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A home made water plant, showing open well, bucket elevator and gasoline engine house—a small investment, but costly water.

Cost of Pumping for Irrigation.

(REPRINT)

BY SHERMAN M. WOODWARD

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UNIVERSITY OF ARIZONA
AGRICULTURAL EXPERIMENT STATION

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THE EXPERIMENT STATION,

Tucson, Arizona.

COST OF PUMPING FOR IRRIGATION,

By S. M. Woodward.

INTRODUCTION.

In the following pages are given the results of Investigations of the actual cost of pumping water for irrigation at a number of representative pumping plants at present in operation in Arizona. The plants described in this bulletin are probably but a small proportion of the total number of pumping plants in successful operation in the whole Territory. The plants are so scattered that there is no means of easily determining how many there are. Many such plants, in various localities throughout the Territory, have been built, tried and abandoned at considerable money loss, because through some fault in their original design or through some difficulty in their operation, they proved financially unprofitable.

Most of these failures and accompanying losses could have been forseen and avoided if those in charge had had sufficient knowledge of the methods of successfully operating a pumping plant, and had properly understood in advance the conditions under which the pumps would of necessity have to work.

It is hoped that the information herein presented may be of use to those who are contemplating the installation of a pumping plant by giving some idea of the probable cost of operation, and by throwing light upon some of the frequently but little understood points affecting the cost of operating a pump.

METHOD OF INVESTIGATION.

Each different plant was visited and measurements were made of the amount of water pumped and the quantity of fuel consumed under the conditions of its everyday working. No attempt was made to put the plant into any unusual condition favorable for a test. In numerous cases it was recognized that the performance of a plant could be much better under improved conditions, but our present object was to find out actual rather than possible results. Data regarding the cost of plants and the general features of their operation were kindly furnished by the owners, and grateful acknowledgement is hereby made to all who supplied valuable information. The data obtained are given later in tabular form to facilitate comparison of the different plants.

NUMERICAL RELATIONS.

The following numerical relations, used throughout this bulletin, may be of value to any who wish to make calculations on the subject of pumping:

A discharge of one cubic foot per second (called also one second foot), equals 450 gallons per minute, or 27,000 gallons per hour.

One acre-foot of water is the amount of water which will cover one acre to the depth of one foot,

A discharge of one second-foot equals two acre-feet per twenty-four hours.

One cubic foot of water weighs about sixty-two and one-half pounds.

The weight in pounds of the water pumped per second, multiplied by the lift in feet, equals the work done per second in foot-pounds.

One horse power equals 550 foot-pounds per second.

Therefore, the useful horse power developed by a pump equals sixty-two and a half times the lift in feet, times the discharge in second-feet, divided by 550.

Or, expressed by a formula, if H=lift in feet,

Q=discharge in second-feet,

and H.P.=useful horse power or as it is often called, the water horse power,

$$\text{then H.P.} = \frac{62.5\ HQ}{550}$$

When a pump is run, only a part of the power supplied is used in actually lifting the water. The remainder is consumed in friction of the water through the pump, and in giving the water the velocity necessary to make it move through the pipes and pump.

The efficiency of a pump is the ratio of the power usefully applied to the lifting of the water as calculated by the formula above, to the total power supplied to the pump. The efficiency of a pumping plant is usually between one-third and one-half. Hence, the rated capacity of an engine must be from two to three times the useful horse power to be developed by the pump calculated as above.

In computations upon the cost of power, the unit in general use is the horse power hour, that is, the amount of work done by one horse power running continuously for one hour. In each test described in this bulletin, the cost per horse power hour is given. One and three-eighths horse power hours will lift one acre foot of water through a height of one foot. Hence, the cost of raising one acre foot one foot high is found by multiplying the cost of one horse power hour by one and three-eighths. The cost of raising one acre-foot to any other height is directly proportional to the height.

For the benefit of those contemplating the use of electricity it may be stated that one kilowatt hour equals one and one-third horse power hours.

INTEREST CHARGES AND DEPRECIATION.

A most important point to be considered in connection with the buying of a pumping plant, but one of the things most frequently ignored, is the matter of interest upon the first cost of the plant, and the depreciation in value of the plant due to the wear and tear in operation.

A conservative estimate of the rate of interest which ranchers pay in this Territory is ten to twelve percent per annum.

The life of the average pumping plant, in use every year, will probably not much exceed ten years, although there is very little data yet upon which to base an estimate. This would indicate that at least twenty percent of the first cost of the plant should be included each year as a part of the expense of running the plant, in order to cover these items "of interest and depreciation.

In the results given in this bulletin no calculations have been made of the charges for interest and depreciation because of the impossibility of securing sufficient data upon which to base the figures, but the following illustration will serve to indicate the method of making such allowances. Suppose a plant to cost, complete, $2,000. Twenty percent of this is S400. If the plant runs only one hundred days a year, $4 a day is the proper charge for interest and depreciation. This is just as real as any other item of expense, and should be added to the cost of fuel, attendance, etc., to obtain the real cost of running

DESCRIPTIONS OF PLANTS TESTED.

No. 1. On the ranch of C. 0. Crane, three miles north of Tucson. An open dug well to water 53 feet below the surface of the ground. A new Robinson geared vertical plunger pump eight inches in diameter, stroke nineteen inches, belted to a traction engine. Plant worked at great disadvantage on account of deficient supply of water. Cost of engine and pump, $1,200. Date of test, July 10, 1903.

No. 2. Wm. Tonkin's ranch, four miles south of Tucson, Open dug well, about 20 feet to water. Centrifugal pump belted to horizontal slide-valve engine. Stationary boiler in brick setting. Plant in use for seven years and apparently in perfect condition. Cost unknown. Date of test, July 15, 1903,

No. 3. Seedless Grape Co., three miles southwest of Tempe. Twelve-inch drilled well, 340 feet deep, stove pipe casing. Natural water level about thirty feet below surface of ground. New Fairbanks-Morse centrifugal pump about seven feet above water level in open pit, and belted to a new twelve horse power Fairbanks-Morse gasoline engine. Cost not obtainable. Date of test, July 25, 1903.

No, 4. Ranch of E. Olsen, nine miles southeast of Tempe. Five twelve-inch drilled wells in a straight line, thirty feet apart, each about two hundred feet deep, and about 23 feet to water level. An eight-inch suction pipe down each well. A twenty inch centrifugal pump belted to a 65 horse power 12x30 condensing Corliss engine. Return tubular cylindrical boiler in adobe and brick setting. Plant one year old, repairs negligible. Cost, including wells, $10,000 to $11,000. Date of test, July 29, 1903.

No. 5. Cooper Bros' ranch, one mile northwest of Tempe. Open dug well, twenty-four feet deep to the surface of the water. Chain elevator, carrying thirty-three buckets about two feet apart. Each bucket carried, when running, about four gallons. New four horse power gasoline engine belted to elevator. Cost of engine, $250; of elevator, $50. Date of test, July 30, 1903.

No. 6. Government Indian School at Yuma. Water pumped from the Colorado river. Five-inch centrifugal pump, about four years old, belted to a ten horse power horizontal slide valve engine. Return tubular cylindrical boiler in brick setting. Cost of engine and pump, $600. Cost of boiler unknown. Pump" is run by Indian boys and consequently no cost is given for attendance. Date of test, Jan. 13, 1904.

No. 7. University of Arizona, Tucson. An open well to fifteen feet below natural water level. A six-inch perforated steel pipe in bottom of well reaches fifty-five feet below natural water level. Natural water level is eighty-five feet below surface of ground. At the water level a duplex steam pump in poor condition. Large return tubular cylindrical boiler in brick setting. For about six hours of the test the water was pumped to the surface of the ground, and for the other two hours into a tank thirty-two feet above the ground. Date of test, May 7, 1904.

No. 8, University of Arizona, Tucson, Same well as No. 7. A new three and one-half inch Byron-Jackson two-step centrifugal pump direct connected to a 15 horse power, three-phase induction motor. Cost about $1,000. Date of test, July 27, 1904.

No. 9. Geo. W. Kohler's ranch, three miles south of Tucson. Open well supplemented by three 8-inch wells bored to the depth of thirty feet below the water level and situated about fifty feet apart and fifty feet from the open well, all connected together and connected to the open well by a pipe below the water level. Natural water surface about 11 1-2 feet below the surface of the ground, A six-inch Byron-Jackson centrifugal pump belted to a 17 horse power Hercules gasoline engine. Date of test, May 26, 1904.

RESULTS.

The accompanying Table I summarizes the results obtained. Some of the figures of the table, such as cost of repairs, attendance, etc., are estimates based upon all the information obtainable. A comparison of the figures of the table shows that there is a great variation in the cost of running different plants. In some cases there are very apparent reasons why one plant is more economical than another. In other cases it would probably require a very careful and complete examination to determine the causes of a plant's lack of good efficiency.

There is apparently no great difference in the cost of fuel for pumping, between mesquite wood at $3.50 per cord, and distillate at $.22 a gallon. Along the railroads crude oil for burning under boilers can he obtained at present at about $1.60 per barrel of 42 gallons. Distillate from California for use in gasoline engines can also be obtained at railroad points in any part of Arizona for about 22 cents a gallon.

Good hard wood can be obtained at present in most agricultural districts throughout the Territory for from $3.50 to $4.00 per cord. Although the supply is diminishing it will apparently suffice for many years to come.

The height which the water was raised in pumping varied in the different plants tested from 15 feet to over 100 feet. The lifts given in the table include not only the distance from the natural level of the source of water supply to the surface of the ground, but include also the amount which the surface of the water supply was lowered by the pumping and the amount which the end of the discharge pipe was above the surface of the ground.

When the lift is more than ten feet, the power required for pumping is approximately proportional to the lift, so that this factor is of great importance in determining the cost of pumping, or the possibility in any particular case of profitably pumping for

TABLE I.—SUMMARIZING RESULTS OF INVESTIGATION OF COST OF PUMPING IN ARIZONA

Number	Location	Kind of fuel used	Cost of fuel	Kind of pump	Duration of test in hours.	Amount of fuel consumed.	Discharge in second feet.	Discharge in gallons per minute.	Discharge in gallons per hour	Lift in feet.	Average useful horse power developed.	Cost of fuel per horse power hour.	Cost of attendance per horse power hour.	Cost of oil, repairs, etc., per horse power hour.	Total cost of running per horse power hour.	Cost to lift one acre-foot one foot high.	Cost to lift one acre-foot to surface of ground.
1	Crane's Ranch	Mesquite wood	$3.50 per cord	Reciprocating	9.25	0.42 cords	0.27	121	7,290	54.5	1.67	$.095	$.097	$.022	$.214	$.294	$ 16.02
2	Tonkin's Ranch	Mesquite wood	$1.50 per cord	Centrifugal	10.0	1.00 cord	1.23	551	33,200	35.0	4.89	.072	.031	.007	.110	.151	5.28
3	Seedless Grape Co.	Distil late	$0.22 per gal.	Centrifugal	1.5	2.04 gals.	1.15	518	31,000	47.0	6.14	.049	.017	...	.066	.091	4.28
4	Olsen's Ranch	Mesquite wood	$4.00 per cord	Centrifugal	7.0	1.15 cords	9.60	4320	259,000	30.3	33.0	.020	.006	.002	.028	.039	1.18
5	Cooper Bros. Ranch	Distil-late	$0.22 per gal	Bucket	3.58	1.00 gal	0.33	150	9,000	26.0	0.98	.063	.100	.020	.183	.252	6.55
6	Yuma Indian School	Mesquite wood	$4.00 per cord	Centrifugal	7.92	0.59 cords	1.25	562	33,800	15.5	2.20	.135	...	..			...
7	University of Arizona	Mesquite wood	$3.50 per cord	Reciprocating	8.05	0.80 cords	0.62	279	16,700	97.9 130.	6.70 9.25	.048	.051	.017	.116	.160	15.52
8	University of Arizona	Elec-tricity	$0.05 per k.w.h.	Centrifugal	3.88	51.4 k w h	0.574	258	15,500	98.2	6.41	.104	.010	.003	.117	.161	15.81
9	Kohler's Ranch	Distil-late	$0.22 per gal	Centrifugal	9.00	15.0 gals	1.60	720	43,200	26.5	4.82	.076	.020	.007	.103	.142	3.76

irrigation. To estimate what might be expected of any of the plants in the table in some other location, the next to the last column, headed "Cost to lift one acre-foot one foot high" should be used. The sum given in the table multiplied by the lift in feet at the assumed location would give the cost of pumping one acre-foot of water at the assumed location with the given plant. For instance, plant number 4 raising one acre-foot of water at about four cents per foot would pump from a depth of sixty feet at a cost of $2.40 per acre-foot. This is much less than the actual cost of water at some of the plants given in Table I, which are known to be working profitably.

A steam plant while running, without regard to its size, requires some one constantly in attendance and demands practically his whole time. With a gasoline plant however, it is quite different, and while it needs considerable attention, the man in charge can give a large part of his time to other matters such as taking care of the irrigating stream. As would be expected, the table shows that the cost of attendance is greater when burning wood than when using a gasoline engine.

The cost of labor in Arizona varies from one dollar per day, without board, for unskilled Mexicans, to three or four dollars per day for the best class of skilled labor. Cases have been observed in which a steam plant was successfully run by a Mexican or a Chinaman who could not talk English, working for a dollar and a half per day; but this is much below the average price for such services. A competent stationary engineer would usually command from two and one-half to four dollars per clay.

The most conspicuous fact shown by the table is the great advantage in point of economy possessed by the large plants over smaller ones. Number 4 is many times larger than any other, and shows by far the least cost for power. It has the highest economy in both cost of fuel and attendance. The saving in fuel was due to the character of the engine, which was a good Corliss using a condenser, and together with the boiler, apparently working with all conditions conducive to a high economy. The relative saving in cost of attendance is more striking even than in cost of fuel. This is due, of course, to the fact that it requires but little more work and skill to take care of a large plant than a small one. The two smallest plants, numbers 1 and 5, show especially a greatly increased cost for attendance. The advantage of a large size is also shown in the discussion of a plant at Yuma, which follows.

PLANT OF THE COLORADO VALLEY PUMPING AND IRRIGATING COMPANY.

The present plant of this company, located at Yuma, replaced, in the early part of 1903, a smaller plant operated by the same company. The present plant consists of a twenty-four inch double suction centrifugal pump belted to a 125 horse power condensing Corliss engine, taking steam from a return tubular cylindrical boiler in an adobe setting. The present pump, engine, and boiler cost, erected, about $8,000.

Water is pumped from the Colorado river into a canal. The lift varies from less than four feet at time of flood, to about fourteen feet at extreme low water. Wood, costing $3.50 a cord, is used for fuel when it can be obtained from the ranchers under the canal, and at other times California crude oil is burned under the boiler, costing $1.60 a barrel.

Table II shows by months for one year the amount of water pumped in acre feet; the average lift; the equivalent number of acre-feet that would be lifted through a height of one foot by the same power; the cost of operating the plant as a total, and also the cost itemized under the heads of fuel, attendance and incidental expenses; the cost per acre-foot itemized in the same way; and the cost per equivalent number of acre-feet lifted one foot.

The table covers the year 1903 and is based upon figuies for cost furnished by the officers of the company, and measurements of the quantity of water pumped made by a member of the U. S. Geological Survey. The horse power hour is not used as a unit for comparison in this table, but instead only the acre-foot of water pumped.

TABLE II —SHOWING CAPACITY AND COST OF OPERATION OF PUMPING PLANT OF COLORADO VALLEY PUMPING AND IRRIGATING COMPANY AT YUMA, ARIZONA, FOR THE YEAR 1903.

Month.	Total acre-feet pumped	Average lift in feet	Equivalent number of acre-feet lifted one foot	Actual monthly expenses				Expense per acre foot			Expense per equivalent number of acre-feet lifted one foot.		
				Fuel	Labor	Incid'tal	Total	Fuel	Labor	Total.	Fuel	Labor	Total
January........ ...	346	13 8	4,775	$145 25	$112 00	$ 13 00	$270 25	$ 420	$ 324	$ 781	$ 0304	$ 0235	$.0566
February...	583	13 6	7,929	262 50	126 85	15 10	404 45	450	218	694	0331	0160	.0510
March.............	608	12.0	7,296	255 50	150 85	17 15	423 50	420	248	697	0350	0207	0580
April......	791	10.0	7,910	290 50	182 50	28 70	501 70	367	231	634	0367	0231	0634
May	1,027	7 0	7,190	302 60	166 00	50 25	518 85	295	162	.505	0421	0231	0722
June..	1,088	4 5	4,896	300 50	151 00	45 55	497 05	276	139	457	0614	0308	1015
July..	1,808	7 4	13,466	479 70	169 50	16 35	665 55	265	094	368	0357	0126	0494
August	1,647	10 7	17,619	568 70	196 00	19 60	784 30	345	119	476	0323	0111	0445
September	1,275	11 6	14,778	429 05	177 50	34 18	640 73	336	139	503	0290	0120	0434
October.	617	11 1	6,855	175 00	136 00	22 65	333 65	284	.220	541	.0256	0198	0487
November	528	11.3	5,966	154 00	134 50	20 00	308 50	.292	255	584	0258	0225	0517
December	369	11 8	4,354	105.00	106 00	15 00	226 00	285	287	613	.0241	.0243	0519
Total	10687		103,034	3468 30	1808 70	297.53	5574 53						
Average		9 6						3245	1692	5216	03366	01755	0541

The cost of pumping one acre-foot of water varied between seventy-eight cents in January with a lift of nearly fourteen feet, and thirty-seven cents in July with a lift of seven and a half feet. It was lower at the latter date, partly because of the decreased lift, and partly because more water was being pumped at that season, giving a more continuous operation of the plant and on that account greater economy.

The cost of lifting one acre-foot one foot varied between four and three-tenths cents in September, and ten and two-tenths cents in June The pump works much less efficiently at the low lift of four and one-half feet than at the higher lift, and hence, although in time of Hood in the river the actual cost of lifting water into the canal is least, the cost of lifting the water per foot at such times is greatest.

In such a location as this, with large fluctuations in the river level, it might be profitable to have two or more pumps, one carefully designed to have the best efficiency under a low head, and another designed to have the best efficiency under the higher head. At any particular time that pump would be used which was best adapted to the stage of the river.

This plant has about double the horse power of number 4 in Table I, and a comparison of the figures of the two tables shows that when the Yurna plant is working under the most advantageous conditions it has an economy just about equal to that of number 4. The fact that its economy is a little less than that of number 4 is accounted for by the fact of its smaller lift.

When compared with the smaller plants of Table I, the Yuma plant again illustrates very forcibly the economic advantage of the larger plant.

RECOMMENDATIONS AND CONCLUSIONS.

1. The sufficiency and constancy of the water supply should be carefully determined before installing a pumping plant, especially if the supply is obtained from wells. In many cases costly plants have been built only to find on starting up that the

water supply was entirely inadequate. This has resulted in numerous cases in the abandonment of the entire project with great financial loss.

2. A plant should be carefully adapted in size and kind to the lift and the amount of water it is required to raise; and the pump and engine should be adjusted to each other in size and speed. If the plant is too small and is pushed beyond its proper capacity, there will be a great loss in efficiency. If it is too large there will usually be some loss in efficiency besides the loss due to an unnecessarily large investment.

3. The suction and discharge pipes should be of ample size, and as short and straight as possible. The effect of obstructions and friction in the pipes has a greater proportional effect with low lifts than with high lifts.

4. Making the lift any higher than actually necessary should be carefully avoided. When a well is pumped the surface of the water in the well always falls and remains lowered while the pumping continues, so that the lift is greater than the distance from the mouth of the discharge pipe to the level of the water when the pump is not running. The greater the amount of water pumped from a well, the more the surface falls, but the increase in the quantity of water obtained does not seem to be proportional to the lowering of the surface of the water. On this account and because a pump can not in practice lift water by suction more than about twenty-five feet, experience seems to indicate that in general it is not profitable to lower the natural surface much more than ten feet. The end of the discharge pipe should be no higher than necessary to raise the water to the desired level.

5. All kinds of pumping machinery, like all other machinery, should be carefully housed to secure protection from dirt and the weather.

6, When a plant has been built and put into successful operation, it should be made as much use of as possible, for the interest on the investment continues just the same whether the plant is idle or running.

7. In general, a large plant is more economical in running than a small one, because it Is not much more work to ran a

large plant than a small one. Hence where the water supply ib sufficiently abundant it will be cheaper for several neighbors close together to cooperate in building a large central plant rather than for each to have his own separate plant. Long ditches permitting extensive loss from seepage would tend to offset this advantage. It is to be noticed also that where there is a definite amount of water to be pumped, it is possible to make the pumping plant too large for the greatest economy. If it is too large the gain in economy when running is more than balanced by the disadvantage of the larger investment.

8. Complete pumping plants, not including cost of wells, can be built in reasonably accessible locations in Arizona for approximately $100 per rated horse power, or $200 per water horse power. Small plants may exceed this cost while very large ones will probably fall below.

9. Small plants of 12 rated horse power or more, under favorable conditions, should lift one acre-foot of water one foot in height for fifteen cents or less. Plants of 100 rated horse power or higher should do the same for about five cents.