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Design of Small Irrigation Pipe Lines

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FOR any pipe line the economical pipe size is that at which the total annual cost, including fixed charges (taxes, interest, and depreciation) and operating costs (power and labor), are a minimum. Many different methods have been used for determining the discharge at which pipe size should be changed or the most economical pipe size for a given discharge. In irrigation practice the important variables are the cost of electric energy, the over-all efficiency of the pumping plant, the number of hours pumped per season, the cost of pipe, and the tax, interest, and depreciation rates.

As the discharge and friction head in a given pipe line increase, a point is reached where the possible saving in annual power cost by changing to a larger pipe will just equal the greater annual fixed charges on the larger pipe, and at that point it becomes economical to change to the larger pipe.

In designing sprinkler lines the computation of friction losses is somewhat tedious. Charts 2 and 3 are designed to help in this process where sprinklers or laterals are spaced at 60-foot or 40-foot intervals respectively. By starting at the last sprinkler on a line the friction head in the 60 or 40 feet of pipe serving that sprinkler can be found from the chart and noted. The friction in the next section with the discharge of two sprinklers can then be added. By the use of the adding machine, only a few moments are required to determine the total loss in a line with many sprinklers.

In Table 2 and Chart 1 a unit called the gallon-per-minute-foot is used. This is somewhat similar to the foot-acre-foot, but differs in that it is a rate of flow times a head rather than a volume times a head. As used herein, it is the product of the discharge rate through a given pipe line times the friction head in the pipe.

Table 1 gives the cost of pumping 1 acre-foot of water against a head of 1 foot at the different prices for electric energy and at different over-all (wire to water) efficiencies of the pumping plant. The formula is $C = \frac{K}{E} \times \frac{2{,}718{,}144}{2{,}655{,}300} \times 100$, where C = cents per foot-acre-foot; K = cents per kilowatt-hour; E = efficiency in per cent; 2,718,144 = the weight of 1 acre-foot of water or the number of foot-pounds of energy required to raise 1 acre-foot 1 foot; and 2,655,300 = the number of foot-pounds in 1 kilowatt-hour of energy.

Table 2 gives the cost of pumping 1 gallon per minute against a head of 1 foot for different lengths of time at different costs of pumping per foot-acre-foot. The formula is $B = \frac{CT}{5{,}445}$, where C = cents per foot-acre-foot as before; B = cents per gallon-per-minute; T = hours of pumping per season, and 5,445 = the number of hours required for 1 gallon per minute to equal 1 acre-foot.

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Table 3 gives the saving in annual fixed charges of pipe for different savings in first cost in place, at different annual rates for interest, taxes, and depreciation.

On Chart 1 will be found the saving in friction head that might be gained by the substitution of the next larger size of pipe for different discharges and pipe sizes. The products of the savings in head by the corresponding discharges are shown in gallon-per-minute-foot units. From this chart and the data from Tables 2 and 3 the discharge at which it will pay to change pipe sizes may be found.

Chart 2 gives the friction head in feet per 60 feet of pipe for different discharges and different sizes of standard and 16-gage O. D. welded steel pipe.

Chart 3 similarly gives the friction head in feet per 40 feet of pipe.

All three charts are based on the Scobey formula $H = 0.34 \frac{V^{1.9}}{D^{1.1}}$ for steel pipe 4 to 6 years old.

If it is desired to make an allowance for the extra labor involved in moving pipes of larger sizes, the saving in cost per 100 feet of pipe per year may be estimated and added to the amounts shown in the body of Table 3.

Use of the tables and Chart 1 is illustrated by the following examples:

1. Assume: Energy cost 2 cents per kw.-hr.; over-all efficiency 50 per cent; hours of pumping 2,000; depreciation, interest, and taxes 15 per cent; 2½-in. pipe costs $10 per 100 feet less than 3-in. pipe. No change in labor cost or in capital cost of pumping plant.

   Find at what discharge a change should be made from 2½-in. to 3-in. pipe.

   From Table 1 the cost for energy will be 4.1 cents per ft.-ac.-ft. with an over-all efficiency of 50 per cent and energy at 2 cents per kw.-hr. From Table 2 the annual cost of pumping for 2,000 hours per year at 4.1 cents per ft.-ac.-ft. will be 1.51 (interpolated between 1.47 and 1.84) cents per g.p.m.-ft. From Table 3 the extra cost of taxes, interest, and depreciation for 3-in. pipe will be 150 cents per 100 ft. of pipe per year. To save 150 cents at 1.51 cents per g.p.m.-ft. will require a reduction of 100 g.p.m.-ft. units. From Chart 1 we find that the line showing the saving in friction head per 100 ft. (1.75 ft.) for 3-2½-in. pipe intersects the 100 g.p.m.-ft. line at 57 g.p.m We will therefore use a 2½-in. pipe for flows less than 57 g.p.m. and 3-in. pipe for larger flows. At 57 g.p.m. the change from 2½-in. to 3-in. pipe will reduce the friction head by 1.75 ft. and save 57 times 1.75 equals 100 g.p.m.-ft.

2. Assume: Energy cost 2.5 cents per kw.-hr.; over-all efficiency 50 per cent; depreciation, interest, and taxes 20 per cent; 4-in. pipe costs $15 per 100 feet less than 5-in.; required discharge of 200 g.p.m. No changes in labor or pumping-plant costs.

   Find how many hours per season we can afford to pump through 4-in. pipe.

   From Table 1 the cost for energy will be 5.1 cents per ft.-ac.-ft. From Table 3 the extra annual cost of 5-in. pipe per 100 ft., will be 300 cents per year. On Chart 1 the 200 g.p.m. line intersects the 4-5-in. friction-saving line at a value of 400 g.p.m.-ft. units. To save 300 cents per year on 400 g.p.m.-ft. units, each unit must cost 0.75 cent. From Table 2 we find that at a cost of 5 cents per ft.-ac.-ft. we can pump 800 (interpolated between 500 and 1,000) hours before our cost

per g.p.m.-ft. unit becomes 0.75 cent. We can therefore use 4-in. pipe in those lines that will carry 200 g.p.m. for 800 hours per season or less.

3. Assume: Energy cost 4 cents per kw.-hr.; over-all efficiency 40 per cent; depreciation, interest, and taxes 20 per cent; 3-in. lateral costs $10 per 100 feet less than 4-in.; hours of pumping 2,000 per season; saving in labor cost 1 cent per change per 100 feet of pipe for 170 changes or 170 cents per season.

   Find the discharge at which a change should be made from 3-in. to 4-in. pipe.

   From Table 1 the cost of energy will be 10.2 cents per ft.-ac.-ft. From Table 2 the cost of energy will be 3.75 cents per g.p.m.-ft. unit. From Table 3 the saving in annual cost of lateral pipe is 200 cents per 100 feet of pipe. We add to this the saving of 170 cents for labor to make a total saving of 370 cents per 100 feet of pipe. Dividing the increase in annual cost resulting from the use of 4-in. pipe as compared with 3-in. (370 cents) by the cost of energy per g.p.m.-ft. unit (3.75 cents) we have 99 g.p.m.-ft. units at the point where the two values are equal and the change of size should be made. From Chart 1 this point is found to be at a discharge of 72 g.p.m.

The use of these tables and charts will give lines for high-pressure sprinklers with satisfactorily uniform pressures up to at least a quarter mile. For low-pressure lines the need for rather uniform pressure may require larger pipe sizes. In both cases care should be used if any extra allowances in annual savings are made on account of labor.

Table 1. COST OF ENERGY FOR PUMPING IN CENTS PER FOOT-ACRE-FOOT.

Over-all efficiency	Cost of electric energy in cents per K. W. H.							
	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0
Per cent	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
30	1.7	3.4	5.1	6.8	8.5	10.2	13.7	17.1
40	1.3	2.6	3.8	5.1	6.4	7.7	10.2	12.8
50	1.0	2.0	3.1	4.1	5.1	6.1	8.2	10.2
60	.8	1.7	2.6	3.4	4.3	5.1	6.8	8.5
70	.7	1.5	2.2	2.9	3.7	4.4	5.9	7.5

Table 2. ANNUAL COST OF PUMPING IN CENTS PER G.P.M.-FT. UNIT

Cost per foot-acre-foot	Hours pumping per year							
	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000
Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
2	0.18	0.37	0.55	0.74	0.92	1.10	1.29	1.47
4	.37	.74	1.10	1.47	1.84	2.20	2.58	2.94
5	.46	.92	1.38	1.84	2.30	2.76	3.22	3.68
6	.55	1.10	1.66	2.20	2.76	3.31	3.86	4.42
8	.74	1.47	1.84	2.94	3.68	4.42	5.15	5.89
10	.92	1.84	2.76	3.68	4.60	5.52	6.44	7.36
12	1.10	2.20	3.31	4.42	5.52	6.62	7.73	8.83
14	1.29	2.58	3.86	5.15	6.44	7.73	9.02	10.30

Table 3. SAVING IN ANNUAL COST OF PIPE IN CENTS PER 100 FEET OF PIPE

Interest, taxes, and depreciation	Difference in cost in place in dollars per 100 feet												
	1	2	4	5	6	8	10	12	14	15	16	18	20
Per cent	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
10	10	20	40	50	60	80	100	120	140	150	160	180	200
15	15	30	60	75	90	120	150	180	210	225	240	270	300
20	20	40	80	100	120	160	200	240	280	300	320	360	400

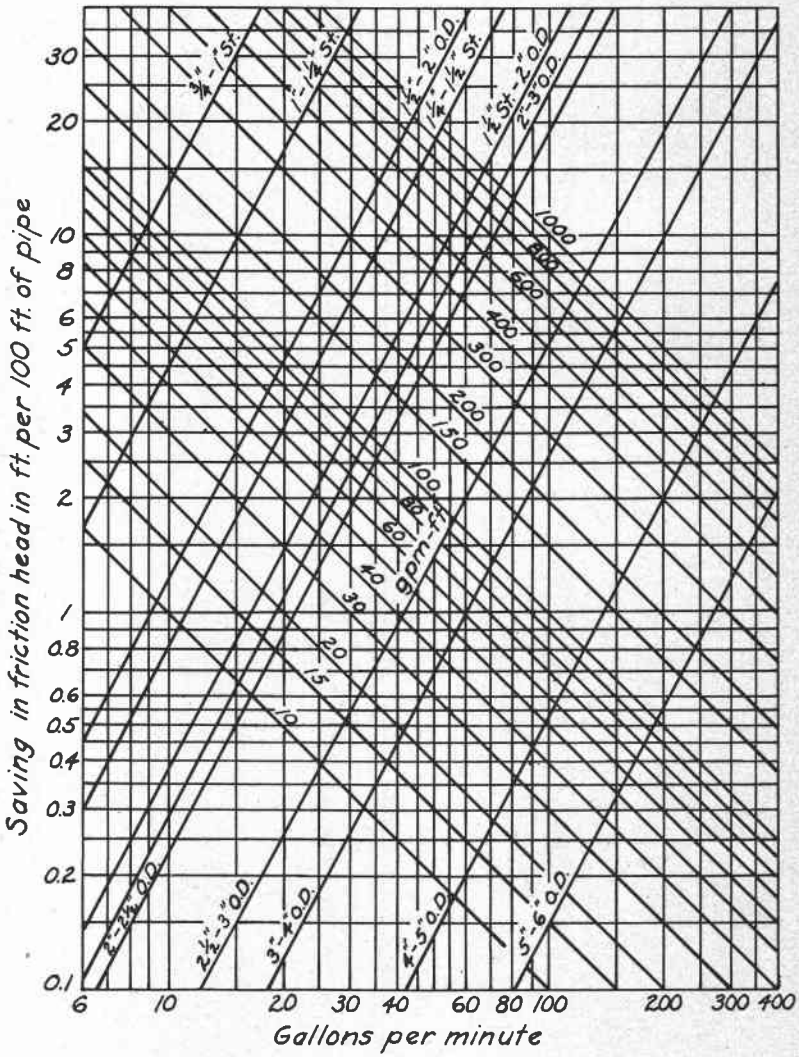

Chart 1.

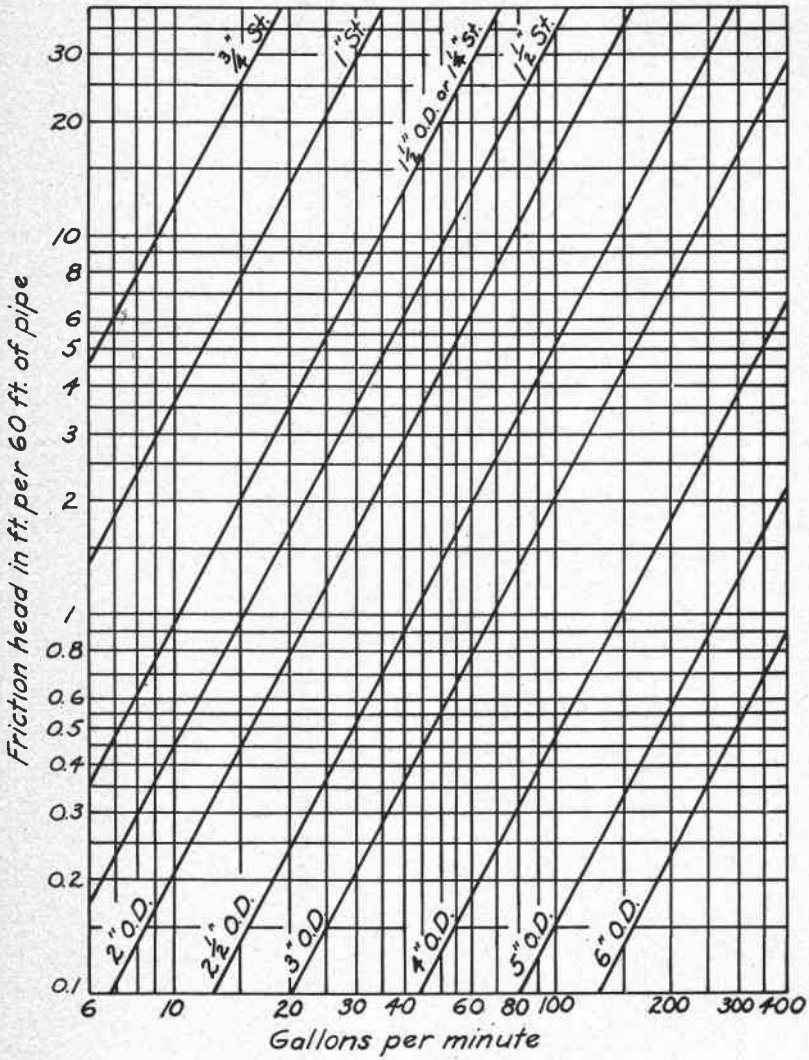
Friction head in ft. per 60 ft. of pipe
30
20
10
8
6
5
4
3
2
1
0.8
0.6
0.5
0.4
0.3
0.2
0.1
3" St.
1" St.
1¼" O.D. or 1" St.
1½" St.
2" O.D.
2½" O.D.
3" O.D.
4" O.D.
5" O.D.
6" O.D.
6
10
20
30
40
60
80
100
200
300
400
Gallons per minute

Chart 2.

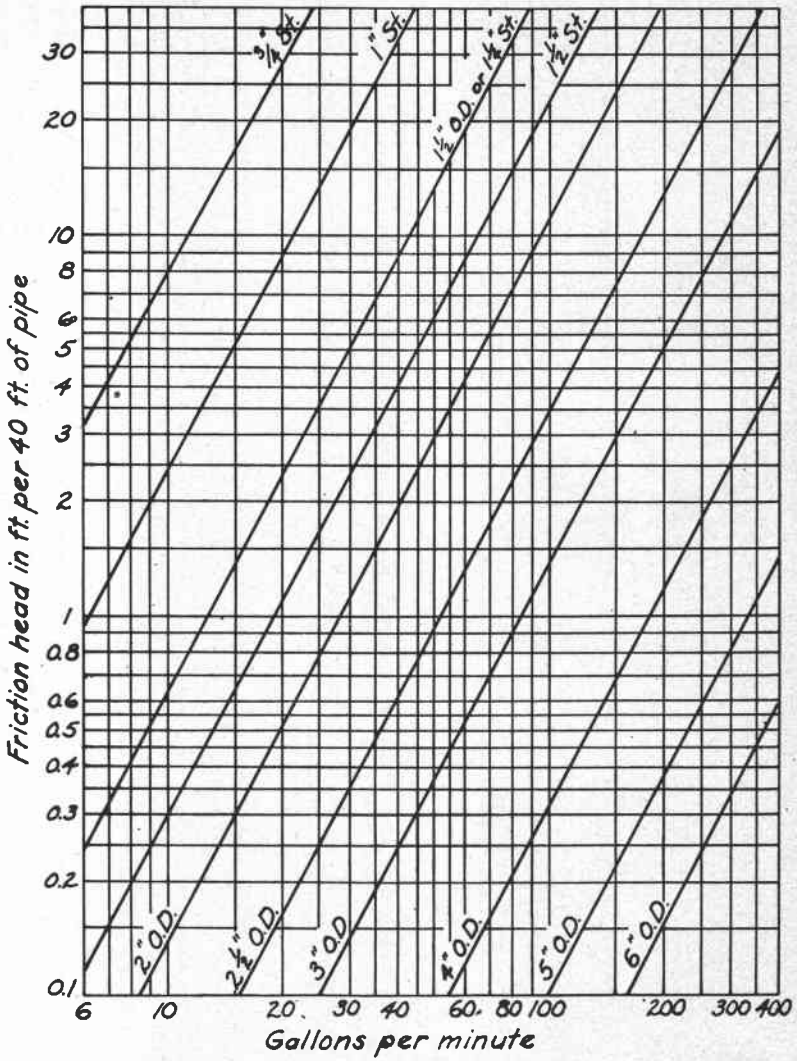
Friction head in ft. per 40 ft. of pipe
30
20
10
8
6
5
4
3
2
1
0.8
0.6
0.5
0.4
0.3
0.2
0.1
3/4" St.
1" St.
1 1/2" O.D. or 1 1/4" St.
1 1/2" St.
2" O.D.
2 1/2" O.D.
3" O.D.
4" O.D.
5" O.D.
6" O.D.
6
10
20
30
40
60
80
100
200
300
400
Gallons per minute

Chart 3.