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FARM IRRIGATION PUMPING PLANTS

BY
A. S. CURRY

Pumping plant on the farm of the New Mexico Agricultural Experiment Station, State College, N. M. The discharge is 1625 gallons a minute from a 12-inch turbine pump installed in a 16-inch well.

AGRICULTURAL EXPERIMENT STATION
of the
NEW MEXICO COLLEGE OF AGRICULTURE AND MECHANIC ARTS
State College, N. M.

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FARM IRRIGATION PUMPING PLANTS

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INTRODUCTION

The widespread nature and seriousness of the drouth in 1934 and the fore part of 1935, along with preceding water shortages, created a need for greater assurance of an adequate water supply for farm crops. This condition has brought about wider interest in the development of irrigation, with resultant increased Governmental assistance in the construction of both large and small irrigation works.

There are only three methods by which irrigation water can be placed on the land. One method is by gravity systems, one by means of artesian sources, and the other is by pumping. It is with the last-mentioned method that this publication is concerned.

Since pumping is practiced only to supplement the water obtained from other sources, its many phases should be given careful and accurate attention, as it is an expensive procedure, both as to installation and operation. In analyzing the situation, one should take into consideration the questions as to whether the plant is actually needed and whether or not the proposition is economically sound. Careful consideration should be given the water supply and its availability; the location, depth, size, drilling, and cost of the well; size, kind, and cost of casing and strainers; the pumping equipment and motive power; the kind of crops; the nature and productivity of the soil; the climate; marketing facilities; the total cost of placing the water on the land; and a number of other factors. Many pumping enterprises have failed owing to the fact that inadequate attention has been paid to the many questions involved. Some have failed because of excessive pumping costs, poor soil, insufficient water supply, selection of poor or unadapted machinery, improper installation, operation, and care of the machinery, and the production of crops not suited to the growing and marketing conditions.

A careful investigation of the points involved may reveal that the water supply is neither sufficient nor dependable, that the lift is too great, or that the cost of the plant is too high to justify its installation in view of the productivity of the soil, the crops to be grown, or the marketing facilities.

The practice of providing water for irrigation by means of pumping plants is not new. It dates back as far as historical records, showing that originally water was transported to the

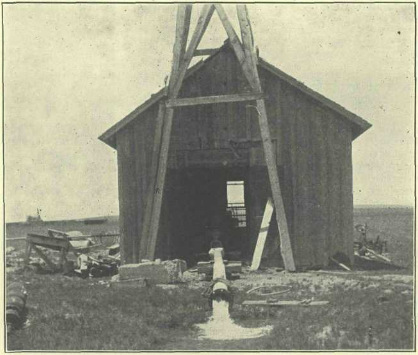

Fig. 1.—A pumping plant that was installed in a locality where the average annual precipitation is 13.09 inches. The plant is operated only occasionally, during dry years.

crops by hand. Since that time a gradual improvement in methods and equipment has taken place, the pumping machinery of today having been developed to such an extent that it is dependable and requires a relatively small amount of attention for its operation. The materials used in its construction are usually of good quality, and the design is such that efficiency has been greatly increased.

The advisability of installing a pumping system merely to meet emergency needs is often debatable. Whether or not a farmer can afford to go to the expense of drilling a well, pro-

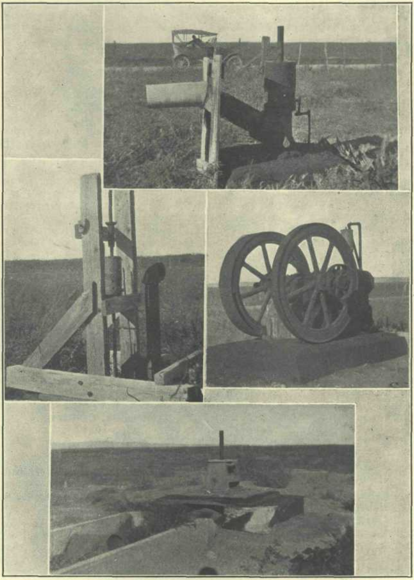

Fig. 2.—The pumping equipment shown above, all located in New Mexico, has been abandoned.

viding pumping and power equipment, and paying all fixed and operation charges can be answered only by himself. When the annual precipitation is deficient only occasionally, the pumping plant enthusiast should realize that whether he is using the plant or not, the fixed charges continue to be a burden without returning any benefits.

ADVANTAGES OF PUMPING

The practice of pump irrigation has certain advantages that cannot usually be obtained by use of the different gravity systems. The fact that one can obtain water when it is needed, instead of having to wait for one's turn as is the case in some of the other systems, may materially assist in increasing the yield and quality of the crops, whereas, waiting may hinder crop development. With an efficient pumping system it is not always necessary to run the plant at night, except during the rush season; also, it may be feasible to pump into a reservoir at night and irrigate with a larger stream during the daytime. With a pumping plant it is sometimes possible to grow truck or other crops which could not be grown if the period between rotations were too long for the crop to be without water. Weeds, including Johnson grass and the wild morning-glory, can be more easily controlled in pump irrigated districts than in areas irrigated by gravity water where the distribution ditches pass through the lands of many different types of farmers. Other advantages are evident in connection with the cropping system, as certain rotations can be practiced which could not otherwise be carried out. The fact that a pump operator is not subject to the rulings of a ditch boss or a major-domo is considered by some to be a distinct advantage. One of the more important advantages of the individual pumping system is that an efficient and intelligent operator is not inclined to overirrigate, as he realizes that every acre-inch of water represents a direct cash outlay for operation and maintenance. As a community proposition, pumping is and has been a means of developing certain agricultural areas which could not have been developed by gravity systems.

DISADVANTAGES OF PUMPING

Despite the fact that there are several seemingly outstanding advantages possessed by the individual pumping system, there are also disadvantages, many of which are responsible for farm failures where the system is used. The cost of the well, pump, and motive power is no small item and frequently runs into thousands of dollars. The investment in expensive machinery carries with it interest, depreciation, and tax charges which may mount into large sums annually. The operation of the equipment may be rather expensive if the local charges for gasoline, oil, and electricity for pumping purposes are high. Occasionally one may experience considerable difficulty when there is a breakdown, which may require several days for repairing. In the meantime, the crops may suffer intensely for moisture. The actual operation of the plant itself is no small task, and frequently a skilled mechanic is needed. In order to be most successful it is desirable that the owner-operator be at least a fair mechanic, as well as a business man and a good farmer. Success also demands superior managerial ability in connection with the selection and handling of the crops, as well as in the operation of the plant. Another disadvantage is that in good moisture years there is a tendency for inefficient managers to irrigate more than is actually needed, thus decreasing the farm profits. Therefore, the fact that there are many disadvantages involved may make the pumping enterprise an unsuccessful one.

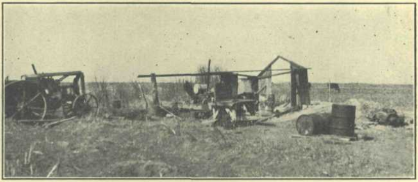

Fig. 3.—This plant is in poor condition, and the efficiency is probably low. The tractor is being used for power. Three old engines have been discarded, thus indicating that makeshift power may be unsatisfactory.

DEFINITIONS OF TERMS

Acre-foot is a measurement of volume and is equal to 43,560 cubic feet, or the amount of water required to cover one acre of land to a depth of one foot.

Acre-inch is a measurement of volume and is equal to 3,630 cubic feet, or the amount of water required to cover one acre of land to a depth of one inch. It is one-twelfth of an acre-foot.

Cubic foot per second (c.f.s., cusecs., or sec. ft.) is a measurement of flow or discharge and is one cubic foot of water passing a given point per second. One cubic foot per second flowing for twenty-four hours equals 1.98 acre-feet.

Miner's inch is a measurement of flow, according to certain specified conditions, and in New Mexico is equal to one-fiftieth of a cubic foot per second.

G.P.M. is an abbreviation for gallons per minute. It is a measurement of flow or discharge and is the number of gallons of water passing a given point per minute. It is generally used in connection with pump discharge. Four hundred and fifty gallons per minute equal approximately one cubic foot per second.

A **weir** is one of several devices used for measuring the flow of water.

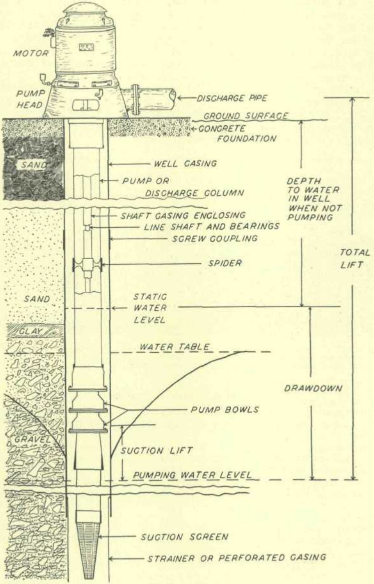

Fig. 4.—Diagram of deep well and turbine pump installation.

There are several types and each should be installed and used according to certain specifications in order that an accurate measurement be obtained.

Water table is the upper surface of zone of saturation, except where that surface is formed by an impermeable body.

Static level of water is the point to which water will rise in a well under its full pressure head. It can be expressed as static head in terms of feet from the ground surface or point of discharge. It is not necessarily at the same point as the water table.

Drawdown is usually expressed in feet and is the actual difference between the level of water in the well before and while pumping.

Discharge is the amount of water delivered by the pump and can be expressed by any of the terms of flow but usually in g.p.m. (gallons per minute).

Friction of water in pumping plants is the resistance of a pipe to the flow of water. It may be expressed in feet of head per 100 feet of pipe. The friction increases with the velocity of the water. An elbow offers about the same amount of friction as 40 feet of pipe of the same size. The friction, or friction head, should be carefully considered, since undue friction creates the need for additional power.

(See Table 9 for friction losses in smooth straight cast iron pipe.)

Lift is the vertical distance between the elevation of the water while pumping and the highest point to which the water is lifted.

Suction lift is the distance from the center line of the pump down to the top of the water while pumping.

The **suction head** is the suction lift plus velocity, friction, and entrance losses. This head should not be more than 15 to 18 feet in New Mexico. In the case of a pump operating under water there is no suction lift.

Total head is usually expressed in feet and includes the suction lift, the lift, and all friction losses in pipes and elbows.

Water horsepower or **theoretical horsepower** is the power required to lift 33,000 pounds of water through a distance of 1 foot per minute. The power required to lift 500 gallons a minute through a total head of 50 feet would be 500 x 50 x 8.33 (the weight, in pounds, of 1 gallon of water) $\div$ 33,000 $=$ 6.3 water horsepower.

The **actual horsepower** required for the plant will be considerably in excess of this, because a large amount of energy is lost in mechanical inefficiencies. For example, if the pump is 60 percent efficient ($6.3 \div 60 \times 100 = 10.5$), 10.5 horsepower will be required to drive it. In the case of a belt-driven installation a certain amount of power is lost in transmission; also, the motive power may not be 100 percent efficient. These factors have to be considered in selecting the proper size of power plant to do the work, and explain the reason that the theoretical and actual horsepower are not the same.

Brake horsepower is the amount of power actually delivered by the shaft of the engine or motor.

Pump efficiency is the ratio of the amount of water delivered, in terms of water horsepower, to the amount of power required to drive the pump.

Plant efficiency refers to the entire installation. The losses of power in the pump, transmission, and power plant in connection with the actual work accomplished are considered in making the calculations.

The log of a well is a written record explaining the kind, type, and characteristics of the various materials and formations encountered while digging the hole.

Voltage is electric pressure, the unit of measurement being the volt.

Compared with water in a pipe line, this pressure can be thought of as feet of pressure. As this pressure or voltage is increased the rate of flow of current power is increased.

Current is the rate of flow of electricity (or electric charge) through a conductor. The ampere is the unit of measurement.

Watt and **kilowatt** are units for measuring electric power. The kilowatt is 1000 watts, and equals about one and one-third horsepower.

Kilowatt-hour (kw.hr.) is a unit of work and represents the amount done per kilowatt per hour.

Resistance is an obstruction to the flow of electric current through a conductor and can be compared to the friction offered by pipes to water flowing in them.

Insulation is a nonconductor of electricity, because of the large amount of resistance it offers.

WATER SUPPLY

One of the first things to consider in the installation of a pumping plant is the amount of water required and the period of maximum usage. These phases vary greatly, depending upon such factors as climatic conditions, type and class of soil, crops to be grown, distribution system, and skill of the irrigator. In localities where the climate is usually such that only one irrigation is necessary to supplement the precipitation, it is probably advisable to install a smaller plant (thus reducing the fixed charges) than would be installed if the requirements were such that the plant would be operated a greater number of hours during the season.

Soils vary in texture and structure, which influence the amount of water they will absorb, the amount they will retain against gravity, and the amount they will hold against evaporation. Some soils absorb water so readily that six, eight, or even ten inches may be used in one application, even where the runs are reasonable in length and the skill of the irrigator is above the average. Other soils may use only four or five inches. Occasionally a soil is encountered where approximately one and one-half or two inches are all that can be absorbed readily by the ground, and consequently may require more frequent irrigation than other types of soils.

TABLE 1.—TIME, IN HOURS AND MINUTES, REQUIRED FOR STREAMS OF DIFFERENT SIZES TO COVER 1 ACRE OF LAND TO DIFFERENT DEPTHS.

Gallons per minute	Cubic feet per second	Depth over 1 acre															
		1 inch		2 inches		3 inches		4 inches		5 inches		6 inches		7 inches		8 inches	
		Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min	Hr.	Min.	Hr.	Min.	Hr.	Min.
200	.44	2	16	4	32	6	47	9	3	11	19	13	35	15	50	18	6
400	.89	1	8	2	16	3	24	4	32	5	39	6	47	7	55	9	3
600	1.33	0	45	1	31	2	16	3	1	3	46	4	32	5	17	6	2
800	1.78	0	34	1	8	1	42	2	16	2	50	3	24	3	58	4	32
1000	2.22	0	27	0	54	1	21	1	49	2	16	2	43	3	10	3	37
1200	2.67	0	23	0	45	1	9	1	31	1	53	2	16	2	38	3	1
1400	3.11	0	19	0	39	0	58	1	18	1	37	1	56	2	16	2	35
1600	3.56	0	17	0	34	0	51	1	8	1	25	1	42	1	59	2	16

Crops vary greatly in their irrigation requirements. Truck crops, being of a succulent nature and shallow rooted, as a rule require more frequent irrigations during their growing period than do other crops. The periods between irrigations for small grains, sorghums, and similar crops may be rather long. The deep-rooted crops, such as alfalfa and trees, can utilize deep irrigation to better advantage than can those with shallow roots. Alfalfa, because of its heavy vegetative growth, has a high total water requirement.

A distribution system laid out with runs that are too long causes excessive use of water. Some water is lost in long ditches and some may be lost by deep percolation or runoff. Upon the irrigator devolves the necessity of adapting the available stream of water to the distribution system, to the soil, and to the crop.

SIZE OF PLANT

The size of plant to install will depend upon the conditions to be met. After the situation is studied and analyzed, if it is decided to irrigate 60 acres during a maximum period of usage of 2 weeks, and if the land requires about 4 acre-inches per acre for each irrigation, one should select a plant that will be suitable for the conditions and that will deliver 20 acre-feet over the 14-day period, making an average of 1.44 acre-feet for 24 hours, or about 325 gallons a minute. Since farm usage of water does not average 100 percent efficient, a plant should be installed which will discharge about 450 gallons a minute. In addition to determining the amount used during the maximum requirement period, an estimate of the seasonal demand should be made so that the operating expenses can be calculated.

TABLE 2.—TIME IN DAYS (24 HOURS) REQUIRED TO APPLY A 4-INCH IRRIGATION ON DIFFERENT ACREAGES OF LAND WITH STREAMS OF DIFFERENT SIZES.*

Gallons per minute	Cubic feet per second	Amount of land receiving a 4-inch irrigation									
		5 a.	10 a.	20 a.	30 a.	50 a.	75 a.	100 a.	150 a.	200 a.	300 a.
		Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
200	.44	1.89	3.77	7.5	11.3	18.9	28.3	37.7	56.6	75.4	113.1
400	.89	.94	1.89	3.8	5.7	9.4	14.2	18.9	28.3	37.8	56.7
600	1.33	.63	1.26	2.5	3.8	6.3	9.4	12.6	18.8	25.1	37.7
800	1.78	.47	.94	1.9	2.8	4.7	7.1	9.4	14.2	18.9	28.3
1000	2.22	.38	.76	1.5	2.3	3.8	5.7	7.6	11.4	15.1	22.7
1200	2.67	.32	.63	1.3	1.9	3.2	4.7	6.3	9.5	12.6	19.0
1400	3.11	.27	.54	1.1	1.6	2.7	4.1	5.4	8.1	10.8	16.2
1600	3.56	.24	.47	.9	1.4	2.4	3.5	4.7	7.1	9.4	14.2

*This table may be used to estimate the size of plant needed to irrigate a farm of given area in a given number of days.

COOPERATIVE PUMPING

Although cooperative pumping has not been developed to any great extent, there are certain phases in connection with it which should serve to decrease the cost of water to the users.

In many instances it is necessary for the individual who pumps water for irrigating a small acreage to install a plant that is capable of supplying more water than he needs, in order to provide an irrigating stream of adequate size. In cases of this sort the owner is burdened with excessively high fixed charges. These charges could be reduced if he would arrange neighborly cooperation so that additional land could be supplied with water from the one pump. Cooperating could be done either by selling the water outright to a near-by farmer or by sharing in the entire installation.

A large number of the pumping plants in New Mexico are too small to yield a stream of adequate size for efficient irrigating. The installation of the larger plants should be encouraged, other things being favorable, if enough land can be placed under them so that the plant can be operated both day and night for at least 20 or 25 days a month during the rush season. Also, it will generally be found that the larger plants will operate more efficiently. Arrangements of this sort should reduce the fixed costs, which in many cases are considerably more than 50 percent of the total costs. Although cooperative pumping has not been greatly developed, it presents features which will be a distinct advantage when it is done under the proper conditions.

SOURCE

Water for pump irrigation may be obtained from surface or underground sources. The amount available from surface sources can usually be fairly accurately determined; so the selection of a pump and a power plant to meet the conditions is comparatively simple.

The problem of obtaining water from underground sources (wells) is a serious one and deserves careful consideration. In localities where the water appears to be stored in an underground reservoir, the wells installed therein do not possess the ultimate possibilities of those located where the water is apparently in the form of an underground stream, or where the movement is fairly rapid.

The soil beneath the surface is usually made up of layers of different kinds of materials. The layers are not uniform in thickness nor do they appear at the same elevation. They are not necessarily continuous. The materials vary as to texture and structure. Some layers may consist of fine tight clay, practically prohibiting the movement of water. Others may be made of coarse sand and gravel with large open spaces, thus permitting rapid movement of the water. Strata possessing intermediate characteristics may permit of only slow movement of the underground water. Wells differ greatly in the quantity of water that can be obtained from them. This difference is due largely to the fact that variations exist in underground formations and characteristics. It is necessary, however, that the drainage and underground receiving area for a given locality be of such nature that water can be supplied to the strata, before satisfactory wells can be obtained. Inflow to the underground supplies may be somewhat slow, a condition which would limit the ultimate development of the area. It should be remembered that for each gallon removed from the source in any locality an equal amount must be returned or the supply will be depleted in the end. Because of this fact, a record should be kept of the water level in each pumping area, so that, if necessary, steps can be taken to prevent overdevelopment.

There is no assurance that every well installed will be a good one. The materials encountered and their stratification may be of such nature that underground water movement is practically prohibited. Another well near by may prove to be a good producer because of favorable circumstances.

In a locality where several irrigation wells have been constructed and tested, an idea can be obtained as to the nature of the underground conditions which will be encountered. This can be done by carefully studying the logs, histories, and performances of neighboring wells. Virgin territory presents a different picture, in that the prospective driller has no idea as to the conditions existing beneath the surface. The first well may be a good one or it may be a dry hole. For this reason it is advisable that a test hole be drilled to determine the conditions, and that the capacity be determined as nearly as possible. In case a dry hole or poor water-bearing formation is found the expense of the larger well is saved. In some localities several water-bearing formations may be encountered, in which case the well should be so constructed that advantage can be taken of them.

Occasionally when water is found it is unfit for irrigation purposes. Water carrying more than about 300 parts of total solids per 100,000 should be used with extreme caution, as some of the ingredients may be of such nature that their presence would be detrimental to plant growth. The drainage and soil conditions also affect the permissible amounts of salts which can be carried in the irrigation water.

RESERVOIRS

The use of reservoirs in connection with the pumping plant is more or less common in some localities. The principal advantage in this practice is that frequently more economical use can be obtained than would otherwise be possible from both the irrigation water and the entire plant. The reservoir enables one to operate the pump at night as well as in the daytime, thus storing water for use the following day. This arrangement permits of the selection of a smaller unit than would be possible if there were no reservoir. The storing of water overnight provides a larger stream for irrigating the next day. Wherever it is possible or feasible to construct a reservoir, the operator can obtain better use of his equipment at less cost, and a sufficiently large stream to require the entire attention of the irrigator, thus increasing the efficiency of the entire setup. In cases in which the pump discharges enough water for one irrigating stream, the reservoir may have no particular advantage.

If the topography of the farm is such that the reservoir can be located below the pump, this should be done to avoid lifting the water higher than absolutely necessary. Otherwise, the well and reservoir will probably be located at or near the highest edge of the land to be irrigated.

In constructing the reservoir every care should be taken to make it practically watertight. Some soils are not adapted to reservoir construction. A clay soil or mixture of sand and clay provides a very satisfactory material; however, concrete or any other watertight material tends to eliminate losses.

The farm-constructed reservoir, even at its best, is subject to certain losses, such as evaporation, seepage, and leakage from the turnout gate. Ordinarily, under farm conditions, evaporation losses can be reduced only by making the floor area as small as practicable, thus presenting only a minimum area of water surface to the air. Seepage loss in porous material may amount to as much as 1 foot per 24 hours, a fact which shows the necessity of making the reservoir as nearly watertight as possible.

After the reservoir has been placed in use it should be properly maintained. The banks will have to be straightened and heightened occasionally. Also, it may need cleaning, at intervals, or aquatic plants may collect wind-blown weeds or trash.

A more complete and detailed discussion of farm reservoirs is given in U. S. Department of Agriculture Farmers' Bulletin 1703.

WELLS

Well sinking, regardless of the kind and size of well, when properly done in all respects, is an art. The more skill, judgment, and experience a driller has, the better work he will ordinarily do. Anyone who contemplates the installation of a pumping plant should obtain advice from a competent local driller concerning the water-bearing formations, size and depth of well, kind of strainer and casing to use, and amount of flow to be expected. Owners of other wells in the locality should be consulted to determine, if possible, the good and poor points of their plants, so that practical suggestions for improvement may be obtained.

In locating the well, the topography of the farm should be considered. If possible, the location should be such that the distribution system can conveniently reach all parts of the farm. Occasionally it is preferable to place the well on lower ground and conduct a comparatively small quantity of water through a built up ditch to a little high land, rather than lift all the water to the high point and allow it to flow by gravity to the lower land. Sometimes a neighboring well may affect the flow at the desired point, in which case the location should be shifted. In some cases adequate flow can be found only in strata at a distance from the ground to be irrigated.

The size of hole will be determined by the flow desired and expected, by the kind of pump installation to be made, and by the nature of the water-bearing formations. The exact relationship between the size of hole and the capacity of the well is not definitely known. It is, however, believed to be poor economy to skimp on the well diameter, especially where a turbine type of pump is to be used. The cased hole should be straight, vertical, and of sufficient diameter to permit the easy entrance of the turbine pump. For the pump to operate satisfactorily it should hang freely in the casing. A crimp or bind may throw the working parts out of alignment, with the result that the life of the pump will be shortened. The diameter should be sufficient to allow an inch or two of clearance between the casing and pump bowls. If this allowance is made, the pump can be easily inserted even though the hole is not perfectly straight; also, in testing the well, this space will permit the entrance of a small air line or sounder down beside the bowls. The depth of the hole depends upon the water available. It frequently happens that the heavier yielding strata appear at the greater depths.

A complete and accurate log should be kept while the well is being sunk. It should show the exact depth and thickness of all formations, with complete descriptions as to the nature and characteristics of the different materials encountered. The log should be included in the driller's contract. When an old well is being repaired, a reliable log is a distinct asset, as it may give a good indication of the trouble and suggest a possible remedy. It would be wise to include in this record all data concerned with developing the well.

TABLE 3.—DRILLER'S LOG OF IRRIGATION DEPARTMENT WELL NO. 3, DRILLED IN JUNE 1935 FOR THE NEW MEXICO AGRICULTURAL EXPERIMENT STATION, STATE COLLEGE, NEW MEXICO.

Dept in feet	Material
0 to 5	Soil
5 to 20	Sand
21	Sand with trace of gravel*
21 to 24	Sand
25	Sand with trace of clay
25 to 30	Sand
30	Thin layer of clay
30 to 50	Gravel and sand

*The sand from 21 to 29 feet carried traces of gravel.

In some localities wells may be sunk by merely digging a pit down into the water-bearing formations. For this process to be satisfactory the stratum encountered at the bottom should possess a strong flow, so that the required amount of water can be obtained. The pit should be curbed, during construction if necessary, to prevent caving. The material used for curbing and method of construction will depend on the local conditions. Occasionally it appears desirable to dig and curb an open pit, either to water or for several feet in depth. Drilling can proceed from the bottom of the pit until the desired depth or amount of water is obtained. The diameter of the pit should be great enough to permit of the installation and operation of the equipment. In cases in which the depth of pit is excessive it may be desirable to dig a hole of as small diameter as practicable and enlarge it at the bottom to provide working room for the machinery.

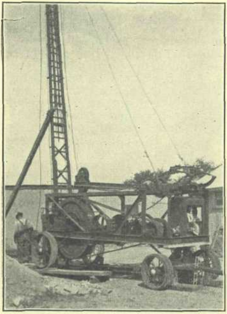

Fig. 5—All steel machine used in drilling wells on New Mexico Experiment Station Farm in 1935.

It is sometimes desirable to drill the well from the surface to the desired depth, but when the well is constructed in this manner, care should be exercised to see that the casing used is of sufficient size to receive readily the pump to be used. If the exact locations of the water-bearing strata are known, the casing can be perforated before it is placed in the well; otherwise, the perforations will have to be made in place as determined by the well log.

The well sinking job, or a portion of it, may be done by the owner, but usually it is done by contracting with a well driller. If a contract is entered into it should be specific and clear as to details, so there will be no misunderstanding between the parties concerned. Among the most important things to consider before a contract is made are the experience, qualifications, and reputation of the driller, and the condition of his well sinking apparatus. Considerable difficulty is sometimes encountered because the driller attempts the job with worn-out, inefficient, or unadapted machinery, the result being that the work is left in an unsatisfactory condition. Specifications concerning the details of the casing, starter sections, strainer, dimensions of the hole, time to be consumed in drilling, thoroughness of testing and developing the well, and method of payment should be given careful attention in formulating the contract.

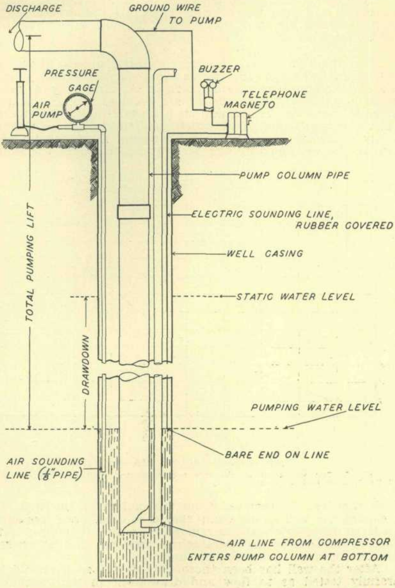

Fig. 6.—Diagram of air-lift pump installation, showing two methods of testing depth to water and drawdown.

The method of making payment varies in different localities, but it is usually based on a "block" or sliding-scale rate, varying with the diameter and depth of the hole, kind of casing, and the local geological formations.

DEVELOPING AND TESTING

After the well is cased, the next step is a process known as development, which means the carrying out of necessary procedures to obtain the maximum flow. At first only a small stream is pumped, but as the stream becomes clearer the discharge is increased. This operation is repeated until the stream is clear, or practically so, at which time the maximum flow is usually obtained. Sometimes a sand bucket is worked up and down in the well opposite the perforations to loosen the sand,

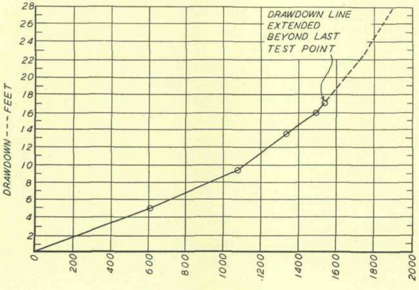

Fig. 7.—Test well curve of discharge and drawdown on Irrigation Department Well No. 3, State College, N. M.

which then can be removed from the bottom of the well. In developing the well an old pump should be used, since frequently a large quantity of sand is removed. An air-lift pump is satisfactory for this, as the operator can vary the flow as desired and remove larger quantities of sand.

After the well has been thoroughly developed it should be carefully tested as to flow and drawdown, so that accurate information can be furnished the pump and power dealers. *It is the responsibility of the well owner to see to it that the well meets certain specifications as to straightness, size, dis-*

charge, drawdown, and other conditions concerning operation. It is then the pump dealer's responsibility to select the pump properly designed to meet the given conditions.

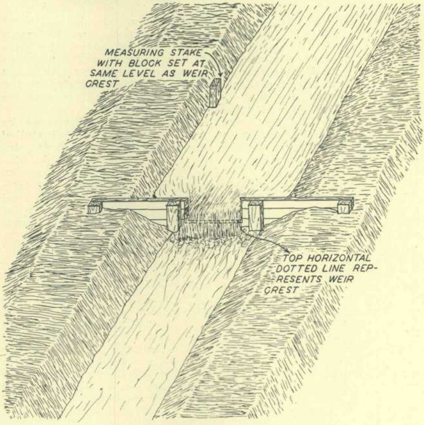

Fig. 8.—A small rectangular weir in a ditch.

The testing also should be done with temporary machinery, probably furnished by the driller. A tractor or other available power may be used for this purpose. The pump used should, if practicable, be of about the same size and kind as the one to be finally installed. Certain data, as indicated by the chart in Figure 7, should be collected and plotted, so that an estimate of the capacity of the well can be made. After pumping has been continued for several hours, until the maximum capacity of the well or testing equipment has been reached and there is no apparent fluctuation in the discharge, accurate measurements of the flow and drawdown should be made. The discharge should then be decreased, so the drawdown will be about 4 feet. Pumping at this level should continue until the discharge and water plane are constant, both of which should be measured and plotted. The discharge should then be increased until a drawdown of about 2 feet more has been established. Measurements of drawdown and discharge should again be taken and plotted. This procedure should be repeated until the capacity of the plant has been reached. After the data have been plotted, a good estimate can be made of the behavior of the well under more severe pumping conditions. Although the test plant may not discharge the greatest capacity of the well, the plotted line may be extended somewhat to give an estimate of the flow with greater drawdown.

In making the test, one can measure the discharge by means of a small rectangular weir constructed and installed as indicated in Figure 8. The size of weir to be used will depend upon the discharge of the pump, but this can be determined by estimating the size of stream and selecting, by means of Table 4, the length of crest most suitable for the conditions. The weir should be set vertical with the crest level and perpendicular to the direction of flow. The crest should have a sharp edge, as indicated in the cut, and set high enough above the bottom of the ditch so that it will be an inch or more above the water surface on the downstream side of the installation.

A measuring stake should be set in the ground about a foot from the bank and about 4 feet upstream from the crest. A block, the top of which should be on the same level as the crest as determined by a carpenter's level, should be fastened to the stake. A rule placed in a vertical position on the block will give the depth of water passing over the weir. This depth should then be found in one of the columns headed "Depth over crest" of Table 4. If, for instance, the reading is 3 inches over a 1½-foot rectangular weir, the discharge will be 274 gallons a minute. The ditch upstream, for a distance of 20 or 30 feet, should be widened and deepened and the banks heightened. This is done to create a large stilling pool so that the velocity of approach of the water will be controlled and all eddies will be reduced. For more complete instructions pertaining to the measuring of water, Farmers' Bulletin 1683 of the United States Department of Agriculture should be consulted.

The depth to water and the drawdown can be obtained only by means of some sort of sounding line. In some installations a chalked string with a weight tied to the end can be used where there is sufficient clearance between the casing and the pump to permit of its passage. By measuring the length of string dropped into the casing and subtracting the length of the wetted portion, the depth to water can be obtained. If there is dripping water within the casing, this method

TABLE 4.—DISCHARGE TABLE FOR RECTANGULAR WEIRS WITH COMPLETE CONTRACTIONS.

Depth over crest		Discharge for crest lengths of				
		1 foot	1.5 feet	2 feet	3 feet	4 feet
Feet	Inches	G.P.M.	G.P.M.	G.P.M.	G.P.M.	G.P.M.
.10	1 3/16	50	72	99	148	198
.11	1 5/16	54	81	112	166	225
.12	1 7/16	63	90	126	189	256
.13	1 9/16	68	99	144	212	288
.14	1 11/16	76	112	158	238	320
.15	1 13/16	86	126	176	261	356
.16	1 15/16	94	140	194	288	387
.17	2 1/16	104	153	212	315	428
.18	2 3/16	112	166	230	342	464
.19	2 1/4	122	180	248	374	500
.20	2 3/8	130	198	266	400	536
.21	2 1/2	140	212	284	428	576
.22	2 5/8	153	225	306	459	616
.23	2 3/4	162	243	324	490	657
.24	2 7/8	171	256	346	522	698
.25	3	180	274	369	554	742
.26	3 1/8	194	292	387	590	788
.27	3 1/4	202	306	410	621	832
.28	3 3/8	216	324	432	657	878
.29	3 1/2	225	342	459	688	922
.30	3 5/8	238	360	482	724	972
.31	3 3/4	248	378	504	760	1017
.32	3 13/16	261	396	531	796	1066
.33	3 15/16	274	414	554	837	1116
.34	4 1/16	284	432	576	873	1170
.35	4 3/16	297	450	603	909	1220
.36	4 5/16	310	468	630	950	1269
.37	4 7/16	324	486	652	990	1323
.38	4 9/16	333	508	680	1026	1377
.39	4 11/16	346	526	706	1066	1431
.40	4 13/16	360	544	734	1107	1485
.41	4 15/16	374	567	760	1148	1539
.42	5 1/16	387	585	788	1192	1593
.43	5 3/16	400	608	814	1233	1652
.44	5 1/4	414	630	846	1274	1710
.45	5 3/8	432	648	873	1318	1768
.46	5 1/2	446	670	900	1364	1822
.47	5 5/8	459	693	932	1404	1881
.48	5 3/4	472	716	958	1449	1944
.49	5 7/8	486	738	990	1494	2002
.50	6	500	756	1017	1539	2061
.51	6 1/8	518	778	1048	1584	2124
.52	6 1/4	531	801	1080	1629	2187
.53	6 3/8	544	828	1107	1678	2246
.54	6 1/2	562	850	1138	1724	2308
.55	6 5/8	576	873	1170	1773	2372
.56	6 3/4	590	896	1202	1818	2439
.57	6 13/16	608	918	1233	1868	2502
.58	6 15/16	621	940	1264	1917	2565
.59	7 1/16	639	968	1296	1962	2632
.60	7 3/16	652	990	1332	2012	2700
.61	7 5/16	670	1012	1364	2066	2763
.62	7 7/16	684	1040	1395	2110	2830
.63	7 9/16	702	1062	1426	2164	2898
.64	7 11/16	720	1089	1462	2214	2966
.65	7 13/16	734	1112	1494	2264	3038
.66	7 15/16	752	1138	1530	2318	3105
.67	8 1/16	770	1166	1562	2367	3172
.68	8 3/16	783	1188	1602	2421	3244
.69	8 1/4	801	1215	1634	2470	3312
.70	8 3/8	819	1242	1670	2524	3384
.71	8 1/2	837	1264	1701	2578	3456
.72	8 5/8	855	1292	1737	2632	3528
.73	8 3/4	868	1318	1773	2686	3600
.74	8 7/8	886	1346	1809	2740	3676
.75	9	904	1372	1845	2794	3748

may not be satisfactory. As indicated in Figure 6, an electric sounding line may be used. An insulated wire with an exposed end may be let down into the well so that it will ground when it comes in contact with the water. As the circuit is closed, a bell rings. The length of wire then indicates the depth to water. Also a small air line (Fig. 6) of known length may be run down into the well. The end should extend below the surface of the water. Air is forced into the line until the maximum amount of pressure is obtained, as indicated in the gage mounted at the surface end of the line. (Some gages read in feet direct, and others in pounds per square inch. If the reading is in pounds, the necessary corrections should be made. One pound equals 2.31 feet of water.) The gage reading indicates the number of feet of air line that are submerged. By subtracting this from the total length the depth to water is obtained. Drawdown in installations which do not permit the use of these methods is sometimes obtained by means of vacuum gages attached to the suction end of the pump. For more complete discussion of methods of determining drawdown, see Farmers' Bulletin No. 1404.

CASING

Many different kinds of casing are used in well construction. They vary in size, thickness or weight, length of joints, and in the manner in which the different lengths or pieces are connected. Sometimes the pieces are lap jointed and riveted, or they may be butt jointed and riveted together by means of bands. Screw casing may be fastened together by having both parts threaded to screw into a band coupling, or one end of one part may be expanded and threaded inside to receive one end of the next part.

The particular type of casing to select depends on local availability and cost, depth and size of well, and kind of formations encountered.

One type, known as stovepipe or double stovepipe casing, is used under a variety of conditions, but is best adapted to coarse, unconsolidated materials. It is made of 8-gage to 16-gage sheet metal known as hard, red steel, containing a high percentage of carbon. The joints are made in 2-, 3-, and 4-foot lengths with diameters varying from 4 to 36 inches. The vertical seam is lap jointed and single riveted. The joints for each sized casing are made in two sizes so that one piece fits snugly inside the other. Each piece is lapped halfway over the other, so that the stovepipe effect is obtained. The rivets are countersunk in such a manner that there is a smooth contacting surface between the parts. The heavier weights of casing are used in the deeper wells of larger diameter. Irrigation wells of 16-inch diameter or less and up to 250 feet deep are usually cased with 12-gage material. Deeper and larger wells require heavier weights of metal. This casing is usually installed by means of hydraulic jacks, although it is occasionally driven and will stand considerable pressure. It has been used in wells to a depth of several hundred feet. A starter, composed of several sections of casing riveted together and then riveted to a drive shoe, forms the first section to enter the well. In formations where there is danger of the casing pulling apart it is generally riveted together before being sunk. One disadvantage of this casing is that usually it cannot be withdrawn from the well.

Riveted casing, composed of rolled-steel sheets, is made in lengths of from one to two feet. The weight of the metal used depends upon the diameter of the well, and the cost varies accordingly. In the lighter weights it can be made up by local sheet iron works, but in the heavier weights it may be necessary to obtain the material from boiler or sheet iron manufacturers. This casing can be strengthened by the use of collars riveted to each section. Riveted casing, because of its weak construction, will not stand the application of much pressure and should be used in formations offering little resistance. A drive shoe should be used to avoid damaging the end of the casing.

TABLE 5.—RECOMMENDED WELL CASING THICKNESSES FOR SHALLOW WELLS.[1]

U. S. Standard Gage.

Depth of well	Diameter of well casing in inches																
	8	10	12	14	16	18	20	24	26	30	36	42*	48*	54*	60*	66*	72*
20 feet	16	16	16	16	16	16	14	14	14	12	10	16	16	14	12	12	10
30 feet	16	16	16	16	16	14	14	14	14	12	10	16	14	12	12	10	10
40 feet	16	16	16	16	14	14	14	14	12	12	10	14	14	12	10	10	10
50 feet	16	16	16	14	14	14	14	12	12	12	10	14	14	12	10	10	10
60 feet	16	16	14	14	14	14	14	12	12	10	10	12	12	10	10		
70 feet	16	14	14	14	14	14	12	12	10	10	10	12	12	10			
80 feet	14	14	14	14	14	12	12	10	10	10	10	12	12				
90 feet	14	14	14	14	12	12	12	10	10	10	10	12					
100 feet	14	14	14	14	12	12	10	10	10	10	10						
†Band thickness in inches	¼	¼	⅜	⅜	⅜	⅜	⅜	⅜	⅜	⅜	⅜	½	½	½	½	½	½
†Band width in inches	1	1	1½	1½	1½	1½	2	3	3	3	3	3	3	4	5	5	5

*Reinforcing bands placed on inside of casing at 3-foot intervals and on the outside at top and bottom.

†Thickness and width of top and bottom reinforcing bands and intermediate bands for casing over 42 inches in diameter. Gage thickness of casing to be the same for the entire depth of well.

Screw casing, so called because the lengths are fastened together by means of threaded ends or by couplings, is usually made of standard wrought-iron pipe. It can be obtained in various weights. It will stand more severe driving than will the other types. For heavy driving, screw casing made of extra strong material threaded to permit the ends to butt and fastened together by line pipe couplings, should be used, as this kind of joint will withstand more driving than will the

[1]From Colorado Experiment Station Bulletin 415.

inserted joint type. Screw casing has an advantage over the other types in that it can be pulled from the well if necessary. Also, if for any reason it is desirable to withdraw the casing for a few feet, this can be done. This is sometimes necessary in the construction of open-bottom wells or wells in which it is desirable to install a strainer.

PERFORATIONS

Stovepipe, riveted, and screw casings may be perforated after they are placed in the well, although the first two types lend themselves more readily to this operation than does the last one. The advantage of making the perforations after installation is that, where an accurate log of the drilling procedure has been kept, the perforations can be placed opposite the water-bearing formations. A disadvantage is that the openings may not be placed in the proper location, or the openings may not be clear-cut and properly spaced. In some cases an insufficient number of perforations may be made, and on the other hand if they are spaced too close together the casing may be weakened. The maximum amount of perforating depends on the strength of the casing and the size and shape of the openings. It has been stated that as much as 40 percent of the metal can be cut away.

Fig. 9.—Perforated 12-inch casing used in New Mexico Experiment Station Horticultural Farm Well No. 3, drilled in 1935. Perforations are ⅜ inch by 8 inches, and were made with an acetylene torch.

These perforations are made by special tools or knives operated by the well-drilling machinery. There are several different types of perforators on the market, and some of them, naturally, do a better job of making the openings than others. It is always advisable that the well owner see the perforating process before the perforator is lowered into the well. The practice of making the perforations after the casing has been set enables one to take advantage of all the water-bearing strata. Where the exact location and nature of the water-bearing formations are known before drilling begins, it is advisable that the perforations be made before the casing is lowered into the well.

STRAINERS

The purpose of the strainer is to prevent caving in of the well, and to permit the entrance of the water so it can be withdrawn through the suction pipe. Strainers may be located at intervals in the various water-bearing formations or they may be placed only at the bottom of the hole. They may be homemade or obtained from a manufacturer. They may vary as to the size, number, and shape of the holes. Some are wrapped with wire and others with gauze or fine screen.

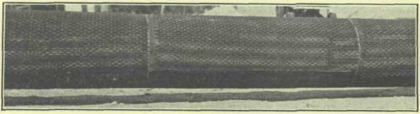

Fig. 10.—Porcher strainer used in New Mexico Experiment Station Irrigation Department Well No. 3, 1935. Perforations are ⅛ inch by 1⅛ inches. Although 40 percent of the material is cut away, the strainer still has adequate strength.

The use of strainers has been confined largely to fine sand formations and in many cases they have proved unsatisfactory because of expense, corrosion, lack of capacity, or failure to keep out the finer materials. On account of these disadvantages and the uncertain results obtained from the use of strainers, wells requiring their use are being replaced by the double casing and gravel screen type of well. Under certain conditions where the water is not too corrosive, the materials to be kept out of the well are not too fine, and where the well has adequate flow, a strainer, if of the proper type, is satisfactory.

DOUBLE CASING WELL

In some localities the double casing or gravel screen type of well is satisfactory. In sinking this type of well a temporary casing, at least six inches and sometimes more in diameter than the desired diameter of the finished well, is used. After the larger casing has been installed the smaller one, well perforated, is lowered and centered in the hole. The space between the two casings is then filled with gravel or crushed stone as the outer casing is withdrawn. This gravel acts as a screen and is often very efficient in permitting easy entrance of the water and in preventing the finer materials from entering the well.

Where this type of installation is made the outer casing should be fastened together, so that it can be withdrawn. Sometimes stovepipe casing of extra large diameter is used for the outside casing. After it has been sunk to the desired depth it is perforated opposite the water strata and left in place. The smaller, perforated casing is then placed inside the larger one and the intervening space filled with gravel. This type of installation is expensive, but it is very efficient in permitting the entrance of water into the well. Also there is little danger of the casing's collapsing and trapping the turbine pump if one is being used, since the outside casing and gravel screen tend to reduce and equalize the pressure on the inside screen.

OPEN-BOTTOM WELL

The open-bottom well, as the name implies, is one in which the bottom of the casing is left open. It is through this opening that the water enters the casing, as a strainer is not used. Special types of stratification are required for this well to be a success. The water-bearing stratum should be overlain with hard, impervious material in which the casing is embedded. The hole through the impervious layer is reduced in size. If the water-bearing formation is of fine sand a large cavity will be made during the developing process, so that water can readily enter the open end of the casing. In case the impervious stratum or roof fails to hold, the casing can be lowered and perforated or a strainer may be installed, thus changing the well into the ordinary type.

PUMPS

Many different kinds and designs of pumps used for irrigation are on the market. The selection of the proper one to install will depend to a certain extent upon the preference of the owner, but in the main this responsibility should be delegated to the manufacturer; that is, the owner should furnish a reliable well which will supply a definite quantity of water with a definite drawdown and a specified total lift. The manufacturer can then select the kind and design of pump which will best meet the given conditions. Pumps, as is true of all other kinds of machinery, vary widely in design, material, and workmanship in accordance with the various policies of the manufacturers. Some manufacturers attempt to turn out a product of high quality, which, of necessity, demands a high price. On the other hand, it is the policy of some concerns to manufacture equipment of lower quality, which can be sold for less money.

Bucket elevators, rotary, plunger, and lift pumps, screw or propeller pumps, horizontal and vertical centrifugal, and turbine pumps are some of the kinds found in irrigation practice. Bucket elevators are seldom used and are not to be generally recommended. The use of rotary pumps in irrigation is limited, on account of their lack of capacity, their inability to handle water efficiently if it contains any considerable quantity of abrasive material, and their not being adapted to deep well pumping. The pump derives its name from the rotating motion of its gear-like impellers. Because of the close-fitting case, it is capable of developing greater suction than the centrifugal pump. It is very efficient when it is tight and in good condition, but after it becomes worn the efficiency decreases rapidly.

Plunger pumps find their greatest use in lifting small quantities of water through high heads. When they are in good condition their efficiency is high, but it soon diminishes if sand or other abrasive material is present to any appreciable extent

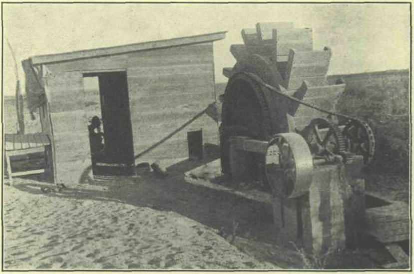

Fig. 11.—Homemade low-lift water wheel used for elevating a large quantity of water through a short distance. The wheel may be propelled by engine or motor.

in the water pumped. Their use is generally confined to the irrigation of small tracts of high-priced crops, and to places where the water is found at considerable depth.

Air lift pumps gain favor through their lack of moving parts in the water. A power plant is needed the same as with other pumps. Also, means of compressing air and delivering it into the well are necessary. Approximately two thirds of the air line, depending upon the conditions of discharge and lift, should be submerged in the water while pumping. This requirement alone limits the conditions under which this pump will successfully operate, as most irrigation wells do not have the required depth of water. The air is carried down into the well in a small pipe, from which it is discharged into the eductor pipe, thus bringing about the discharge of water from the well. This type of pump is capable of delivering more water from a well of given size than are other kinds of pumps, but the efficiency is usually low. Since there are no moving parts in the well and since the discharge is easily controlled, this type is especially adapted to developing wells. The sand and other abrasive material removed with the water have no detrimental effects on the pump.

Propeller or screw-type pumps are made for both high and low lifts. There are two classes of the low lift pumps: those with the horizontal drive shaft and those with the vertical. The horizontal is used for lifting large quantities of water through a short distance, while the vertical type is adapted to raising small amounts of water to a height of only a very few feet. These pumps in some instances are very crudely built and have low efficiencies.

The high lift or deep well type is a combination of several low lift pumps mounted on a vertical shaft, in a pipe column. This pump is usually assembled in sections of about six feet each, containing two screws. Spider frames are mounted between the screws to decrease the whirling motion of the water and direct it into the same plane as the pipe column. In case it is desired to pump against a head at the surface, a series of screws is mounted in the bottom of the pump, since the lift of each screw is limited to about 3 feet. The principal advantage of this type is that since it is built up in short sections it can be adjusted to meet the conditions of a fluctuating water table. On the other hand, the pump is likely to be operated when in need of repairs, since the moving parts are in the well, and as repairing worn parts is a difficult task, it is frequently delayed until the efficiency has been greatly decreased.

Centrifugal pumps, as commonly known, are of two types, namely the horizontal and the vertical. The horizontal derives its name from the fact that the drive shaft lies in a horizontal plane. Power may be applied through a belt and pulley, or in the case of an electric motor, and occasionally with certain types of engines, it may be directly connected to the shaft. This pump may be obtained with either single or side suction, or with double suction. In the latter type, hydraulic balance is obtained automatically but in the former some special mechanical device is necessary to bring this about. Since these pumps cannot be operated under water, they should be installed in New Mexico only where the drawdown and suction lift will not exceed about 15 feet. Where the depth to water and drawdown are more than 15 feet or so it is necessary that a pit be constructed at or near the water level. In case a belt drive is to be used, the maximum practical depth for the pit is about 15 feet. It is necessary that arrangements be made for priming these pumps, since as stated above, they will not operate under water. This can be done by filling the suction pipe with water up to the center of the pump or by withdrawing the air from the pump and suction pipe and allowing them to fill with water from the well.

This type of pump is the most satisfactory for the conditions to which it is adapted. It has few parts to adjust or get out of order, is simple and easy to operate, convenient for repairing, not expensive, has a high efficiency, and is adapted to a wide variety of conditions of discharge and head.

The vertical centrifugal type is so called because the drive shaft is mounted in a vertical position. It can be obtained, as can the horizontal type, with open or closed impellers. It is usually installed where a pit is needed. The pump is installed below water level, so that priming is not necessary. With this pump a vertical drive shaft extends to the ground surface, where belted power can be applied. One disadvantage, especially where long drive shafts are used, is that a rigid frame to support the shaft bearings is necessary, as a whipping shaft is a continuous source of trouble. The bowls on some models of these pumps have been so reduced in diameter that they can be installed in the larger casings. The vertical centrifugal pump, however, is being replaced by the deep well centrifugal turbine type.

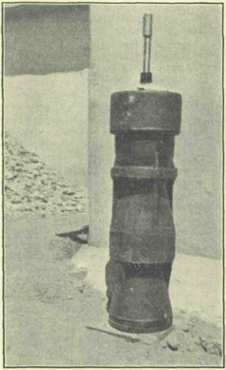

Fig. 12.—Single-stage turbine pump installed in Horticultural Farm Well No. 3, State College, N. M.

The deep well turbine pump operates on the principle of centrifugal force and is sometimes called a centrifugal pump. The drive shaft is vertical. The bowls have been reduced in diameter in some models so that they will operate inside a 4-inch casing. Reducing the bowl diameter has necessitated the sacrifice of some of the better characteristics of the other centrifugal types. This pump is usually installed at, near, or below the pumping water level and priming is not necessary. A sufficient number of bowls are grouped together at the bottom of the assembly to provide the necessary lifting power. Ordinarily, each bowl or stage is capable of lifting the water about 20 or 25 feet.

Power can be applied either direct to the shaft or through a belt and pulley; sometimes geared heads are used. By reason of the fact that this type of pump is driven with a long shaft, considerable difficulty has been encountered in making the proper design to withstand wear and whipping and to maintain alignment. Open bearings, wood liners, rubber bearings or bumpers, and enclosed metallic bearings of different materials and designs have been used in an effort to find the most satisfactory arrangement. Lubrication is accomplished by several methods. Sometimes the shaft housing is packed with grease at the time of installation. Occasionally a hollow shaft is used to facilitate oiling and in other cases oil is conducted to the working parts through the drive-shaft housing. Since the bottom bearing is of such great importance, a separate oil line is sometimes run down the outside of the pump to it. One of the chief disadvantages of the turbine pump is that the moving parts are encased in the well and are difficult to get to when repairs should be made. The result is that they will frequently be operated after they are in need of overhauling.

Fig. 13.—Well pit with concrete curbing extending to water level.

INSTALLATION

Proper installation of the pumping plant is one of its most important features. This is as true of the well as it is of the pump and power system. As has been previously mentioned, the well should be straight and vertical, of the correct diameter, drilled and cased in such a manner that the free flow of water from the water-bearing strata has not been hindered, and developed so that the maximum or necessary flow can be obtained.

Where a pit is to be used it should be properly curbed, preferably with concrete, since this is comparatively cheap and is strong and durable. It should be large enough to permit of the machinery's being readily installed. The foundations for the pump and power plant should be strong, heavy, level, and of proper size, so the machinery can be securely anchored. When the base to the foundation is bolted, care should be exercised to prevent straining of the frame, as the working parts may be thrown out of alignment. In mounting both the pump and power plant, one should follow the recommendations of the manufacturer. Pumps properly set and aligned will be practically free of vibration. In installing a turbine pump it should be lowered gently into the casing. It should never be forced past an obstruction or through a crooked casing, as it may be thrown into a cramp or bind, a condition which would disalign the working parts and cause unsatisfactory operation. The turbine pump properly installed will be suspended freely from the foundation.

All piping for the different types of pumps should line up naturally. It should never be forced, as damage may result. In case threads have been damaged, the necessary remedial measure should be taken before an attempt is made to connect the parts. In order that the friction losses may be decreased,

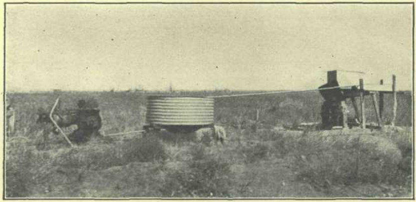

Fig. 14.—An extremely expensive method of providing the power plant with cool water.

the suction and discharge pipes should be from one to two sizes larger than the pump connections. It is recommended that the suction lift be not over 15 feet, although the lifts are occasionally slightly higher. If a foot valve is used its net area should be equal to, and preferably larger than, that of the pipe. Ninety-degree elbows, 8 to 10 inches in diameter, have the same friction loss as about 40 feet of the same sized pipe. Where practicable, it is desirable that the elbows be of the long sweep type.

If a belt is to be used the driver and driven pulleys should be correctly aligned, possess the proper ratio as to size, and be sufficiently far apart to permit of the machinery's being operated without undue belt tightness, which may damage both the belt and the bearings.

The cooling system, where possible, should be of the tank type, as less energy will be used than if the water is circulated

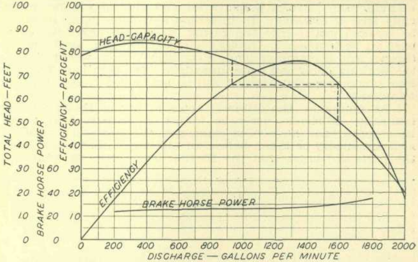

Fig. 15.—The highest 10 percent of the efficiency occurs over a discharge range of 670 gallons a minute and a lift of 26 feet. This design would probably be suitable where the lift is practically constant.

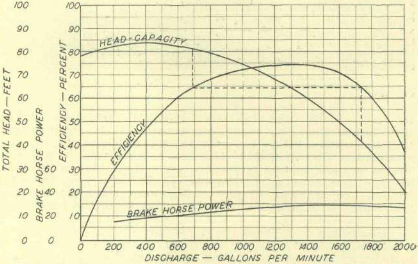

Fig. 16.—The highest 10 percent of the efficiency occurs over a discharge range of 1055 gallons a minute and a lift of 40 feet. This design would probably be suitable where there is or may be considerable variation in the lift.

direct from the well. The practice of raising the discharge to sufficient height to provide circulation through the engine should be avoided, as it is an extremely expensive operation. For example, if 80 acre-feet of water are required per season for a farm and the cost is 10 cents per acre-foot for each foot of lift, and if the water is raised to a point 5 feet higher than necessary, the seasonal cost for cooling water will be 80 x 5 x 10 cents or $40.00.

EFFICIENCY

The efficiency of any piece of machinery may be defined as the ratio between the work accomplished and the energy applied. Naturally, there are many bases of calculation. In considering pumps, the efficiency is the ratio between the water horsepower and the horsepower applied to the pump.

The efficiency of the pump to be installed is one of its most important features and should be carefully considered, since the successful and economical operation of the pump is dependent to a large extent upon this one factor. As has been previously mentioned, the centrifugal pumps are designed to perform certain work, under more or less definite and specific conditions. A pump low in efficiency, other factors being equal, will require more power to deliver the same amount of water, or will deliver less water with the same amount of power, than one of greater efficiency. In other words, the operation of pumps low in efficiency results in extra operating expense to the user.

When a pump is described as being "highly efficient" it does not necessarily indicate that it will hold this efficiency over a wide range of heads or lifts. A particular design and combination of bowls and impellers will give the maximum performance under definite conditions. If the head is increased or decreased from the definite point, the efficiency will be decreased. However, as the pumping level rises, the discharge will increase until the capacity of the bowls is reached; and conversely, as the pumping level lowers, the flow decreases.

Some pumps are designed so that they drop off or decrease in efficiency very rapidly from their point or peak of maximum efficiency when a change of head or speed is encountered, while others change in efficiency more slowly if the working conditions are altered.

The performance curve of the first would be sharp or steep, while that of the second would be more gradual and might be termed "flat." (See Figs. 15 and 16.) Although the pump with the sharp curve may reach a higher efficiency, it is not necessarily the one that should be selected, unless it otherwise is capable of performing the task. An ideal condition might exist for this type where there is a constant, unchanging lift. The pump with the flat performance curve is usually more desirable for most applications, even though its maximum point may not be as high, because practically all wells have some seasonal or long-time variation in water level. The flat curve pump will usually meet the conditions of a receding water level to better advantage than will the sharp curve pump. With a new installation of modern equipment it should be possible, in the majority of cases, to obtain a pump with an efficiency of at least 65 percent, while in some instances the efficiency may be as great as 75 percent.

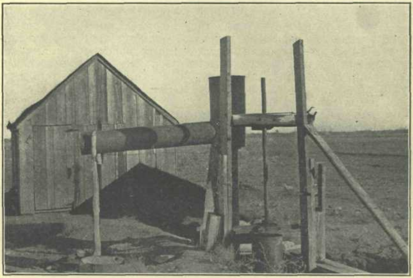

Fig. 17.—Discharge pipes installed in this manner are contributing causes to pumping plant failures.

Generally speaking, the smaller pumps, of the centrifugal type, are lower in efficiency than are the larger sizes. Also, pumps installed in the field and operated by unskilled mechanicians seldom give the efficiencies indicated by the manufacturers. These low efficiencies may be caused by the fact that the well owner did not provide the manufacturer with sufficient accurate information to enable him to select the proper pump; or the seller may have made the wrong selection through carelessness or ignorance. Bearings or other parts, which may be worn or are in need of repair, will decrease the efficiency. The use of pipe which is too small, or has sharp and unnecessary bends in the pipe line, improper speed of pump, and too long a suction pipe, or air leaks, may lower the efficiency of the pumping plant.

The plant efficiency refers to the performance of the entire installation. The selection of too large a power plant will cause the use of more fuel than is actually necessary to perform the work; the selection of an extra large pump will decrease the seasonal efficiency of the plant. If a belt that is too narrow is being used, or if the pulleys are too small there may be considerable belt slippage with a resultant loss in power and pump speed. The practice of installing the discharge

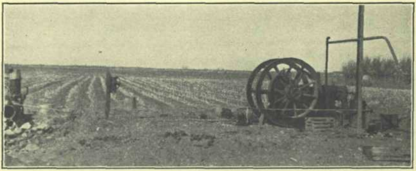

Fig. 18.—The appearance of this plant indicates a high efficiency, both as to operation and management.

pipe at too high a level decreases the plant efficiency and increases expenses for operation. Foul spark plugs, leaky piston rings and valves, or any other worn parts all play an important role in the economical operation of the pumping plant. Theoretically, it appears entirely feasible and possible to make an installation with an over-all efficiency of 55 to 65 percent, but actual field tests show that the majority of plants are

Fig. 19.—The reservoir, as well as the pumping plant, should be properly maintained, in order that the best use of the water may be secured.

operating at a far lower efficiency, which usually could be greatly improved by correct maintenance and care.

It should be remembered that each centrifugal type of pump is built to meet certain specific conditions. If one attempts to lift water with a pump not built and designed for his specific conditions as to total head, discharge, and speed, the efficiency of the plant will be lower than it should be, with consequent greater cost for operation than if the plant were correctly designed, installed, and operated.

POWER

The kind of power plant to select deserves serious consideration, as it depends directly or indirectly on the individual

Fig. 20.—One of the many types of power plant which can be found in some pump irrigation localities. The efficiency of the plant is probably not high.

preference of the owner and operator, the volume of water to be pumped, the acreage of land to be irrigated, the kind of crops to be grown, the nature of the soil, the frequency of irrigation, and the costs of machinery and fuel or electricity.

Tractors, stationary and portable gas engines, new and made-over automobile engines, kerosene and oil engines, and electric motors are all used to furnish power for operating irrigation pumps.

Tractor or any other temporary power is sometimes suitable where the pump is to be run only a small part of the time. With this type of setup the efficiency will probably be low, but the final water cost will be less than if an expensive power plant is installed and operated for the same length of time. Gasoline engines are usually an advantage, in that they represent a fairly low investment, but the operating expense may be rather high. Maintenance, repair, and operator costs for this type of machinery are higher than for some of the other power plants.

Oil, distillate, and similar engines usually represent lower operating costs but the purchase price is generally considerably higher; consequently, it is important that these types, especially, be operated a large percentage of the time, in order to decrease the fixed charges, per unit of water pumped.

Electric motors present the most suitable power insofar as the mechanical operation and care are concerned, as they require practically no attention. The installation cost is reasonable, but the cost for electricity is, in many cases, so high that the use of this type of power is out of the question. In estimating the size of motor to purchase, one can figure on the basis of rated horsepower. A slight overload at times may not be a disadvantage, but the aim should be not to overheat the

TABLE 6.—HORSEPOWER REQUIRED TO LIFT DIFFERENT QUANTITIES OF WATER TO ELEVATIONS OF 10 TO 300 FEET.
(Efficiency of pumping plant 50 percent of theoretical. Use for estimating only.)

Gallons per minute	Cubic feet per second	Horsepower required for elevations of—							
		10 feet	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet
100	0.22	0.50	1.01	1.52	2.02	2.53	3.03	3.54	4.04
150	.33	.76	1.52	2.27	3.03	3.79	4.55	5.30	6.06
200	.45	1.01	2.02	3.03	4.04	5.05	6.06	7.07	8.08
250	.56	1.26	2.53	3.79	5.05	6.31	7.58	8.84	10.10
300	.67	1.52	3.03	4.55	6.06	7.58	9.09	10.61	12.12
350	.78	1.77	3.54	5.30	7.07	8.84	10.61	12.37	14.14
400	.89	2.02	4.04	6.06	8.08	10.10	12.12	14.14	16.16
450	1.00	2.27	4.55	6.82	9.09	11.36	13.64	15.91	18.18
500	1.11	2.53	5.05	7.58	10.10	12.63	15.15	17.68	20.20
600	1.34	3.03	6.06	9.09	12.12	15.15	18.18	21.21	24.24
700	1.56	3.54	7.07	10.61	14.14	17.68	21.21	24.75	28.28
800	1.78	4.04	8.08	12.12	16.16	20.20	24.24	28.28	32.32
900	2.01	4.55	9.09	13.64	18.18	22.73	27.27	31.82	36.36
1,000	2.23	5.05	10.10	15.15	20.20	25.25	30.30	35.35	40.40
1,250	2.78	6.31	12.63	18.94	25.25	31.57	37.88	44.19	50.50
1,500	3.34	7.58	15.15	22.73	30.30	37.88	45.45	53.03	60.61

Gallons per minute	Cubic feet per second	Horsepower required for elevations of—							
		90 feet	100 feet	125 feet	150 feet	175 feet	200 feet	250 feet	300 feet
100	0.22	4.55	5.05	6.31	7.58	8.84	10.10	12.63	15.15
150	.33	6.82	7.58	9.47	11.36	13.26	15.15	18.94	22.73
200	.45	9.09	10.10	12.63	15.15	17.68	20.20	25.25	30.30
250	.56	11.36	12.63	15.78	18.94	22.10	25.25	31.57	37.88
300	.67	13.64	15.15	18.94	22.73	26.52	30.30	37.88	45.45
350	.78	15.91	17.68	22.10	26.52	30.93	35.35	44.19	53.03
400	.89	18.18	20.20	25.25	30.30	35.35	40.40	50.51	60.61
450	1.00	20.45	22.73	28.41	34.09	39.77	45.45	56.82	68.18
500	1.11	22.73	25.25	31.57	37.88	44.19	50.51	63.13	75.76
600	1.34	27.27	30.30	37.88	45.45	53.03	60.61	75.76	90.91
700	1.56	31.82	35.35	44.19	53.03	61.87	70.71	88.38	106.06
800	1.78	36.36	40.40	50.51	60.61	70.71	80.81	101.01	121.21
900	2.01	40.91	45.45	56.82	68.18	79.55	90.91	113.64	136.36
1,000	2.23	45.45	50.51	63.13	75.76	88.38	101.01	126.26	151.52
1,250	2.78	56.82	63.13	78.91	94.70	110.48	126.26	157.83	189.39
1,500	3.34	68.18	75.76	94.70	113.64	132.58	151.52	189.39	227.27

motor. This should be considered in making the installation, as adequate ventilation should be provided. The maximum summer temperatures should also be taken into consideration, as the motor should not be run with the windings subjected to temperatures greater than 190° F. Hot summer air does not cool the motor to so great an extent as does the cooler air of other seasons.

In estimating the size of power plant needed, it is advisable to make an allowance for about 10 percent overload. The power is computed in terms of horsepower. Theoretically, one horsepower is equal to the energy required to lift 33,000 pounds through a vertical distance of one foot in one minute of time. Thus, 500 gallons per minute with a total head of 40 feet, including lift, friction, etc., would require 500 (g.p.m.) x 8.33 (pounds per gallon) x 40 (feet lift) ÷ 33,000 (1 horsepower) = 5 horsepower. Assuming the plant to be 50 percent efficient, the requirement would be 10 horsepower. The actual power required will be considerably in excess of the theoretical amount, because the final installation will not be 100 percent efficient. The over-all pumping plant efficiency may be somewhere in the neighborhood of 50 percent. Tests have shown that some plants may operate at 20 or 25 percent efficiency and others at 60 or 65 percent. The manner of connecting the power plant and pipe friction and other losses affect the efficiency, and care should be taken to adopt the best possible practices in all instances. Table 6, taken from Farmers' Bulletin 1404 of the United States Department of Agriculture, shows the horsepower requirements under specified conditions.

Since small plants are generally less efficient in the use of power than the larger ones, extra allowance should be made in calculating the horsepower required. Table 7 shows results obtained from a survey covering a large number of belt-connected plants and will be of assistance in making the power

TABLE 7.—SHOWING GALLONS OF GASOLINE, DISTILLATE, OR CRUDE OIL USED, UNDER AVERAGE FARM PRACTICE, TO LIFT ONE ACRE-FOOT OF WATER ONE FOOT HIGH.*

Horsepower	Engine belted to a centrifugal pump		Engine belted to a deep well pump	
	Gallons	Efficiency of plant	Gallons	Efficiency of plant
2	1.14	.15	1.8	.10
3	.94	.18	1.2	.15
4	.83	.20	.91	.19
5	.76	.23	.79	.22
6	.70	.26	.70	.25
7	.66	.27	.63	.27
8	.62	.28	.58	.30
10	.58	.29	.53	.33
12	.57	.30	.49	.35
15	.55	.31	.45	.38
20	.51	.34	.40	.43
25	.48	.36	.36	.48
30	.45	.38	.33	.52
35	.42	.41	.29	.60

*From Washington Extension Service Bulletin No. 103.

estimates. Direct-connected plants should be about 10 percent higher in efficiency, which would reduce the fuel requirements.

Power consumption for installations permitting the use of direct-connected electric motors on centrifugal or turbine pumps can be estimated from Table 8, which shows current requirements of different sized plants and different efficiencies.

TABLE 8.—SHOWING KILOWATT-HOURS OF ELECTRIC CURRENT USED UNDER FARM CONDITIONS TO PUMP ONE ACRE-FOOT OF WATER ONE FOOT HIGH.*

Horsepower	Kilowatt-hours	Efficiency of plant
2.5	3.25	.31
5	2.85	.35
7.5	2.50	.40
10	2.35	.42
15	2.20	.45
20	2.05	.49
25	1.90	.52
30	1.80	.55
35	1.70	.59
40	1.65	.60
50	1.60	.62

*From Washington Extension Service Bulletin No. 103.

TABLE 9.—NUMBER OF KILOWATT-HOURS REQUIRED TO PUMP DIFFERENT AMOUNTS OF IRRIGATION WATER UNDER VARIOUS CONDITIONS.*

Annual acre-feet for farm	Over-all efficiency of pumping plant											
	40 percent				50 percent				60 percent			
	Lift in feet				Lift in feet				Lift in feet			
	1	5	10	50	1	5	10	50	1	5	10	50
5	13	64	128	641	10	51	103	513	9	43	86	428
10	26	128	256	1282	21	103	205	1026	17	86	171	858
25	64	320	641	3205	51	256	513	2565	43	214	428	2138
50	128	641	1282	6410	103	513	1026	5130	86	428	855	4275
100	256	1282	2564	12820	205	1026	2052	10260	171	855	1710	8550
150	385	1923	3846	19230	308	1539	3078	15390	256	1282	2565	12825
200	513	2564	5128	25640	410	2052	4104	20520	342	1710	3420	17100
300	769	3846	7692	38460	616	3078	6156	30780	513	2565	5130	25650

*Theoretically, 1.02575 kilowatt-hours are required to lift one acre-foot of water one foot high. At 40 percent efficiency, 2.564 kilowatt-hours are required to lift one acre-foot of water one foot high; at 50 percent, 2.052 kilowatt-hours; and at 60 percent, 1.71 kilowatt-hours are required.

Table 9 should be used for estimating purposes only. As an example, if a farm contains 100 acres to be irrigated with a pump that is operating at 60 percent efficiency and the lift is 50 feet, with an average consumption of 3 acre-feet per acre, the total annual amount used would be 300 acre-feet. The annual current consumption would be 25650 kilowatt-hours, as shown in the table by reading down in the left-hand column to 300 acre-feet, then reading to the right under 60 percent efficiency and a 50-foot lift. In case 250 acre-feet of water are used, the current consumed can be found by adding the amounts for 200 acre-feet and 50 acre-feet for the efficiency and lift of the particular condition. For a 40-foot lift the current can be estimated by subtracting the amount for a 10-foot

TABLE 10.—LOSS OF HEAD, IN FEET, DUE TO FRICTION IN VARIOUS SIZES OF SMOOTH, STRAIGHT CAST IRON PIPE FOR EVERY 100 FEET USED. THE FRICTION LOSSES ON WOOD PIPE WILL BE LESS THAN THOSE GIVEN IN THIS TABLE.*

Gal. per Min.	¾ In.	1 In.	1¼ In.	1½ In.	2 In.	2½ In.	3 In.	3½ In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	10 In.	12 In.
5	7.6	1.9	.71	.27	.09	.05	.01	---	---	---	---	---	---	---	---	---
10	29.9	7.3	1.4	1.0	.28	.09	.05	.01	---	---	---	---	---	---	---	---
15	66.0	16.1	5.5	2.2	.57	.18	.09	.05	.02	---	---	---	---	---	---	---
20	115.	28.0	9.5	4.8	.96	.32	.13	.07	.03	.01	---	---	---	---	---	---
25	179.	43.7	14.7	6.0	1.7	.48	.23	.09	.05	.02	.01	---	---	---	---	---
30	264.	63.2	21.0	8.6	2.1	.69	.30	.14	.07	.03	.01	---	---	---	---	---
35	372.	85.1	28.9	11.6	2.7	.92	.39	.20	.11	.04	.02	---	---	---	---	---
40	461.	110.	37.0	14.9	3.7	1.2	.53	.25	.14	.05	.02	---	---	---	---	---
45	594.	145.	46.5	18.7	4.6	1.5	.64	.32	.16	.07	.02	---	---	---	---	---
50	----	185.	57.3	23.0	5.6	1.9	.80	.39	.20	.09	.03	.01	.01	---	---	---
60	----	253.	82.8	32.2	8.0	2.7	1.2	.55	.30	.11	.05	.01	.01	---	---	---
70	----	340.	116.	46.0	11.0	3.5	1.4	.87	.44	.16	.06	.02	.01	---	---	---
75	----	393.	129.	51.4	12.2	4.1	1.7	.90	.48	.17	.07	.02	.02	---	---	---
80	----	442.	147.	57.5	14.5	4.6	2.0	.93	.53	.18	.07	.03	.02	---	---	---
90	----	580.	184.	73.6	17.9	5.9	2.5	1.1	.60	.21	.09	.04	.02	---	---	---
100	----	----	228.	89.7	21.7	7.3	2.9	1.5	.74	.27	.11	.05	.03	.01	.01	---
125	----	----	367.	150.	34.3	10.0	4.6	2.1	1.2	.39	.16	.07	.04	.02	.01	---
150	----	----	516.	207.	48.8	16.1	6.5	3.1	1.6	.57	.23	.09	.06	.03	.02	.01
175	----	----	----	294.	64.6	21.7	8.6	4.2	2.1	.78	.30	.11	.07	.04	.03	.01
200	----	----	----	359.	86.2	28.6	11.5	5.4	2.8	.96	.39	.16	.10	.05	.04	.02
250	----	----	----	600.	137.	41.7	17.7	8.5	4.3	1.5	.60	.28	.15	.09	.05	.02
300	----	----	----	----	195.	64.4	25.7	11.5	6.2	2.1	.85	.39	.21	.11	.07	.03
350	----	----	----	----	258.	86.8	34.9	16.3	8.4	2.9	1.1	.53	.28	.16	.10	.04
400	----	----	----	----	345.	114.	44.9	21.3	10.9	3.7	1.5	.69	.37	.21	.13	.05
450	----	----	----	----	439.	145.	57.5	26.9	13.8	4.6	1.8	.85	.43	.25	.15	.06
500	----	----	----	----	549.	167.	70.8	33.4	17.1	5.5	2.3	1.0	.56	.32	.20	.08
750	----	----	----	----	----	375.	159.	76.5	38.7	13.5	5.1	2.3	1.4	.69	.41	.18
1000	----	----	----	----	----	670.	283.	134.	68.4	22.0	9.0	4.1	2.2	1.2	.73	.30
1250	----	----	----	----	----	----	442.	212.	107.	37.5	13.8	6.6	3.7	1.9	1.1	.46
1500	----	----	----	----	----	----	637.	301.	154.	49.5	19.8	10.4	5.0	2.7	1.6	.66
1800	----	----	----	----	----	----	----	430.	220.	73.6	28.8	13.6	6.9	4.0	2.3	.94
2000	----	----	----	----	----	----	----	534.	273.	88.	35.6	16.4	8.5	4.8	2.8	1.2
3000	----	----	----	----	----	----	----	----	615.	198.	81.	36.9	19.8	10.8	6.3	2.6

To find friction loss in pounds, multiply figures by 0.434.

Figures given are for clean, straight pipe and do not allow for friction in elbows or short bends. If many short radius elbows are used they should be taken into account in making calculation.

*From Washington Extension Service Bulletin 103.

lift from the amount for a 50-foot lift, or by multiplying the amount for a 10-foot lift by 4. In case the efficiency is 55 percent, the current consumption can be estimated by averaging the amounts for 50 percent and 60 percent. The seasonal cost of the current will depend on the local rate and method of making the charges. If payment is to be made by the month, the monthly consumption should be assumed and the minimum or demand charges should be considered.

SUMMARY AND SUGGESTIONS

1. Anyone contemplating the installation of a pumping plant should inspect other plants and attempt to learn the good and bad points of each setup.
2. A thorough investigation should be made to determine if the pumping enterprise is economically sound.
3. Soils that are capable of producing good or high yields of marketable crops should be selected.
4. An adequate supply of suitable water which can be obtained within a reasonable pumping lift is essential. It is usually advisable to drill a test hole in order that the soil and water conditions may be determined.
5. A capable and reputable well driller with considerable local experience should be employed for drilling the well.
6. The well should be sufficiently large to accommodate the pumping equipment if a turbine pump is to be used.
7. The plant should be only large enough to provide an adequate supply of water for the area to be irrigated. Continuous operation of the plant tends to reduce the cost per unit volume of water.
8. The pump and power plant should not be selected and purchased until the well has been developed and thoroughly tested.
9. When the power requirements and pump performance are being estimated, the depth to water, drawdown, friction in all pipes and elbows, and entrance and discharge losses should be considered.
10. If a pump or plant is purchased with guaranteed performance it should be tested after it is installed, to determine if the setup is meeting the guarantee.
11. When the pumping machinery is being installed, the instructions of the manufacturer should be followed, in order that satisfactory operation may be assured.
12. Pipe sizes should be such that the velocity of the water will not exceed 4 or 5 feet a second.
13. All working parts should be kept in good repair at all times, as this aids materially in maintaining efficiency and decreases the operation costs.
14. Occasional tests should be made to determine if the efficiency of the plant is what it should be.
15. Small plants are usually less efficient than larger ones.

16. An attempt should be made to standardize on the pumping equipment in any given locality, as this would facilitate purchases, installation, and repairs.

17. A reservoir, when constructed under the proper conditions, may prove to be a distinct advantage.

18. In order that the amount of water required may be reduced to a minimum, the field should be properly prepared for irrigating; the runs should be of the correct length; the most satisfactory method of irrigating should be practiced; distribution ditches should be of the right size and properly laid out; and the person who does the irrigating should be skilled in the handling of water.

19. One of the important advantages of the use of pumped water will be lost if noxious weeds, such as Johnson grass and wild morning-glory, are permitted to get a foothold and spread over the irrigated land. While often the expense of keeping these pests off pump-irrigated areas is very small, it may be found impracticable to eradicate them, or even keep them under control, after they are once well established. Johnson grass makes a fair quality of hay but it is not probable that it would pay to raise it with pumped water anywhere in New Mexico.

APPENDIX

CHAPTER 131, Session Laws of 1931, and CHAPTER 122, Session Laws of 1933, Relating to Underground Water Laws.

Be It Enacted by the Legislature of the State of New Mexico:

Section 1. The waters of underground streams, channels, artesian basins, reservoirs, or lakes, having reasonably ascertainable boundaries, are hereby declared to be public waters and to belong to the public and to be subject to appropriation for beneficial use.

Sec. 2. Beneficial use is the basis, the measure and the limit to the right to the use of the waters described in this act.

Sec. 3. Any person, firm or corporation desiring to appropriate for irrigation or industrial uses any of the waters described in this act shall make application to the State Engineer in a form to be prescribed by him in which said applicant shall designate the particular underground stream, channel, artesian basin, reservoir or lake from which water is proposed to be appropriated, the beneficial use to which it is proposed to apply such water, the location of the proposed well, the name of the owner of the land on which such well will be located, the amount of water applied for, the use for which it is desired and if the proposed use is irrigation, the description of the land to be irrigated and the name of the owner thereof.

Upon the filing of such application the State Engineer shall cause to be published in a newspaper of general circulation in the county wherein the proposed well will be located, for at least once a week for three consecutive weeks, a notice of the filing of such application, and that objections to the granting thereof may be filed within ten days after the last publication of said notice.

After the expiration of the time for filing objections, if no such objections shall have been filed, the State Engineer shall, if he finds that there are in such underground stream, channel, artesian basin, reservoir or lake, unappropriated waters, grant the said application and issue a permit to the applicant to appropriate all or a part of the waters applied for subject to the rights of all prior appropriators from said source.

If objection or protest shall have been filed within the time in said notice specified the State Engineer shall set a date for a hearing on the application and the objections or protest thereto, and shall notify the applicant and the objectors or protestants thereof. Such hearing shall be held in the courthouse of the county in which the proposed well will be located. If after such hearing it shall appear that there are no unappropriated waters in the designated source, or that the proposed appropriation would impair existing water rights from such source, the application shall be denied.

Sec. 4. Existing water rights based upon application to beneficial use are hereby recognized. Nothing herein contained is intended to impair the same or to disturb the priorities thereof.

Sec. 5. Any person, firm or corporation claiming to be the owner of a vested water right from any of the underground sources in this act described, by application of waters therefrom to beneficial use, may make and file in the office of the State Engineer a declaration in a form to be prescribed by the State Engineer setting forth the beneficial use to which said water has been applied, the date of first application to beneficial use, the continuity thereof, the location of the well and if such water has been used for irrigation purposes, the description of the land upon which such water has been so used and the name of the owner thereof. Such declaration shall be verified but if the declarant cannot verify the same of his own personal knowledge he may do so on information and belief. Such declarations so filed shall be recorded at length in the office of the State Engineer and may also be recorded in the office of the County Clerk of the county wherein the well therein described is located. Such records or copies thereof officially certified shall be prima facie evidence of the truth of their contents.

Sec. 6. Declarations heretofore filed in substantial compliance with Section 5 hereof shall be recognized as of the same force and effect as if filed after the taking effect of this act.

Sec. 7. The owner of a water right may change the location of his well or change the use of the water but only upon application to the State Engineer and upon showing that such change or changes will not impair existing rights and to be granted only after such advertisement and hearing as are prescribed in the case of original applications.

Sec. 8. When for a period of four years the owner of a water right in any of the waters described in this act shall have failed to apply the same to the use for which the right has vested, was appropriated or shall have been adjudicated, such water right shall be forfeited and the water so unused shall revert to the public and be subject to further appropriation.

Sec. 9. Upon the taking effect of this act, the State Engineer shall, by regulations, establish the fees to be paid by applicants and declarants, which fees shall not exceed the reasonable cost of the service to be performed by the State Engineer, and the applicant shall pay to the publisher the cost of the necessary advertising, and before ordering any hearing the State Engineer shall require the applicant and protestant, or protestants, to each deposit with him a sum equal to the estimated cost of the hearing and, after the decision, the State Engineer shall refund to the prevailing party or parties the sum so deposited by him or them and shall refund to the losing person or persons any unused portion of the moneys deposited by them. All fees collected under the provisions of this act shall be deposited with the State Treasurer and by him covered into the "Underground Water Fund" to be withdrawn by the State Engineer, upon vouchers properly audited, for the purpose of administering this Act.

Sec. 10. The decision of the State Engineer shall be final in all cases unless appeal be taken to the District Court within thirty days after his decision as provided by Section 151-173 of the 1929 New Mexico Statutes Annotated.

Sec. 11. The State Engineer is hereby given the power and it is made his duty to formulate rules and regulations for the purpose of carrying out the provisions of Act, which rules and regulations shall be printed and made available for distribution to all applicants.

Sec. 12. That Article 2 of Chapter 151, New Mexico Statutes Annotated, 1929 Compilation, be and the same is hereby repealed.

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