the water spread over the field surface, ditch spacing should be limited to a maximum of about 200 feet. Sandy soils, shallow depths of application or steep slopes may require closer spacing. Rough-rolling topography also may require a closer head ditch spacing. Table 6 is a guide for the spacing of head ditches on fields with reasonably uniform slopes. Where fields have been dissected by erosion channels, a greatly reduced spacing usually will be required.

Table 6—Normal spacing of head ditches for the controlled flooding method of irrigation on fields having reasonably uniform slopes*

Soil texture	Field slope			
	Under 2%	2% to 5%	5% to 8%	8% to 12%
	Spacing in feet			
Coarse	100-125	75-100	50-75	———
Light	150-175	100-150	75-100	50-75
Medium or heavy	175-200	150-175	100-150	75-100

*Spacing should be reduced 25 to 50 per cent for dissected slopes or warped and rolling topography.

Water is delivered to the head ditches from a pipeline or from a supply ditch. Since supply lines must run down the prevailing land slope to feed the "contour" head ditches, open supply ditches generally must be lined or must be provided with drop structures to prevent erosion. Also, in most instances, turnout structures will be needed to control flows into the various head ditches.

Water is spread over the field through takeouts from the head ditches. The spacing of these takeouts is dependent upon topographic conditions. Usually they should be installed on the ridges or high points, to insure complete coverage of the field. Maximum spacing, even on the most uniform slopes, generally should not exceed about 20 or 25 feet, and some fields may require much closer spacing. The surface runoff from the area below one head ditch is collected in the head ditch immediately below and is redistributed, along with water added from the supply ditch.

Unit streams for uniform-efficient applications of water with the controlled flooding method of irrigation will be about the same as would be used for the border method for similar soils and depths of application. Figures 3 and 4, therefore, can be used for estimating the required unit streams. The stream needed per unit width of field can be determined by multiplying the unit stream by the length of run in hundreds of feet. The total irrigating stream needed in the head ditch, then, will be this value multiplied by the width of the field in feet. For example, assume a field 600 feet wide, with a basic soil intake rate of 0.5 inch per hour and a slope of 4 percent, requiring a 3 inch depth of application. Assume further a fairly uniform topography with a design length of run of 150 feet.

From Figures 3 and 4 the required unit stream would be 0.005 x 0.63 = 0.00315 c.f.s. The stream needed per unit width of field would be 0.00315 x 1.5 = 0.00473 c.f.s. This stream is well under the maximum value of 0.021 c.f.s. shown in Figure 5 for a four percent slope. The total irrigating stream needed to supply the 600 foot width of field would be 0.00473 x 600 = 2.84 c.f.s. On the basis of a 65 percent field application efficiency this stream would need to be applied for about 3½ hours.

$$T = \frac{D}{4.32\ Eq} = \frac{3}{4.32 \times 65 \times 0.00315} = 3.4 \text{ hours}$$

In cases where the available irrigation stream is limiting, the width of field (length of head ditch) that can be "set" at one time can be computed by dividing the available stream by the stream needed per unit width of field. For example, if in the problem given above, the available irrigating stream was only 0.7 c.f.s., the field would need to be irrigated in four "sets" of approximately 150 feet width (0.7 ÷ 0.00473 = 148 feet).

Sprinkler Method

Sprinkler irrigation provides an excellent means for controlling the application of water to crops. Sprinklers can be successfully used for the irrigation of forage crops on nearly all soil types and slopes adapted for the production of these crops. Sprinkling is the most efficient method known for the irrigation of forage crops on coarse sandy or gravelly soils or on lands of uneven or steep topography. Because of the erosion hazard or limitations of land capability, these lands are generally restricted to the production of hay and pasture crops. Sprinklers, also, often are used on sites having more favorable soils and topographic conditions. However, on sites well adapted for surface irrigation, sprinklers may provide no improvement in irrigation efficiency and may increase annual costs of operation.

Several types of sprinkler systems are available to meet various conditions. Systems are classified as permanent, portable, or semiportable according to the permanent or portable nature of the pumping unit, main lines and lateral lines. The type of system used is dictated by location of water supply, topography, shape of fields and other factors. The system most extensively used in Idaho is the one with a permanent pumping unit, a permanent or portable main pipeline and portable lateral pipelines.

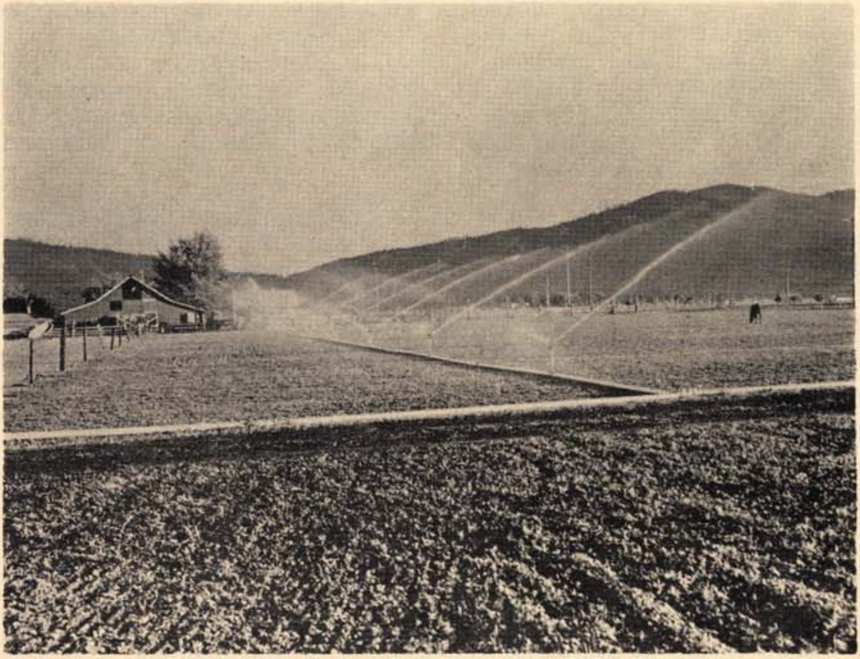

Figure 6.—Sprinklers being used for the irrigation of pasture on gravelly soil in northern Idaho. Quick-coupled light-weight portable pipes are used for both main and lateral lines.

The economics of any method of irrigation should be carefully considered before a system is installed. However, because of the high initial costs involved in most sprinkler installations, economic studies are doubly important. This is especially true of those sites that could be developed for successful irrigation by surface methods. Table 7, extracted from Idaho Experiment Station Bulletin No. 287,[2] shows items that should be considered in computing average annual costs of sprinkling. The study, described in this bulletin, revealed that, of the systems investigated, the average total annual cost was about $18.50 per acre at 1947 to 1949 prices.

Table 7—Average values and ranges of cost items for sprinkler irrigation in Idaho

Cost item	Average	Range
Depreciation	1/15 purchase price	1/10 to 1/40
Interest on investment	5% of ½ purchase price	3% to 8%
Water assessment	$3.55 per acre	$0.77 to $7.10
Repairs & maintenance	0.4% of purchase price	0 to 2.3%
Power	1 cent per kw hr.	0.57 to 4.27 cents
Labor	0.9 man hours per acre each irrigation	0.3 to 1.8

The same study indicated a wide range in the per-acre purchase cost of sprinkler systems. The variation indicates that each farm is a separate problem of design. The average cost of all systems studied was $82.90 per acre with a variation from $28.31 per acre to $222.22 per acre. Factors affecting cost spread are the size of system, source of water supply, shape of field and elaborateness of the layout.

The correct design and proper operation of a sprinkler system are the factors governing success in the use of this irrigation method. Sprinkler system design is an engineering problem. The designer's objective should be satisfactory sprinkler performance at lowest cost. Proper operation of the system is the responsibility of the irrigator. No system will give satisfactory performance unless it is operated according to the designer's specifications. Most reputable sprinkler equipment manufacturers and dealers provide engineering services for designing sprinkler systems.

The design, installation and operation of all sprinkler systems should meet the following standards developed by the American Society of Agricultural Engineers.[5]

1. **Application Rate.**—A portable sprinkler irrigation system, when properly designed and operated, will apply water at a rate which does not cause runoff during the normal operating period nor cause water to stand on the surface of the ground after the sprinkler line is shut off. As a guide, the maximum application rates, shown in Table 8, have generally been found satisfactory for forage-crop irrigation under Idaho conditions.

Table 8—Maximum sprinkler application rates for average conditions

Soil	Maximum application rate		
	0-4% Slope	4-8% Slope	8-12% Slope
	In./Hr.	In./Hr.	In./Hr.
Coarse textured sands, fine sands and loamy sands	1.50	1.25	0.75
Moderately coarse textured sandy loams and fine sandy loams	1.25	1.00	0.50
Medium textured very fine sandy loams, loam, sandy clay loams and silt loams	0.60	0.40	0.25
Moderately fine textured clay loams and silty clay loams	0.30	0.25	0.20
Fine textured sandy clays, silty clays and clay	0.20	0.15	0.10

2. **System Capacity.**—For regularly irrigated areas, the system should have the capacity to meet the peak moisture demands of the crop to be irrigated. Table 2 of this bulletin shows the consumptive use requirements for forage crops for the peak month of July, for areas in Idaho, and Table 3 shows the av-

erage peak daily consumptive use rates for irrigation system design. The system capacity must also allow for reasonable water losses during the application periods.

For supplemental irrigation and/or special uses, the system should have the capacity to apply a stated amount of water to the design area in a specified net operation period.

3. **Depth of Water Application.**—In the design of the system, total depth of application per irrigation is governed by the capacity of the soil for moisture storage and the depth of the principal root zone of the crop. The general range of available moisture holding capacities for soils of various textures is shown in Table 1.

4. **Uniformity of Water Application.**—Since uniformity of water application is affected by both pressure in the line and spacing of sprinklers, recommendations for desirable operating pressures and spacings for different types of sprinklers and nozzle sizes should be obtained from the sprinkler manufacturer.

   Differences in pressures at the sprinklers should be kept to a minimum. A common rule, which should be adhered to as closely as practicable, is to limit pressure differences along a sprinkler lateral to 20 percent of the highest pressure.

5. **Crop Damage.**—Water should be applied in a manner which will not cause direct physical damage to plants.

The climatic, soil, and crop factors governing use of the sprinkler method are the same as those that should be observed for any other method of irrigation application. The time to irrigate should be determined by the amount of moisture in the root zone. Two general rules of operation that should be followed are:

1. Irrigate only when the crop is in need of irrigation. A safety factor should be allowed, however, as it takes some time to get over the area being sprinkled. If soil moisture is adequate over the entire farm, the system should be shut off for a few days, a practice that will result in a saving of water, power costs and labor.

2. Apply only enough water to fill the root zone. Sprinkler systems usually are designed for maximum operation only during peak consumptive use periods. In the spring and fall, when consumptive use rates are low, sprinklers will need to be in operation only one-third to one-half the time required during maximum use periods.

In recent years, some manufacturers have developed sprinkler laterals that can be moved mechanically as a complete unit. Notable among these developments are the wheel-move and the tow-type systems. The adaptation of these systems is somewhat limited. They operate best on fairly smooth terrain and on crops that do not interfere with the rolling of wheels or with the towing operation. The size and shape of the fields to be irrigated also limit the possibilities of successful use of both of these systems. Tow-type systems are poorly adapted for use on small fields, and neither system is well adapted for use on irregular-shaped fields. Both types are suitable for use on hay and pasture crops where topographic and field layout conditions are favorable. Low-growing and sod-forming pasture crops are especially well adapted for tow-type moves. Under favorable conditions the use of a wheel-type or a tow-type system will reduce irrigation labor requirements. However, the tow-type system requires the use of a tractor or other power unit, and the initial cost of either system is considerably higher than the cost of a conventional hand-move system.

Since power is almost always an important factor in sprinkler irrigation, Table 9 has been developed to indicate the average power costs for various sizes of pumping installations in the major irrigated areas of the state. The assumption is made that each installation is efficiently designed to meet the maximum water needs of the crops. The costs shown are based on season lengths and consumptive irrigation requirements as indicated in Tables 3 and 6 of Idaho Experiment Station Bulletin No. 291.[3]

The energy costs are based on total hours of operation required to pump enough water to meet the crop requirements for the various areas, allowing for a 60 percent efficiency of application. Demand charges are based on the number of months included in the frost-free growing periods. Cost figures shown in Table 9 are the total of energy costs plus demand charges. There is an annual tax refund made to power users amounting to approximately 11.5 percent of the annual irrigation power costs. The figures shown in Table 9 should be reduced by the amount of the tax refund.

Energy and demand charges shown in Table 9 are computed from schedules furnished by power companies serving the areas. Where more than one power company serves an area, more than one figure appears in the table for each size of installation.

REFERENCES

1. Engineering Handbook, Table VI-7, U.S.D.A. Soil Conservation Service, Portland, Oregon.
2. Jensen, Max C., and Bevan, Roland C., *Costs of Sprinkler Irrigation on Idaho Farms*, Idaho Agricultural Experiment Station Bulletin No. 287, Moscow, Idaho, December, 1952.
3. Jensen, Max C., and Criddle, Wayne D., *Estimated Irrigation Water Requirements for Idaho*, Idaho Agricultural Experiment Station Bulletin No. 291, Moscow, Idaho, November, 1952.
4. "Methods for Evaluating Irrigation Systems," Agriculture Handbook No. 82, U.S.D.A., Soil Conservation Service, Washington, D. C.
5. "Minimum Requirements for the Design, Installation and Performance of Sprinkler Irrigation Equipment." *Agricultural Engineering*, Vol. 23, No. 3, P. 166, March, 1951.
6. Shockley, Dale R., "Capacity of Soil to Hold Moisture," *Agricultural Engineering*, Vol. 36, No. 2, pp. 109-112, February, 1955.

Table 9—Estimated average seasonal power costs for irrigation of forage crops

Area No.	Area description	Size of pumping installation							
		3 HP	5 HP	7½ HP	10 HP	15 HP	25 HP	50 HP	100 HP
1	Kootenai River	$ 34.99** To 112.56	$ 54.02** To 143.83	$ 87.45** To 173.17	$116.53** To 195.66	$174.90** To 248.43	$291.63** To 402.59	$ 582.67** To 771.95	$1165.33** To 1526.84
2	Pend Oreille River	21.50* 28.48 42.70 To 93.17	35.39* 43.84** 65.00 To 121.95	53.15* 73.28** 97.50 To 148.17	70.86* 95.16** 124.00 To 166.66	116.20* 142.58** 185.00 To 209.63	176.90* 237.71** 301.00 To 335.57	353.40* 475.02** 591.00 To 637.27	706.80* 950.03** 1159.00 To 1253.93
3	Coeur d'Alene	54.25 To 120.44	81.40 To 153.90	121.00 To 185.30	153.00 To 209.39	232.00 To 265.39	377.50 To 426.84	730.00 To 814.18	1435.00 To 1605.30
4	St. Maries	49.00	75.70	111.30	142.50	211.50	347.50	665.50	1299.00
5	Moscow	46.70	71.10	103.70	132.00	195.00	323.00	616.00	1199.00
6	Lower Clearwater River	70.00	106.90	160.20	203.80	307.50	497.50	972.00	1905.00
7	Upper Clearwater River	29.31* To 51.94	48.91* To 83.00	66.30* To 119.30	97.74* To 155.70	146.50* To 233.50	244.30* To 378.50	488.00* To 742.00	976.20* To 1467.00
8	Camas Prairie	21.07* To 42.00	35.12* To 64.00	52.65* To 96.00	70.31* To 122.00	105.40* To 182.00	175.60* To 296.00	350.80* To 580.00	701.80* To 1138.00
9	Lower Salmon River	35.30* 65.90 To 91.00	58.72* 103.00 To 145.30	87.15* 151.10 To 194.80	117.58* 193.00 To 247.25	176.10* 291.00 To 353.30	293.75* 470.00 To 539.15	586.70* 926.00 To 1004.70	1173.40* 1820.00 To 1935.45
10	Little Salmon River	33.00	51.10	64.90	80.40	120.60	206.00	412.00	824.00
11	Upper Weiser River	68.20	108.85	140.25	184.95	265.15	407.00	762.25	1472.55
12	Lower Weiser River	77.75	124.60	159.55	210.45	301.60	463.45	868.90	1679.55
13	Long Valley (N. Fk. Payette)	38.00	60.95	77.85	102.60	147.10	226.45	433.40	838.45

**There is also an annual connection charge.

*There is also a fixed annual charge of 10% of the special investment to serve the irrigation load, including line, transformer, meter, etc.

Table 9—Estimated average seasonal power costs for irrigation of forage crops

Area No..	Area description	Size of pumping installation							
		3 HP	5 HP	7½ HP	10 HP	15 HP	25 HP	50 HP	100 HP
14	Squaw Creek	64.30	103.05	132.65	174.80	250.35	384.70	720.25	1391.70
15	S. Fk. Payette River	56.70	87.50	112.80	148.70	213.05	327.15	612.35	1182.62
16	Lower Payette River	78.00	125.15	160.30	211.50	303.00	465.85	873.35	1688.10
17	Boise River	77.25	123.80	158.50	209.05	299.65	460.40	863.25	1668.60
18	Bruneau-Snake River	76.95	123.30	157.10	207.10	297.05	457.85	859.05	1661.75
19	Mountain Home	63.60	101.80	130.10	171.35	245.70	378.45	710.15	1373.55
20	Upper Wood River	55.00	88.15	112.65	148.50	212.90	327.65	627.10	1213.25
21	Middle Wood River	56.55	90.55	115.25	152.15	218.00	336.15	631.15	1221.15
22	Lower Wood River	61.05	97.90	124.20	163.90	235.15	362.60	680.85	1317.55
23	North Side	70.00	112.20	143.40	189.00	271.20	417.25	782.60	1513.30
24	Twin Falls	71.05	114.05	146.10	192.75	276.15	424.55	795.90	1538.40
25	Salmon Falls	62.00	99.40	127.00	167.40	240.00	369.40	707.00	1367.80
26	Rupert-Burley	65.55	105.05	134.25	176.95	253.90	390.65	732.70	1416.80
27	Goose Creek	63.55	101.70	130.70	172.15	246.60	379.15	710.60	1373.05
28	Raft River	77.45	102.46	153.62	204.95	307.25	512.28	1024.57	2049.13
29	Malad	54.15 54.55 To 59.76	89.05 96.35 To 99.59	114.80 144.54 To 149.28	151.20 184.50 To 199.26	216.65 278.33 To 298.49	332.60 446.73 To 475.75	622.70 827.78 To 861.50	1202.80 1572.29 To 1634.56
30	Bear Lake	55.10	97.08	145.55	184.46	276.48	442.49	816.30	1540.71

Table 9—Estimated average seasonal power costs for irrigation of forage crops

Area No.	Area description	Size of pumping installation							
		3 HP	5 HP	7½ HP	10 HP	15 HP	25 HP	50 HP	100 HP
31	Middle Bear River	53.56	94.44	141.48	180.15	269.73	434.86	804.00	1523.81
32	Lower Bear River	54.71	96.90	145.22	185.26	281.89	453.75	838.91	1607.75
33	Aberdeen-Springfield	52.00	83.25	106.35	140.05	200.85	309.35	580.50	1122.85
34	American Falls	56.75	90.95	116.20	153.15	219.80	338.20	634.30	1226.45
35	Pocatello-Fort Hall	68.45	109.35	141.00	186.00	266.30	409.10	765.90	1479.45
36	Idaho Falls-Blackfoot	60.30 To 57.08	96.40 To 101.04	123.80 To 151.36	163.30 To 193.20	233.90 To 293.84	359.70 To 471.96	673.75 To 873.04	1401.90 To 1664.44
37	Teton River	62.50	102.80	154.10	205.60	308.21	513.76	1027.52	2055.04
38	Sugar-Idaho Falls	56.20 To 77.92	99.24 To 129.90	148.92 To 194.89	190.14 To 259.81	287.52 To 389.79	458.47 To 649.52	850.04 To 1299.04	1609.95 To 2598.07
39	Henry's Fork	51.63 To 70.31	89.07 To 117.19	132.12 To 175.46	168.78 To 234.37	252.74 To 350.92	403.58 To 585.61	742.74 To 1171.22	1424.12 To 2342.44
40	Dubois	54.20	96.24	144.36	183.60	279.88	455.92	840.96	1626.96
41	Mud Lake	49.00 54.50	78.55 93.99	100.35 139.57	132.30 178.46	189.80 266.72	292.05 419.91	547.80 775.29	1059.25 1471.16
42	Lost River	54.76 To 116.40	96.13 To 154.01	141.91 To 200.91	180.04 To 248.01	270.90 To 371.82	434.03 To 520.04	792.24 To 1240.07	1501.26 To 2480.14
43	Upper Salmon River	158.94	214.95	277.27	342.67	514.54	856.84	1749.46	3426.65
44	Middle Salmon River	56.60	86.60	111.25	145.55	209.90	322.80	604.90	1168.85

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