MOTOR DRIVEN IRRIGATION
PUMPING PLANTS AND
THE ELECTRICAL DISTRICT

By G. E. P. Smith

Three thousand gallons a minute from one well in Maricopa County—enough for
the irrigation of 500 acres of land, but a waste of power in lifting water sev-
eral feet needlessly.
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MOTOR DRIVEN IRRIGATION
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By G. E. P. Smith
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COOPERATIVE PUMPING

ILLUSTRATIONS

Pumping Plant in the Agua Fria Valley, showing weir box for measurement of flow.

Fig. 1—Discharge outlet of pumping plant in Santa Cruz County, and weir box for measurement of flow.

Fig. 2—Map of Pinal County Electrical District No. 2, showing depths to water table.

Fig. 3—"Act" of reclamation by pumping, the arrival of the well rig.

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Table II. Number of acres of winter crops required to utilize minimum monthly charge of $1.00 per kv.-a., with rate of 2.25 cents per kw.-hr.

Table III. Water horsepower required for various discharges and lifts.

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Table V. Pipe sizes for discharge columns.

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Table VII. Approximate weights and retail prices of three-phase, horizontal, squirrel-cage motors, complete.

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Table IX. Approximate amperes per terminal of three-phase motors at full load.

Table X. Sizes, weights, and carrying capacities of copper wires, bare and rubber-insulated.
Fig. 1.—A valuable water supply, about 1500 gallons a minute, from a well in Santa Cruz County. The weir box is incorrectly designed, so that it is impossible to get an accurate measurement of the discharge of the pump. The discharge should be horizontal, at the level of the crest of the weir.
INTRODUCTION

Pumping for irrigation has attained considerable importance in Arizona. According to the census of 1920, 10 percent of the area under irrigation in this State in 1919 was dependent entirely upon pumped water, and 55 percent of the total irrigated area was supplied, in whole or in part, with water pumped from wells. Practically all of the development of pumping for irrigation occurred between 1907 and 1920.

The earliest pumping plants for irrigation in Arizona used steam power, with wood as fuel. Internal-combustion engines were introduced about 1904. They came into general use in 1912, when it was found that cheap gas oil, with a gravity of about 40° B., could be used as fuel for these engines. Beginning in 1910, hydroelectric power has been used to a considerable extent in the Salt River Valley for irrigation pumping. Owing to the increased cost of gas oil, which reached a maximum in 1920, and to the probability that prices of fuel oils in the future will be higher than they are at the present time, there is a general desire in pumping districts to secure hydroelectric power.

The transmission and distribution of electric power for pumping requires a large initial investment, and it becomes necessary for the landowners to form some sort of effective organization in order to finance, construct, and operate transmission systems. To afford greater security to bond issues, and to make them more salable, special legislation has been enacted. An electrical district act was passed by the Arizona legislature in 1915, and one district was organized under it, and another district partially organized, before the act was recognized to be unconstitutional. Another act, similar but designed to obviate the defects of the former act, was passed in 1922, but a few months later it was declared to be unconstitutional. A third electrical district act was passed in 1923 and is now in force. Also, a power district act, designed primarily for smaller
organizations, was passed by the legislature of 1919, and one district is in operation under it.

The function of an electrical district is to bring electric power to a pole close to the farmer's pumping plant. The farmer must supply the electric motor and usually he must supply transformers, switches, and other accessory equipment. A demand is created, therefore, for such information on motor-driven pumping plants as the farmer needs to have. The primary purpose of this bulletin is to supply such information, both for those who desire to change their pumping plants from engines to motors and for those who desire to install new motor-driven pumping plants. General discussions of wells and pumps are included; and, also, an explanation of the legal character, function, and operation of electrical districts is presented.

The author has obtained assistance from many sources in the preparation of this bulletin, but he desires to acknowledge especially the valued aid of Mr. H. J. Lawson, Superintendent of Power of the Salt River Valley Water Users' Association. The drawings, except one, were made by W. E. Code, Assistant Irrigation Engineer of the Agricultural Experiment Station.

Footnote: For those who propose to install internal-combustion engines for power, Bulletin 74 of this Station, Oil Engines for Pump Irrigation and the Cost of Pumping, and Bulletin 92, The Supply, the Price, and the Quality of Fuel Oils for Pump Irrigation, are recommended.
THE ELECTRICAL DISTRICT

An electrical district is analogous to an irrigation district, the distinction being that the one is organized to provide power for pumping plants throughout a district, while the other is to provide and distribute a water supply, usually a gravity water supply. These districts are quasi-municipal in character, and are based on the theory that irrigation, and the furnishing of water and power therefore, are public uses, as are streets and street lighting in cities. Taxes for the purposes of the districts are levied and collected by county officials. These districts, as organized under the laws of Arizona, California, and a few other states, are exceedingly effective in the accomplishment of the purposes for which they are formed.

ATTRIBUTES

The fundamental attributes of an irrigation district have been expressed succinctly by Wells A. Hutchins, of the Division of Agricultural Engineering, United States Department of Agriculture. Inasmuch as his analysis applies, with slight modification, to electrical districts, it is quoted here, as follows:

“(a) An irrigation district is a public corporation, a political subdivision of a State, created under authority of the State legislature through the county governing body at the instance of the landowners or citizens, as the case may be, of the particular territory involved. Being public and political, the formation of a district is not dependent upon the consent of all persons concerned, but may be brought about against the wishes of the minority. In this respect the district differs fundamentally from the voluntary cooperative or the commercial irrigation company.

“(b) It is a cooperative undertaking, a self-governing institution, owned, managed, and operated by the landowners or citizens within the district. Supervision by State officials is provided for to the extent of seeing that the laws are enforced, and in most States is extended in greater or less degree over organization, plans, and estimates prior to bond issues, and construction of works.

“(c) It may issue bonds for the construction or acquisition of irrigation works, which bonds are payable from the proceeds of assessments levied upon the land.

“(d) Hence, it has the taxing power. Each assessment becomes a lien upon the land. While the ultimate source of revenue, therefore, is the

assessment, an additional source frequently provided for is the toll charged for water. Other revenue may in some cases be obtained from the sale or rental of water or power to lands or persons outside the district.

"(e) Finally, the purpose of the irrigation district is to obtain a water supply and to distribute the water for the irrigation of lands within the district. Additional authority is granted irrigation districts, almost without exception, to provide for drainage. In some States districts may also develop electric power. These additional powers, however, are subsidiary and are intended to make more effective the principal function of the organization, which is to provide for irrigation."

The constitutionality of the irrigation district law (in California) was upheld by the United States Supreme Court in 1896. Laws for the formation of districts are long and detailed, and must be drawn with greatest care in order to avoid the inclusion of some unconstitutional feature, and in order to prevent the abuse and misuse of the powers conferred.

THE ELECTRICAL DISTRICT LAW

The creation of an electrical district under the Arizona law, (Act of February 19, 1923), is initiated by filing a petition with the board of supervisors of the county in which the lands, or the larger part of the land, is situated. The petition defines the boundaries of the tract or tracts to be included in the district, and must be signed by 25 or more of the resident landowners within the area defined, or by at least one-third of the resident landowners.

The board of supervisors must then fix a date for a judicial hearing, and due notice must be given to "all owners of the lands or interests in lands." At this hearing the board determines whether or not the lands are arid lands, whether they are reclaimable, whether there is a supply of water which can be made "efficiently available" by the use of the proposed power system, and whether the development to result from the introduction of power is of such benefit to the whole district as to impress it with the character of a public use.

If the question of public use is determined in the affirmative, the board then hears the objections of any landowners who wish to be excluded from the district, or of any who wish to be included in the district, and the board has the right to change the boundaries stated in the petition. The board then appoints three resident freeholders to constitute a board of election commissioners whose duty is to call and conduct the first or organization election. Any person affected by the decisions of the board of supervisors has the right of appeal to the Superior Court of the county.

At the organization election it is determined whether or not the proposed district shall be formed, and a majority of the votes cast is required
to adopt or reject the proposal. On the same ballot the electors vote for
seven directors, who, if the vote on organization is affirmative, serve as
the board of directors of the district. Directors serve for 3 years. It is a
continuing or holdover board, a part of the number retiring each year;
elections, therefore, are held annually. The number of the directors can
be changed subsequently by vote of the electors at a regular meeting.

Persons qualified to vote at elections are the “property taxpayers who
shall also in all respects be qualified electors of the State and of the dis-
trict.” It is immaterial whether the voter has much or little land. Non-
residents of the district cannot vote or hold office.

The management of a district is similar to that of a corporation, and a
district has the usual legal powers of a corporation, and also can exercise
the right of eminent domain.

The directors investigate the possible methods of generating or procur-
ing power and of making it available to the members of the district, and
determine the most feasible method, make detailed plans and estimates or
cause such plans and estimates to be made, and then submit to the electors
at a special bond election the question of voting bonds of the district of
an adequate amount. The bonds may run for any length of time not to
exceed 30 years, and may provide for optional or progressive maturity.
The interest rate cannot exceed 7 percent. The bonds are issued and sold
by advertisement in the same manner as municipal bonds.

The needful revenues of the district are raised through the ordinary
processes of taxation. The board of directors certify the requirements of
the district to the board of supervisors of the county and the supervisors
levy the taxes, which are entered upon the tax lists by the county assessor
and are collected by the county treasurer along with other taxes—state,
county, and school. The taxes for the district are of two kinds, namely:
(1) overhead or administration expenses, including salaries of officers,
levied upon all the taxable property, real and personal, in the district;
and (2) the “general burdens,” including amounts required for interest
and sinking fund for the bonds issued, for new construction, for repairs,
for payments on contracts and litigation expenses, and for other general
purposes, assessed solely upon the land, on an acreage basis, each acre to
bear an equal part of the levy.

ADVISABILITY

The advisability of organizing an electrical district and of employing
electric power, instead of individually-owned internal-combustion engines,
is dependent on many things. A comparative study of the economics of
the two kinds of power should be made for each proposed district. This
study must include not only general operating costs and the costs of
maintenance, but also all fixed charges, such as interest charges and depreciation. The cost of attendance for each type of pumping plant should be evaluated as closely as possible, and likewise the probable interruptions to service and the general reliability. It can be stated broadly that, at the prices fixed by the State Corporation Commission for public service corporations of cities throughout the State, electric power cannot compete in economy with oil engines at present prices of fuel oils. Hydroelectric power, from the Salt River Valley project of the United States Reclamation Service, is sold, however, at much lower rates. It is possible also that power, equally cheap, will be available from projects on the Colorado River within a few years. It is anticipated that the prices of fuel oils will be higher in the future than at present, while contracts for hydroelectric power can be made to cover a period of 10 to 30 years.
THE CONTRACT FOR POWER

It is unlikely that any electrical district in Arizona will finance the generation of power. Usually it is possible to enter into a long-term contract with some corporation or other organization which has power for sale, to provide power as needed. Such a contract states not only the prices and terms of payment, but also the conditions under which power will be furnished, the specifications covering the power, the character of the equipment to be provided, and restrictions as to the use. Each landowner in an electrical district should possess a copy of the contract, for many of its provisions affect him directly.

Under the electrical district act it is permissible for landowners to contract separately with the power company and to deal directly with that company instead of through the electrical district. This procedure has some advantages, especially for districts comprising small areas of land. Under this plan, the vendor of the power retails the power to the individual users, carries each user’s account separately, and makes the collections; the vendor operates and maintains the transmission lines under lease, and there is very little overhead and general expense to be borne by the district. The purpose of the district is accomplished in financing the cost of the transmission system through the mortgaging of the land. In addition to the individual power users’ contracts, there is required a more general contract between the district and the vendor.

Another plan, more likely to be followed by electrical districts of large area than by those of small area, is for the district to contract for power to be delivered and measured at the initial point of the system, the district itself to operate and maintain the transmission lines, to stand the line losses, and to retail the power to the individual users. In this case the vendor takes no part in the management of the system, but is concerned only in having the use of the power well distributed as to time, and in maintaining a satisfactory power factor. This can be called the wholesaling plan.

A third plan, a modification of the other two, is for the district to contract for a block of power, with a fixed maximum demand, on which maximum demand the minimum monthly charges are based; the district then to rotate the power among its members in such manner that the maximum demand in effect shall not be exceeded at any time; the vendor to operate and maintain the lines under lease, and to read the meters at the individual pumping plants.

Under the second plan, each landowner deals directly with the district, the vendor collects the total charges from the district, and the district
collects the individual accounts. Under the third plan, the district can assume the burden of collecting accounts, or the vendor may keep the account, and render the bills to the individual power users, but the district must make the payments for TVA and all users who fail to pay their bills promptly.

THE RETAILING PLAN

A form of contract which is used considerably by the Salt River Valley Water Users' Association, and which can be adapted to the first plan given above by suitable change, is as follows:

THIS AGREEMENT, made this day of , 192, between the Salt River Valley Water Users' Association, a Corporation, organized under and existing by virtue of the Laws of the State of Arizona, with its principal place of business in Phoenix, Arizona, hereinafter called the Vendors, and , hereinafter called the Contractor, his executors, administrators, successors and assigns.

WITNESSETH, the parties covenant and agree that

Subject to the terms and conditions hereinafter contained the Association undertakes and agrees to furnish to the Contractor electric energy at a potential of approximately 11,000 volts, 25 cycles, three-phase alternating current not to exceed at any time during the term of this contract a maximum load of kilowatts. It is understood and agreed that this electric energy shall be furnished to the Contractor for pumping water for the irrigation of lands in the vicinity of pumping plants located in the , Township , Range , G & S B & M, and for no other purpose without the consent of the Association.

Article No 2 Part 1 In consideration whereof the Contractor agrees to pay for said service at the rate of one and one half cents per kilowatt-hour for all energy supplied hereunder.

Part 2 During the periods between March 15 and October 15, the Contractor agrees to receive and/or pay for the following minimum amounts of electric energy in each month as follows:

<table>
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<tr>
<th>Period</th>
<th>KWH @ 1½c= $</th>
<th>(Note Figures in parentheses are the minimum charges per kilowatt of maximum demand)</th>
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<tr>
<td>March 15th to 31st</td>
<td>$ (3125)</td>
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<td>April</td>
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<tr>
<td>May</td>
<td>$ (250)</td>
<td></td>
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<tr>
<td>June</td>
<td>$ (475)</td>
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<td>July</td>
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<td>August</td>
<td>$ (375)</td>
<td></td>
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<tr>
<td>September</td>
<td>$ (1875)</td>
<td></td>
</tr>
<tr>
<td>October 1st to 15th</td>
<td>$ (3125)</td>
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It is agreed that power received in any month in excess of aforesaid minimums shall not be applied to reduce the aforesaid minimum payment in any other month, but shall be paid for at the prescribed rate in excess of the minimum for said month. Provided, however, that if power be not available to the extent of the minimum provided for any month, during such month the minimum payment for said month shall be proportionately less.
Article 3. It is further understood and agreed that the Contractor shall install at some convenient place between the point of connection of the Contractor's lines to the lines of the Association and the Contractor's transformers a standard recording watthour metering equipment for the purpose of measuring and recording the energy furnished hereunder. The representative of the Association shall test and seal said meter equipment and the indications of same shall be accepted as correct unless there shall be a reasonable doubt on the part of the Contractor, in which case, upon a written demand, the meter equipment shall be tested by a representative of the Association in the presence of the Contractor or his representative. It is understood and agreed that the Association shall test said meter equipment as often as it shall be deemed necessary without notice to the Contractor, and that the Contractor shall have the right, upon payment of the expense thereof, to have the accuracy of the meter tested at any time during the term of this contract.

Article 4. It is further understood and agreed that all energy furnished to the Contractor as measured and registered by the recording wattmeter aforesaid shall be computed and charged at the end of each calendar month at the rate of one and one-half cents per kilowatt-hour, and same shall be due and payable within thirty days after date of rendering the statement of the consumption of energy for the month preceding. Upon failure of the Contractor at any time during the term of this contract to pay the amount due for the energy consumed within forty days after the statement has been rendered, as above provided, the Association, by its authorized agents acting in its behalf, shall have the right to shut off the supply of energy and refuse to furnish same to the Contractor as long as the said amount remains unpaid. It is further understood and agreed that all deferred payments as applied to this contract shall bear interest at the rate of ten percent per annum until final payment shall be made.

Article 5. It is further understood and agreed that the electric energy available under this contract is surplus energy that the Association may have available, after taking care of existing contracts, or contracts now in course of completion, or the renewals thereof, and after taking care of the requirements of the Association for electrical energy for use in connection with the care, operation, and maintenance of the Project, from any of its now-existing hydroelectric power plants developed by water required for irrigation purposes on the Salt River Project during the period from March 15 to October 15. The Contractor agrees to install and maintain, at no expense whatever to the Association, ample means of taking care of his requirements during the times the Association is unable to furnish electric energy. The service to be rendered under this contract will be limited to the irrigation season of March 15 to October 15. The Contractor agrees to use no other power than that furnished by the Association during the time the Association has power available.

It is further understood and agreed that at any time when the Association notifies the Contractor that no power is available the Contractor will not use power from the lines of the Association until permission to do so is granted by the Association also if the Association notifies the Contractor that a specific amount of power is available for his use the Contractor will not use power in excess of that amount until permission to do so is granted by the Association. The Contractor agrees that the operators of his pumping plants shall implicitly follow the instructions of the operator in charge of the Association's power system at all times in regard to the operation of the 11,000 volt lines, it being understood that the latter shall at all times have due regard for the interests of the Contractor.
Article 6. The electric energy will be delivered to the Association and received by the Contractor at approximately the voltage and frequency indicated in Article 1, and all connections will be made by the Contractor at his own expense. At the point of delivery the Contractor shall be made responsible and have direct control of the opening of switches in case of emergency for the protection of life and property, but the Association shall have at all times the right to inspect the station at said point of delivery and have access to the meter equipment herein mentioned.

Article 7. The Contractor shall, by the use of apparatus of good power factor and suitable capacity, so control the load that as high a power factor as possible shall be maintained. The power factor of the total load at the point of delivery shall be not less than 80 percent.

Article 8. It is further understood and agreed that as the power used under this contract is to be used for irrigation pumping, that the Contractor shall use this power continuously 24 hours each day during the period of his irrigation demand, except at times of emergency or accident, and shall continue steady operation until his irrigation demand ceases, at which time he will discontinue the use of power until time for the next period of continuous operation. It is further understood and agreed that at all times when the power is not being used for the purpose of pumping water, that the power transformers which are the property of the Contractor shall be disconnected from the power line which serves them.

Article 9. It is further understood and agreed that in case there is no hydroelectric power available under this agreement for the Contractor, the Association may, if it so elects, supply without notice to the Contractor power other than hydroelectric power generated by the plants of the Association. The cost to the Contractor of such power generated by steam or supplied in any way from plants other than those of the Association, shall be equal to the rate hereinbefore provided, plus a surcharge equal to the difference in cost per kilowatt-hour to the Association of such other power and the cost of operation and maintenance per kilowatt-hour of hydroelectric power generated by the Association during the preceding month. In case the Contractor does not want to use any power other than hydroelectric power generated by the plants of the Association, he will give written notice to that effect to the Association, in which case no such steam or other power will be supplied to the Contractor.

Article 10. It is further understood and agreed that in case of a shortage of power the Contractor will receive only such power as is available after the demands of prior contracts have been met. It is further understood and agreed that in case power is not available in sufficient quantity to serve all consumers whose prior rights are equal, that the Association shall have the right to distribute the power that is available among the various consumers, and this Contractor agrees to abide by the decision of the Association in such case.

Article 11. It is further understood and agreed that the Association shall not be responsible nor in any way liable to the Contractor on account of delays or interruptions to the service of energy which may be due to the action of the elements, accidents, want of hydroelectric power or scarcity of water. The Association, its agents or representatives, shall be exempt from all responsibilities resulting from accidents to life or damage to property which are due to the action of the said energy which may occur beyond the point of delivery of said energy to the circuit or circuits that shall remain the property of the Contractor.

Article 12. It is further understood and agreed that all transmission lines, transformer installations, switching apparatus, lightning arresters
and wiring that shall be the property of the Contractor shall be constructed and installed according to plans acceptable to the Association and the Secretary of the Interior of the United States Government, and that the operation and maintenance during the term of the contract of the above mentioned apparatus shall be conducted in a manner satisfactory to the representatives of the Association and the Secretary of the Interior. It is further understood and agreed that if any defects develop during the term of this agreement, after the electrical equipment has been installed, of such character as to interfere with the electrical equipment of the Association, the representative of the Association or the Secretary of the Interior may demand at any time that changes be made to eliminate such defects. The Association shall have the right to cease furnishing energy until such changes are made.

Article 13. It is further understood and agreed that the Association shall have the right and privilege of shutting down its plants and ceasing to serve energy to the Contractor at any time in order to make necessary repairs or additions to its transmission lines, canals, or machinery. In such case it shall give reasonable notice of its intention to exercise this privilege.

Article 14. It is further understood and agreed that if the Contractor fails to comply with any of the conditions of this contract within thirty days after being notified by the Association that such conditions must be complied with, then the Association may, at its option, cease delivery of power to the Contractor. It is further understood and agreed that if power is not used under this contract by the Contractor, and the minimum bills, as mentioned in Article 2 of this agreement, are not paid as provided from April 1st to October 15th of any calendar year, then the Association may declare this contract terminated. It is further understood and agreed that the amount of the bills rendered for power shall constitute a first and prior lien against the land to which water has been supplied by the use of the power for which the bills have been rendered, and the owner of the land shall be held liable for the amount of the bills for power as well as all attorneys' fees and incidental and court costs necessary to collect same. It is expressly understood and agreed that in the event that the Contractor shall fail to make any payments due under this contract for a period of six months, or shall fail to keep and perform any other conditions required to be kept or performed by him for a period of six months, then the Association may at its option declare this contract terminated.

In Article 1, the contract specifies the electric current as 11,000 volts, 25 cycles, 3-phase.¹ This, of course, must be transformed to low voltage, outside of the pump house and by the farmer's own equipment. Twenty-five cycle current permits of motor speeds of 1500, 750, 500, and 375 revolutions per minute; for pumping plants either 1500 or 750 should be selected, and in most cases the 750 speed is preferable.

In Article 2 the price of the electric power during the irrigation season is stipulated as 1½ cents per kilowatt-hour. The price is the same whether much or little power is used. This uniformity is advantageous to the owners of small areas of land, and is a desirable feature for an

¹For definition of terms, see p 116.
electrical district, inasmuch as relatively small land holdings and intensive agriculture should be encouraged. (The alternative is to base the charges on a sliding scale of rates, depending on the amount of power used, and sometimes on other factors, also. This system favors the users of large quantities of power.)

The farmer agrees to pay for a certain minimum amount of current each month through the main irrigating season from March 15 to October 15, whether he uses it or not. Such a provision is just and is intended to cover the inevitable cost of readiness to serve. The minimum payments for each month, as given in parentheses, are the amounts per kilowatt of maximum demand and must be multiplied by the maximum number of kilowatts used by the plant, as determined by inspection at various times during the season. Farming operations should be so planned that the minimum amount of power specified for each month will be used.

The distribution of the minimum charges through the months of the irrigating season is important and should be the subject of negotiation. From the farmer's standpoint, the distribution could be much more favorable than as given in the above contract; his schedule of minimum charges should approximate as closely as possible to his schedule of monthly use of water.

In Yuma County and in many places in other states, the minimum charges are additional to the charges based on the total amount of power used. The system used by the Salt River Valley Water Users' Association is an important concession to the users of power for irrigation pumping.

In Article 5 et seq. it is stipulated that, under various circumstances, the vendor is not required to furnish power, but if the vendor so elects, it may furnish power obtained from other sources, in which case it will reimburse itself through a surcharge. Therefore, it is of some advantage perhaps for the farmer to have some other means of operating his pumping plant in case of emergency. It is not expected that such emergency will arise; at least, it is not likely that periods of inability to serve will be of enough duration to cause any material damage to the crops. However, it may be of value, in the case of farmers who now have internal-combustion engines, to retain them in such condition that they can be used if occasion requires.

Under the above contract the vendor does not guarantee to furnish power in the winter months, and from Article 5 it is clear that the contract covers secondary power only. However, with the completion of the Mormon Flats project now under construction, the Association will have a considerable amount of primary power for sale. Also, it should be stated that throughout the period of years in which the Association has been furnishing power for irrigation pumping under contracts of the
above form, it has never failed to provide power as required—from one source or another.

Article 7 requires that the power factor shall be not less than 80 percent. It is necessary, therefore, that the motor carry more than one-half of its rated load. The motor should not be unnecessarily large. Before purchasing a motor, the farmer should ascertain as closely as possible how much power is required, and then he should select a motor of such size that it will be loaded from 80 to 100 percent of its rated capacity. With gas engines it is desirable to have considerable reserve capacity; with motors this is not desirable unless the owner is anticipating changes in the plant which may necessitate increased power.

THE MODIFIED PLAN

The third, or modified plan is proposed for Pinal County Electrical District No. 2, which comprises a large acreage in the Casa Grande Valley.

The main contract will be between the Electrical District and the Salt River Valley Water Users' Association. The District must have a separate contract with each one of its members who desires to use power.

The District leases its transmission system to the Association for 25 years. The Association agrees to maintain and operate the system, to make repairs and replacements as needed, to deliver power to the individual pumping plants, to keep the meters in good condition and to read them monthly. The monthly bills for power will be based on these readings, and will be rendered once to the power users. Accounts which are not paid promptly must be paid by the District, which must then make the collections from the power users.

The District agrees to take a (nominal) maximum demand of 1000 kilowatts, but the maximum demand can be varied between the limits of 1000 and 2000 kilowatts by giving stipulated advance notice. The connected load can be much in excess of 1000 kilowatts, but the District must rotate the use of power that the maximum demand in effect shall not be exceeded at any time. Therefore, power users should be required to place their orders for power several days in advance, and by-laws governing the rotation of power should be adopted by the District. The distribution of power will necessitate the services of a power-master, whose functions will be analogous to those of a water-master.

The contract is for primary power, and the price is 1.55 cents per kilowatt-hour, measured on the low-tension side of the transformer. The minimum charges per month per kilowatt of maximum demand in effect are based in part on the probable duty of water and are as follows:

<table>
<thead>
<tr>
<th>Month</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>$1.00</td>
</tr>
<tr>
<td>April</td>
<td>$2.00</td>
</tr>
<tr>
<td>May</td>
<td>$2.50</td>
</tr>
<tr>
<td>June</td>
<td>$3.25</td>
</tr>
<tr>
<td>July</td>
<td>$3.25</td>
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<td>August</td>
<td>$3.25</td>
</tr>
<tr>
<td>September</td>
<td>$2.75</td>
</tr>
<tr>
<td>October</td>
<td>$1.00</td>
</tr>
</tbody>
</table>
As in all similar contracts, there is a stipulation that the transformers must be disconnected from the power line when the pumping plant is not in operation.

The principal advantage of this plan over the straight retailing plan is that the individual pumping plants are not limited in size by the schedule of minimum monthly charges.

The obligations of the District to use or pay for a minimum amount of power can be analyzed in the following manner. Assuming that the maximum demand in effect is 1000 kilowatts, the minimum charge in a summer month will be $3250. At 1.55 cents per kilowatt-hour, this will pay for 210,000 kilowatt-hours, sufficient to raise 105,000 acre-feet of water one foot high, (see page ——), or 1,750 acre-feet 60 feet high, which is the approximate average lift to be expected. This would be enough for 3500 acres of cultivated land, or 3.5 acres per kilowatt. The directors of the District should be assured each spring of at least 3500 acres, and should engage in advance a "maximum demand" of not to exceed one kilowatt for each 3.5 acres.

Similarly, in October, the minimum charge will be $1000, which covers the cost of pumping 538 acre-feet 60 feet high. This quantity is enough to cover 1075 acres with a 6-inch irrigation, but in a system of diversified farming, it is enough for 3200 acres in October.
If it were feasible to use the maximum demand, say 1000 kilowatts, continuously, then in a month of 30 days, or 720 hours, the total use would be 720,000 kilowatt-hours, sufficient to raise 360,000 acre-feet of water one foot high, or 6000 acre-feet 60 feet high. This would be enough water for 12,000 acres in the summer, and about twice that acreage in the winter.

Fig. 4.—The fluctuations of water level over a period of 7 years in wells of five localities in Casa Grande Valley. The fluctuations were due to recharge from stream flow, seepage from canals and irrigated fields, to natural under-drainage toward the Gila River, and to some extent to the draught made by pumping plants.
In order of importance, the elements of a farm pumping plant stand as follows: well, pump, and power. Quite commonly the power is thought to be most important, and the well least important. It is assumed too often that a good well can be obtained in any location; and frequently one hears the assertion that the groundwater supply is inexhaustible. The possibility of obtaining a good well, the depth to the water table, and the question of the permanency of the supply, should be given first consideration.

LOCATION

The selection of the location of a well should be influenced by the physiographic relations. Thus, in the case of valleys like those of the Santa Cruz and San Pedro, the Recent gravels underlying the bottomlands yield much better water supplies than formations beneath the adjacent sloping plains. As another illustration, there is a buried mountain southwest of Casa Grande which reduces the possibility of obtaining good wells over an area consisting of several sections of good agricultural land. In parts of the Salt River Valley, phenomenal yields can be obtained from wells; in other parts the yields are very meagre.

Fluctuations of the water table must be considered, inasmuch as they affect the yield of wells and the type of pump to be used. In addition to the seasonal fluctuations between wet and dry periods of the year, there are in many districts secular variations due to the wide irregularities in the annual rainfall and in stream flow. There are wells in Arizona which have a range of the water table of over 40 feet due to natural causes. The artificial depression of the water table at a well due to the draught upon the groundwater supply by other pumping plants, especially those in the near vicinity, is in some pumping districts very great. Wide fluctuations, caused by pumping, indicate that the total draught on the water supply should not be further increased.

A farmer who contemplates purchasing a pumping plant can learn much regarding the water supply, if there are other wells in the district. Data should be obtained as to yield and drawdown, the effect of long-continued pumping, and the fluctuations of the water table.

The quality of the groundwater also should be investigated. In a few localities in Arizona the groundwater contains so much alkali salts as to make it unsuitable for continued use for irrigation.
Fig. 5.—A simple design of forms for a reinforced-concrete well caisson. The bolt wooden frame is covered with galvanized iron. Both inside and outside forms are sectional, the number of sections depending upon the diameter of the caisson. Horizontal and vertical reinforcement, both of 3/8-inch or 1/4-inch round iron, are shown in the lower sectional view. The lower part of the caisson is made thicker by means of the insert pieces in the outside forms. Note also the angle-iron shoe to protect the cutting edge.
TYPES

The best type of well in any district depends upon the local conditions, and types that are successful in some parts of the State are ill-suited to other parts. Every known type is represented in Arizona practice.

Dug wells are the most common. For domestic supplies they are simple and cheap, but for irrigation supplies requiring large yields, their use is restricted to localities where the water table is at shallow depths and excellent gravels exist just below the water table. Examples of these conditions are found in the Rillito and Santa Cruz valleys. Well digging is easy above the water level only. The best method of extending a dug well to a considerable depth below the water level is by means of a heavy reinforced-concrete caisson curb, built between forms, and sunk by excavating within it and undermining it. The curb should be thick and heavy, with smooth exterior. It should have a beveled cutting edge, and in most instances it is desirable that the cutting edge be shod with an angle-iron shoe. A centrifugal pump, installed in or over the well, is used to keep the water level down so that workmen can excavate in the bottom, and care is exercised to keep the curb in a vertical position as it settles downward. At Hayden, Arizona, an orange-peel dredge bucket was used to sink the caisson. A simple design of forms for a 7-foot caisson curb is presented in Fig. 5. The six inserts shown in the outer forms are for use in the first few sections at the bottom of the curb. By the removal of the inserts, one by one, the outside diameter is reduced. It is desirable to have two sets of forms so that each set can be placed squarely on the set below and the lower set can then be left on the concrete for another day. An equipment of forms usually serves for many wells.

Drilled wells are the most generally useful for large water supplies. Drop tools, either stem and bit, or more often a mud-scow with a circular cutting edge, are used, with portable drilling rigs, one of which is shown in Fig. 3. The well casing, usually of the California stovepipe type, varies from 6 inches to 26 inches in diameter. The smaller sizes were used formerly, but in recent practice few wells of less than 16 inches diameter have been drilled. If possible, the casing should be 2 to 4 inches larger than the pump that is to be used. If the well is drilled from the surface, it must be straight in alignment and vertical.

A combination dug and drilled well permits of placing a direct-connected horizontal centrifugal pump and motor close to the water table, while at the same time the water supply can be drawn from deep strata. In this case the dug well should be excavated first. It should be circular, with a concrete curb. Eight or ten feet in depth should be excavated and curbed, then another similar section, and so on to the water level.
The rotary process has been employed successfully in Gila and Cochise counties. In this process a line of heavy hollow drill rods is used to rotate a fish-tail bit. Instead of clear water in the hole, the circulating
fluid used is clay mud, the consistency and specific gravity of which are maintained or changed according to the formations encountered. The walls of the hole are sealed with mud and are thus kept intact, but there is danger of sealing off good water strata permanently, and no one but an expert should attempt to use this method for water wells. It is used only for deep wells over 500 feet in depth, and is not adapted to formations that include strata containing boulders.

The jetting process is used almost exclusively in the San Simon Valley. The formations there are fine sands and silts, and wells of 600 to 800 feet depth are sunk in from 2 to 4 weeks at an extremely low cost. This process is not used for wells of large diameter.

Bored wells are common in the Sulphur Spring Valley. Both hand augurs and machine augurs have been used. The formations there are compact and stand to great depth without casing. The method is not to be recommended in districts where loose water-bearing gravels are encountered, or where large well yields are expected.

DEVELOPING

The perforation of well casing and the "developing" of the well after perforation have been much neglected in the past. Instances are known
in which well casings supposed to have been perforated have been found to be almost water-tight. Frequently the perforator knives merely dent the casing instead of cutting through it. In many instances drilling rigs have been set up again and the wells have been re-perforated with excellent results. Fig. 6 shows three sections of well casings actually removed from wells. The lower left casing was cut by a perforator used by the United States Reclamation Service in the Chandler district about 1910. The upper left was perforated by a Star perforator run twice, and the casing at the right was perforated with a Mills knife. Fig. 7 shows a piece of casing cut by a knife ripper; it illustrates poor practice.

After perforation the well should be developed, though many drillers neglect this important work altogether. The object is to open up the water-bearing strata, not only close to the hole, but for a considerable distance back from the casing, and to bring all loose, fine material into the well through the perforations, and then to remove it with a sand-bailer. Great ingenuity has been displayed in the various processes of washing and jetting, with water and with compressed air, and of "rawhiding," either with a plugged bailer or with a centrifugal pump. Every well driller should have adequate equipment for developing wells, and a farmer, when contracting for a drilled well, should include a provision in the contract for developing the well.

TESTING

It is highly desirable to install some sort of a pump and make a real pumping test of a well, before purchasing a pump and motor for permanent installation. For the purpose of the test, the pump need not be efficient nor of the size desired. The test consists of determining the yield of the well in gallons per minute and the corresponding drawdown of the water level after several hours pumping. The yield is proportional to the drawdown, provided the water-bearing strata are not uncovered by the drawdown. Thus, if the test shows a yield of 600 gallons a minute with 10 feet of drawdown, the well will yield approximately 1200 gallons a minute with 20 feet of drawdown. Fig. 8 shows graphically the relation between drawdown and yield in the East well on the Campus of the University of Arizona. In most localities there is a used or idle pump which can be rented for a week, and frequently a tractor is available for a few days to furnish power. In contracts for new wells, it is desirable to include a clause providing for the testing of the wells by the drilling contractor. Misfit pumps, particularly the purchase of a pump that is too large, can be avoided by means of a preliminary test. If the well has not been developed by special means, then it is advantageous to install a large pump for use both for testing and for developing the yield.
Fig. 8.—The relation of drawdown to yield and the relation of discharge to lift at the East well pumping plant on the University Campus. The test point does not fall on the curve, but the test was made nearly a year before the plant was installed and in the meantime the water plane was lowered by the city wells.
UNITS OF WATER MEASUREMENT

Units of flow are:

One gallon per minute

One miner's inch = 11.2 gallons per minute in Arizona.

One cubic foot per second, written second-foot or sec.-ft.,

= 449 gallons per minute

= 40 miner's inches.

Units of quantity, used by irrigationists, are:

One acre-foot, the quantity required to cover 1 acre 1 foot deep

= 43,560 cubic feet.

One acre-inch, the quantity required to cover 1 acre 1 inch deep.

CONVENIENT RULES

One second-foot flowing 1 hour = 1 acre-inch.

One second-foot flowing 12 hours = 1 acre-foot.

In irrigating land, 1 acre-foot provides

a 3-inch irrigation for 4 acres;

a 4-inch irrigation for 3 acres;

a 6-inch irrigation for 2 acres.

One land 33 feet wide and a quarter mile long = 1 acre.

One land 66 feet wide and 660 feet long = 1 acre.
The selection of the right type and quality and size of pump is of great importance. Factors that must be considered are the acreage to be irrigated, the quantities of water required in the months of maximum irrigation, the desirable irrigating head, the lift, the first cost and the cost of upkeep of the proposed pumps, and the efficiencies; also, the provisions of the contract for power, especially the minimum charges per month, must be considered in some cases.

**EFFICIENCY**

By efficiency of the pump is meant the ratio of the power delivered by the pump to the power delivered to the pump. There is no pump or any other machine that can deliver so much power as is being delivered to it. There is always a loss of power in the machine.

Many pumps have efficiencies above 67 percent, that is, they utilize two-thirds (or more) of the power delivered by the electric motor or by the gas or oil engine; the other third (or less) is wasted and lost in the pump. Many pumps operate at efficiencies as low as 33 percent, that is, they save one-third of the power and waste two-thirds. Comparing one with the other, a pump operating at 33 percent efficiency requires twice as large an engine or motor, and requires twice as much power to pump the same amount of water on the same lift, as does a pump operating at 66 percent efficiency. Even small differences in efficiency are important. If, of two pumps that are available, one has an efficiency 5 percent higher than the other, then the purchase of the better pump will reduce the bills for power by 5 percent.

Presumably, the more efficient pump will cost more than the other. If the pump is to be used a great deal, the additional cost will prove to be a good investment. But if the pump is to be used very little, as in cases of supplemental pump irrigation, and if there is a wide difference in price and little difference in efficiency, then the cheaper pump may be the proper one to buy. In electrical districts, pumping plants are likely to be used a large part of the time during the growing season, and the best pumps available should be purchased. Besides, it happens in many cases that the next smaller commercial size of engine can be used with the more efficient pump, and that the saving in cost of engine is greater than the difference in price of the pumps.

The attainment of high efficiencies in the operation of centrifugal and vertical turbine pumps depends upon whether the pumps are operated
under the conditions for which they are designed.

In the proper design of a centrifugal pump, the efficiency will be

It is the pump or machinery that is important, but the
design of the pump and the lift. If a pump is

The efficiency will be lower, and the

discharge of a centrifugal pump varies

The proper speed for

designed, the efficiency will be

The diagrams show differences in the efficiency of electrical machinery. Differences in the efficiency of pumps vary little compared with the wide differences in the efficiency of electrical machinery.
For economy in pumping, the pump must be capable of high efficiency, and must be so operated as to give that high efficiency.

**SELECTION OF SIZE**

In the selection of the right size of pump, the water requirements for the given acreage must be first considered. Thus, in the Casa Grande Valley, if the plant is to be run only 300 hours per month, then a minimum capacity of 9 gallons per minute per acre of land must be provided. If the plant is to operate the plant about 550 hours per month through the summer months, then 5 gallons per minute per acre is sufficient. These capacities should be increased for districts like the Rillito Valley, where the soil is more porous, and should be decreased somewhat for areas where a part of the land is summer-fallowed and the irrigating demand is distributed more evenly throughout the year.

In Fig. 9 is a generalized schedule of the monthly use of water, as measured at the farmer's headgate, for alfalfa, cotton, double-cropping, and a combination of the three on an equal basis.

Although the demand for water in June and July determines the minimum size of pump that can be used, yet for small ranches consideration must be given to certain other factors, such as the size of irrigating head. For flooding, as in border irrigation, it is desirable to have a head of at least 700 gallons per minute, though small plots of alfalfa, as in chicken runs and short lands, can be irrigated with smaller heads of water. In the Salt River Valley the usual "run" of water is 300 miner's inches, or 3360 gallons per minute, and it is divided usually into three unit heads of about 1100 gallons each. One irrigator can take care of 300 miner's inches, on alfalfa, and it is economy to have the irrigator fully employed. For irrigation of gardens, heads as small as 100 gallons can be used, but generally for furrow irrigation it is better to have a much larger stream, 700 gallons or more, so that many furrows can be irrigated at a time. Unless the land has been provided with a cement-pipe distribution system or cement-lined ditches, considerable water is wasted by seepage in the irrigating ditches, and the smaller the head of water the greater is the percentage of loss. The seepage loss is especially important if the water is run a considerable distance. A fruit or truck farm of 10 acres situated close to the pumping plant can be served fairly well with a head of 200 gallons a minute. Another disadvantage of small pumps is that they have lower efficiencies than do large pumps of the same types.

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On the other hand, if the pump is unnecessarily large, then the motor and transformer must be correspondingly large, and the minimum quantities of power that must be paid for according to the contract may be greater than the quantities actually used. The contracts for power that have been used by the Salt River Valley Water Users' Association require payment for large quantities of power in the summer months. The effect of this provision is exhibited in Table I, which gives the acreages required each month to utilize the minimum charges on pumping plants of several different capacities. It is assumed that the land is devoted to diversified agriculture with one-third alfalfa, one-third in cotton, and the balance double-cropped. The duty of water shown in the table is not too high for good, deep soil and good farming practice; for less favorable conditions the water requirements are greater. For alfalfa alone, the water requirements are greater, especially in the months of April, May, and June.

<table>
<thead>
<tr>
<th>Month</th>
<th>Depth of irrigation (Inches)</th>
<th>Minimum charge per kw. of demand (Dollars)</th>
<th>Pump discharge in gallons per minute (400, 700, 1000, 1400)</th>
<th>Acres (400), Acres (700), Acres (1000), Acres (1400)</th>
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</thead>
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<tr>
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<td>6</td>
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<td>19, 32, 46, 65</td>
<td>19, 32, 46, 65</td>
</tr>
<tr>
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<td>6</td>
<td>.3125</td>
<td>15, 26, 37, 52</td>
<td>15, 26, 37, 52</td>
</tr>
<tr>
<td>August</td>
<td>5</td>
<td>2.50</td>
<td>30, 52, 74, 104</td>
<td>30, 52, 74, 104</td>
</tr>
<tr>
<td>September</td>
<td>6</td>
<td>4.375</td>
<td>52, 91, 130, 182</td>
<td>52, 91, 130, 182</td>
</tr>
<tr>
<td>October</td>
<td>2</td>
<td>3.75</td>
<td>45, 78, 111, 156</td>
<td>45, 78, 111, 156</td>
</tr>
<tr>
<td>November</td>
<td>1</td>
<td>.3125</td>
<td>15, 26, 37, 52</td>
<td>15, 26, 37, 52</td>
</tr>
<tr>
<td>December</td>
<td>0</td>
<td>2.50</td>
<td>30, 52, 74, 104</td>
<td>30, 52, 74, 104</td>
</tr>
</tbody>
</table>

The acreages shown in Table I are proportional to the pump capacities. For a 500-gallon plant, the acreages would be one-half as great as those shown in the table for the 1000-gallon plant. The pump capacities are more than adequate for the maximum acreages shown; the acreages are the least possible for the several pump discharges, if the minimum amounts of power are to be used.

Inasmuch as it is desirable to use at least the amount of power represented by the minimum payments, it becomes apparent that the manage-
MOTOR DRIVEN PUMPING PLANTS

The area of the farm must be such as to require much active use of the plant in the summer months. Through June and July the plant must be operated 40 percent of the time, counting 24 hours per day. It is readily seen that, under the contracts referred to, large plants should not be installed for small acreages. Thus, if a 1000-gallon pump is installed for a tract of 60 acres, there are 4 months of the summer, during which the minimum power cannot be utilized. The 10-acre farm mentioned above will pay minimum charges in June if the pump discharge is more than about 90 gallons per minute.

The tabulation of areas would be somewhat different under other conditions. The purpose of Table I is to indicate in a general way how the minimum charges must affect the selection of the size of pump and the farm management.

In some parts of the State, where electric power is furnished by public service corporations, it is the custom to require the same minimum payment each month of the year, usually 75 cents or $1 per brake horsepower or per kw-hr, of installed capacity. Under such provisions, the minimum quantities of power are utilized easily in the summer months but not easily in the winter months. Water applied in the winter does not bring much return financially, except in the case of special crops of limited acreage, such as lettuce, spinach, onions, peas, and cabbage. In some pumping districts it is unwise to deplete the groundwater supply for winter grain crops, and in some districts cheap gravity water supplies are available in the winter. Table II exhibits the effect of the minimum payment provision during the winter months under certain assumed conditions. The 2-inch depth of application in November does not mean a 2-inch irrigation over all of the land, but implies that perhaps one-half of the area is given a 4-inch irrigation. The 1-inch irrigation in December may mean that a portion of the land is irrigated in that month, presumably in order to utilize the amount of power that must be paid for anyway. The public service corporations should be asked to revise the schedule of minimum

<table>
<thead>
<tr>
<th>Month</th>
<th>Average depth of irrigation</th>
<th>Pump discharge in gallons per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches</td>
<td>Acres</td>
</tr>
<tr>
<td>November</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>December</td>
<td>1</td>
<td>44</td>
</tr>
<tr>
<td>January</td>
<td>1</td>
<td>44</td>
</tr>
<tr>
<td>February</td>
<td>2</td>
<td>22</td>
</tr>
</tbody>
</table>
monthly payments for agricultural service, basing it on a schedule of monthly duty of water, such as shown in Table I. If that cannot be accomplished, then the contracts for power should stipulate clearly that if a farmer's disconnecting switch is kept open throughout a winter month there shall be no minimum charge for that month. The present contracts are very unfavorable.

In the proposed contract between the Pinal County Electric District No. 2 and the Salt River Valley Water Users' Association, the individual rancher is relieved of the burden of minimum charges based on the size of his plant. Under agreement with the District, however, he must use or pay for a minimum quantity of power each month, but this is irrespective of whether his motor is large or small.

The strongest argument against unnecessarily large pumps is that the fixed charges, which constitute a part of the cost of pumping, are increased thereby. The fixed charges—interest, depreciation, and taxes—are a definite sum each year. If this sum is divided over a few acres, the amount per acre will be large. At more than half of the one-farm pumping plants in Arizona the cost for fixed charges is greater than the cost of operation of the pumping plant. If the pumping plant is used from 60 to 85 percent of the total time, counting day and night, and then the fixed charges per acre will be moderate. The farmer's best opportunity to reduce the cost of pumped water is through an increase in the running time of his plant and consequent increase in the area irrigated. This subject is treated further on page 139.

In some localities, especially in California, small artificial reservoirs are built close to the pumping plants. This permits the use of a small pumping plant, and yet a large "head" is available for irrigation. This system, however, is objectionable for many reasons, among them being the added lift of 4 or 5 feet, the losses from the reservoir, and the cost of the reservoir. Certainly it is not to be recommended, unless possibly for ranches of a few acres only.

**COMPUTATION OF POWER**

Having determined the desirable size of pump, that is, the number of gallons per minute to be pumped, the next consideration is the computation of the amount of power required. The first step is to find the actual power represented in lifting the water, that is, the power that must be delivered by the pump. This depends on the pump discharge and on the total lift. The total lift equals the depth to the water table plus the amount the water level is drawn down by steady pumping, plus a small amount for friction in the suction and discharge pipes. The pipe friction is equivalent to a little additional lift. It should not be more than about one foot per hundred feet of pipe, and another foot should be added, if
there are a couple of elbows in the pipe. Then the following rule can be used:

Rule No. 1.—Multiply the number of gallons per minute by the total lift in feet, and divide the product by 3960. The result will be the water horsepower.

The result is close enough if 4000 is used as the divisor instead of 3960.

The next step is to find the amount of power that must be delivered to the pump. This depends upon the water horsepower and upon the efficiency of the pump. The efficiency is supposed to be known, at least approximately.

Rule No. 2.—Divide the water horsepower by the efficiency of the pump. The result will be the input of power to the pump.

Next, the motor horsepower is to be computed. It depends in part on the efficiency of the connection, which may be by belt, by gears, by chain, or by direct connection through a flexible coupling.

Rule No. 3.—Divide the input of power to the pump by the efficiency of the connection. The result is the motor horsepower.

The efficiency of a straight belt can be taken as .96, of a quarter-turn belt as .92, of gears as about .95. The efficiency of direct connection is practically 1.00, that is, there is no loss of power in direct connection.

The next step is to find the input of power to the motor.

Rule No. 4.—Divide the motor horsepower as found above by the efficiency of the motor. The result will be the input of power to the motor. This result will be in terms of horsepower, and should be multiplied by three-fourths to obtain the input in kilowatts.

Next, the input to the transformers can be found, though usually this is not of much interest to the farmer.

Rule No. 5.—Divide the input to the motor (expressed in kilowatts) by the efficiency of the transformers. The result will be the input to the transformers.

The losses in wiring between the transformers and the motor are small and can be neglected.

Some of the above computations can be turned about. For instance, when testing a pump, the water horsepower of the pump can be computed, and then, if the input of power to the pump can be ascertained, the water horsepower can be divided by the input, and the result is the efficiency of the pump.

A convenient rule that is approximately correct, is that 2 kilowatt-hours of electric power are required to lift an acre-foot of water through each foot of lift.
Table III is included for convenience of reference in the planning of pumping plants. The figures given therein are the water horsepower, not the actual motor horsepower.

**Table III—Water Horsepower Required for Various Discharges and Lifts**

<table>
<thead>
<tr>
<th>Gallons per minute</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>300</td>
<td>1.5</td>
<td>2.3</td>
<td>3.0</td>
<td>4.5</td>
<td>6.1</td>
</tr>
<tr>
<td>400</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>6.1</td>
<td>8.1</td>
</tr>
<tr>
<td>500</td>
<td>2.5</td>
<td>3.8</td>
<td>5.0</td>
<td>7.6</td>
<td>10.1</td>
</tr>
<tr>
<td>600</td>
<td>3.0</td>
<td>4.5</td>
<td>6.1</td>
<td>9.1</td>
<td>12.1</td>
</tr>
<tr>
<td>700</td>
<td>3.5</td>
<td>5.3</td>
<td>7.1</td>
<td>10.6</td>
<td>14.1</td>
</tr>
<tr>
<td>800</td>
<td>4.0</td>
<td>6.1</td>
<td>8.1</td>
<td>12.1</td>
<td>16.2</td>
</tr>
<tr>
<td>1000</td>
<td>5.1</td>
<td>7.6</td>
<td>10.1</td>
<td>13.2</td>
<td>20.2</td>
</tr>
<tr>
<td>1350</td>
<td>6.8</td>
<td>10.2</td>
<td>13.6</td>
<td>20.5</td>
<td>27.3</td>
</tr>
<tr>
<td>1800</td>
<td>9.1</td>
<td>13.6</td>
<td>18.2</td>
<td>27.3</td>
<td>36.4</td>
</tr>
</tbody>
</table>

**DESIGN OF PUMPING PLANT**

The design of a pumping plant consists of the computation of the elements of the plant as above, the selection of commercial sizes, and then the arrangement of the machinery and auxiliaries for convenience and economy in operation. The lack of symmetry of many pumping plants now in use is so great that it would be real economy to re-design them and make the necessary changes. The most common misfit is a large underspeeded pump operating at low efficiency. Sometimes the pump is set too high, or is set on insecure foundations which permit of much vibration. Belts are often subjected to the weather, and in too many cases the whole plant is out-of-doors. Frequently piping is too small; sometimes it terminates several feet above the ground, creating an unnecessary lift, as is illustrated in the cover cut. In some cases motors or engines are too large. A purchaser should obtain the best advice available to him, and should have his detailed plans thoroughly matured before placing an order for a pumping plant.

**AN EXAMPLE**

An illustration of the main features of design of a pumping plant is here presented.

Let it be supposed that a farmer wishes to irrigate 120 acres of diversified crops, that the soil is a deep loam, and that the climatic conditions and crops are similar to those of the Salt River Valley. It is assumed, also, that the depth to the groundwater plane is 40 feet and that the yield of the well is 50 gallons per minute per foot of drawdown.
From Table I it is seen that an average depth of 6 inches of irrigation will be required during certain summer months. On 120 acres, therefore, 60 acre-feet, or 720 acre-inches, per month, will be required. Inasmuch as 450 gallons per minute gives one acre-inch per hour, 720 acre-inches can be obtained in any one of the following ways:

- 450 gallons per minute for 720 hours.
- 600 gallons per minute for 540 hours.
- 800 gallons per minute for 405 hours.
- 900 gallons per minute for 360 hours.

It would be desirable to have an irrigating head of 1000 gallons or more. On the other hand, every additional 100 gallons increases the drawdown and the lift 2 feet. For that reason, and to keep down the cost of the plant (and the minimum charges, if the contract for power stipulates minimum charges based on the size of the plant), the design will be for 800 gallons per minute.

Assuming that the drawdown may become too great for a horizontal centrifugal pump, a vertical turbine or a propeller pump will be selected. The turbine has reached a definite stage of development with more manufacturers, and so, if the well is of 16-inch diameter or larger, it should be given the preference. The lift will be 58 feet.

The water horsepower can now be computed by Rule No. 1. (See page 97.)

\[ 800 \times 58 = 3960 \div 3960 = 11.7 \text{ water horsepower}. \]

Since the pump is to be built in the factory to meet the exact conditions, it should have an efficiency of about 62 percent. By Rule No. 2,

\[ 11.7 \div 0.62 = 18.9 \text{ horsepower, input to the pump}. \]

The well having been tested, it is safe to place the motor direct-connected on the pump, unless there is reason to expect considerable changes in the water level. There will then be no belt loss, and the motor horsepower will be 18.9 h.p. A 20-horsepower motor will be adequate, if it is not handicapped by poor ventilation.

By Rule No. 4, the input to the motor can be found,

\[ 18.9 \div 0.88 = 21.5 \text{ horsepower, and} \]
\[ 21.5 \times 0.75 = 16.1 \text{ kilowatts}. \]

Therefore, the electric meter can be expected to record at the rate of 16 kilowatt-hours per hour.

By Rule No. 5.

\[ 16.1 \div 0.97 = 16.6 \text{ kw., Input to the transformers}. \]

If the power factor is .90 (see page 118),

\[ 16.6 \div 0.90 = 18.5 \text{ kv.-a.} \]

Two 10-kv.-a. transformers, connected "in open delta," would have a capacity of 17.2 kv.-a., which is not enough to be safe in hot weather. Hence, three 10-kv.-a. transformers must be used. (For some voltages 7.5-kv.-a transformers can be obtained.)
The most practical speed for an 800-gallon turbine pump, direct-connected to a motor, is 870 revolutions per minute, if on 60-cycle current, and 720 revolutions per minute, if on 25-cycle current. Whichever one is required, the pump must be built for that speed.

GUARANTEES AND TESTS

Pumping machines should be purchased with guarantees of efficiency. It is useless to have guarantees, however, unless tests are made after the plant is installed to ascertain whether the efficiencies come up to the guarantees. It is difficult to test the efficiencies of pump and motor separately, but quite simple to test their combined (plant) efficiency. The latter requires only three measurements, the quantity of water pumped, the lift, and the input of power. It is preferable, therefore, to purchase the entire plant from one business house, with guarantees as to plant efficiency. Inasmuch as the exact amount of water yielded by the well for a given drawdown, or the drawdown for a given yield, may not be known in advance, the guarantees should cover several sets of conditions. Thus, the guarantees may state the plant efficiencies for 1000 gallons per minute on lifts of 50, 60, and 70 feet, and the efficiencies for 900 gallons per minute on those lifts. Reliable manufacturers have such information and give it, if requested to do so.

The manufacturer should furnish with each pump a blue-print of the characteristic curves of the pump, and it should be carefully preserved by the purchaser. It happens frequently that a pump is to be moved from one well to another, or is to be operated under changed conditions, and a copy of the characteristic curves is needed to tell the new speed required, or if the contemplated change is feasible.

The following clause, also, should be added to the contract: The Company further agrees to furnish an installing mechanic, to erect the plant complete, to operate it continuously for——-days, to conduct a test for efficiency in the presence of the purchaser or his representative, and to deliver the plant to him in perfect running order.

CLASSIFICATION OF PUMPS

Pumps are best classified according to the principles of their design and construction. Those which are of special interest in irrigation pumping are: Centrifugal pumps, which strictly speaking include vertical turbine pumps; propeller pumps; rotary pumps; reciprocating pumps; and air lift.

———For directions for measuring irrigating streams, see Timely Hint No. 57, Ariz Agr. Expt. Sta. A well should be a part of the equipment of every pumping plant.
Fig. 10.—A horizontal, single-stage centrifugal pump direct-connected to an induction motor. This pump has split case, double suction, and a long bearing on each side.
CENTRIFUGAL PUMPS

Of the various types of pumps, the centrifugal pump has been most used for irrigation pumping. Centrifugal pumps are adapted to large heads of water, they cost the least and are subject to the fewest troubles and interruptions to service. If the bearings are lubricated properly and the water is free from sticks and grit, they last almost indefinitely.

Centrifugal pumps are built either with a short horizontal shaft or with a long vertical shaft reaching to the ground surface. These two kinds are recognized as two distinct types, though the action of the rotating impeller is the same in both cases. The pump casing, or housing, is either circular or spiral in shape. In the latter case the pump is called a volute pump.

A small horizontal centrifugal pump is shown in Fig 11. The suction pipe is connected through a long-turn elbow. An increaser and a check valve are placed in the discharge column just above the pump outlet. The pump has two bearings, both on the same side of the housing, but on larger pumps there should be one bearing on each side. Some desirable features of construction are double suction, split casing, bronze impellers and other fittings, automatic hydraulic balance, and ring-oiling bearings.

The pump should be set as close to the water level as possible, so as to reduce the suction lift. The possible suction lift depends upon the atmospheric pressure, which decreases as the altitude increases. The practical suction lift for altitudes less than 4000 feet is limited to from 17 to 24 feet, though one plant, in Pima County, was found to be operating with 28 feet of suction lift. High suction lifts require especially well made pipe joints and tight gland packing. Tests of the pumping plant in the East well on the University Campus showed a sharp decrease in discharge and in efficiency when the suction lift exceeded 23 feet, though a searching investigation did not reveal any air leak. If, when a new well is tested, the suction lift is found to exceed 17 feet, and if it is desired to use a horizontal centrifugal pump, then it is advisable to try to develop the well to a better yielding capacity.

There are several ways of priming a pump, the most practical one being to exhaust the air from the top of the pump casing with a small hand-operated pump, the discharge pipe being closed by a check valve or a gate valve. Foot valves should not be used if the total lift is over 40 feet. A pump should never be run empty, that is, without water in it.

Multi-stage pumps consist of two or more centrifugal pumps built together as one machine. They permit of pumping against high heads with moderate speeds of rotation.

Horizontal centrifugal pumps are the freest from troubles; there is practically nothing to get out of order. They have the highest efficiencies, they are adapted to direct-connection with electric motors and they cost
Fig. 11.—A direct connected pumping unit in a combined pit and drilled well on the University Campus. The starting compensator is placed near the pump so that the lubrication and care of the pump will not be neglected. This pump and the motor have been in constant service for 8 years, expense for maintenance has been trivial.
Fig 12—Characteristic curves of pumps of three different types—horizontal centrifugal, vertical turbine, and propeller. For each set of curves the speed is approximately constant. The power increases with the discharge in centrifugal pumps, and increases with the lift in propeller pumps. The turbine pump shows a fairly good efficiency over a wide range.
much less than vertical pumps. Their disadvantages are that they must be primed, and, in case the water table fluctuates widely either from natural causes or due to pumping, it may fall below the limit of suction. A farmer is indeed fortunate if his well is such that he can use a horizontal direct-connected unit.

Vertical centrifugal pit pumps, with long vertical shafts held in cross-braced frames, were much used a few years ago, but have given way to vertical turbine pumps, which will be mentioned next. On account of the eccentric weight, it is difficult to hold the vertical shaft in good alignment in the frame, and therefore, vertical pit pumps are not capable of high speeds. They have one advantage over vertical turbines—the automatic water balance.

The "characteristics" of a centrifugal pump for a certain speed are shown in Fig. 12. These include the relation of discharge to lift, of efficiency to discharge, and of power input to discharge. The power required increases as the lift decreases, and consequently the power for a centrifugal pump should be designed for the lowest lift under which the pump will be operated.

VERTICAL TURBINE PUMPS

Vertical turbine pumps have been highly developed during the past decade, and are well adapted to irrigation pumping. Strictly speaking, they are vertical centrifugal pumps, but they are built with the vertical shaft enclosed within the discharge pipe so that they can be lowered into wells drilled from the ground surface, and they are built with such high mechanical perfection, at least by a few manufacturers, that they stand in a class by themselves.

The distinction between a turbine pump and other centrifugal pumps is that the turbine has, in addition to the rotating vanes, scientifically designed fixed vanes. The water issues from the impeller with very high velocity, and the fixed vanes aid in the conversion of the high velocity into pressure without excessive losses in eddies and shock. Horizontal turbine pumps are obtainable also, but few of them are found in irrigation service.

Each set of rotating vanes is called an impeller, or runner; the housing in which an impeller of a vertical turbine pump rotates is called a bowl. The diameter of a bowl is limited by the size of well casing in which it is to be placed, but in general it should be as large as possible, because better efficiencies are obtained with larger impellers and bowls than with small ones. The vertical lift of the water that can be obtained from an impeller varies approximately with the square of the diameter of the impeller and with the square of the speed of rotation. Since the speed is limited for mechanical reasons, it is desirable to have as large a diameter
as is practicable, in order to obtain a considerable life. Even so, it is usually necessary to use several impellers and bowls, one immediately above another, in order to lift the water to the ground surface. Fig. 13 shows the three bowls of a turbine pump. In general, the well casing should be at least 16 or 18 inches in diameter if it is desired to pump 1000 gallons per minute with a vertical turbine pump, and 24 inches in diameter for capacities greater than 2000 gallons per minute.

It is customary to use a turbine with $15\frac{1}{2}$-inch bowls, the most common size, in a 16-inch well casing. In several instances the pump has rusted in or has been sanded in so that it could not be withdrawn. An 18-inch casing would be preferable for lumps of that size. Also, if the well is not quite straight or plumb or if the casing is flattened a little, the additional space will be of great advantage.

The alignment of the pump shaft must be exact, and methods have been developed in several factories for securing accurate alignment. In two instances, at least, both in Pima County, the advantage was lost because
MOTOR DRIVEN PUMPINGPLANTS

One make of pump that is used considerably in California has no shaft bearings except some lubricer sleeves which can hold the shaft in approximate alignment at starting.

Another important feature is the protection given to the shaft bearings to prevent wear from sand and grit carried by the ascending column of water. This matter and the lubrication of the bearings and the construction of the pump head should be investigated closely by the purchaser of a pump, and assurance should be had as to the reliability of the pump when subjected to long, hard service. The record of the pump in irrigation districts should be learned, and no pump that has not proved its reliability absolutely should be purchased. A farmer cannot afford to experiment with pumping machinery, no matter how rosy its virtues may be painted.

A vertical turbine can be direct-connected to a vertical motor, or belted to a horizontal motor with a quarter-turn belt. The direct connection is advisable, if the yield and drawdown of the well are known accurately, and if the pump can be designed especially to fit the known conditions. Some allowance should be made for increased lift due to a moderate lowering of the water table in a district where it is expected that the groundwater development will be greatly increased.

The efficiencies of well-built vertical turbine pumps vary with both discharge and lift. The range of efficiencies is shown in Table IV.

### TABLE IV—APPROXIMATE EFFICIENCIES OF WELL-DESIGNED VERTICAL TURBINE PUMPS.

<table>
<thead>
<tr>
<th>Lift (Ft)</th>
<th>Discharge (gallons per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400</td>
</tr>
<tr>
<td>25</td>
<td>48</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>51</td>
</tr>
<tr>
<td>80</td>
<td>53</td>
</tr>
<tr>
<td>100</td>
<td>56</td>
</tr>
</tbody>
</table>

A groove should be machined in the sides of the bowls, to take a 3/4-inch pipe line for determining the position of the water table and the drawdown. A small charge is made by the manufacturers for this work, but it is essential for the intelligent operation of the pump.

### PROPELLER PUMPS

Propeller pumps, sometimes called direct-flow or axial-flow pumps, have propellers, somewhat on the principle of ship propellers, fastened
Fig. 14.—Interior view of pump house, showing pump head, motor, auto-starter, and enclosed switch.
at intervals of a few feet along a vertical shaft, which extends downward inside the column pipe to below the water level. Also, a nest of propellers is placed on the lower end of the shaft. Fixed vanes are placed just beneath or just above the propellers. The water is forced upward in an approximately vertical path. The pump might be termed an axial-flow turbine pump, but it is not a centrifugal pump.

The slope of a propeller vane with respect to a horizontal plane is called the pitch. It can be stated as the vertical length of a vane having 180° of curvature, or as the angle which the outside edge makes with a horizontal plane. This angle varies from 25° to 50°. Flat pitch gives good efficiency, but necessitates more propellers or that the pump be run at higher speed. Hence the design must be a compromise between the various desired features.

The design of the shaft bearings is of great importance. In the course of the development of propeller pumps during the past 10 years many designs of bearings have been tried and have failed, usually because they did not exclude sand and grit, but in some cases because of excessive speed. Some makers are endeavoring to do away with the shaft bearings, except for loosely fitting rubber sleeves to support the shaft when the pump is started. In one make at present on the market, the bearings seem to be well protected from sand and to be properly lubricated.

The characteristics of propeller pumps are quite different from those of vertical turbine pumps, as is shown in Fig. 12. In the case of a turbine, assuming that a constant speed is maintained, an increase in the lift causes a relatively big decrease in discharge, and causes a small decrease in power requirements. In contrast with this, an increase of head in a propeller pump causes much less decrease in discharge, but a big increase in the power required. In the former case, the owner may be disappointed in the amount of water delivered by the pump; in the latter case, he may be forced to buy a larger motor. In either event there is a decrease in pump efficiency, if the pump was properly designed for the original conditions.

In the case of a propeller pump, good efficiency can be restored by increasing the speed, if the pump is belted to a motor, or by adding more propellers if the pump is direct-connected to the motor. However, in either case there will be a comparatively large increase in the power required.

In the purchase of a propeller pump, therefore, the power should be designed for the highest lift for which the pump will be operated, and if there is any doubt in this regard, or if there is a possibility that the water table will recede considerably, then a motor with excess capacity should be bought.

The rotating vanes should not be called impellers, since that term has come to mean a runner through which the water moves under the action of centrifugal force.
The discharge of a propeller pump is determined largely by the speed, the effect of an increase in speed being about the same as in the case of vertical turbine pumps.

A great advantage of propeller pumps is that they can discharge comparatively large quantities of water from wells of small or medium diameters, provided, of course, that the wells can yield the water. A propeller pump of the Salt River Valley Water Users' Association in an 18-inch well yields 5450 gallons per minute. With a vertical turbine pump it is not practicable to pump more than 2200 gallons per minute from an 18-inch well. If it becomes advisable to pump very heavily from a drilled well, especially from a well of 12-inch or smaller diameter, a propeller pump is probably the best for the purpose.

The advisability of using small well casing for a new well is questionable. If the small casing is used, then there can be no choice as to the type of pump; and furthermore, the yield from a small casing may be disappointing. It should not be forgotten, that increasing the draught
Fig. 16.—Pump head of a reciprocating pump of good design and construction. It has overlapping strokes, constant discharge, and silent chain drive. On account of high cost, the field of use of pumps of this type is limited to high lifts and high-priced crops.

on, as well causes a deeper drawdown, resulting in a greater lift and in increased cost of pumping.

It is believed that propeller pumps will be improved much further in the next few years. It is probable that better shapes of propeller vanes and fixed vanes will be found by laboratory research.

Screw pumps are built on the same principle as propeller pumps, but are designed to handle very large discharges against heads of less than 10 feet—conditions which occur frequently in drainage practice. A screw pump has one propeller with many vanes.
ROTARY PUMPS

Pumps of this type have one or two rotating members which with each revolution cut off a certain amount of water from the suction side of the pump, and drive it to the discharge side. The pump shaft is horizontal. Small rotary pumps are quite common and rotary pumps of large capacity can be had.

The adaptability of rotary pumps is much circumscribed. Like horizontal centrifugal pumps, they must be placed just above the water. They run at low speeds and, therefore, are not adapted to direct-connection with electric motors. They are larger in size than centrifugal pumps, and it is necessary to keep them in close adjustment to prevent excessive "slip" of the water.

A rotary pump does not have to be designed especially for the conditions under which it is to be used. A stock pump can be used for any lift, and the discharge, also, can be varied by changing the speed. The efficiency of a new pump is high over a wide range of vertical lift, but the efficiency decreases as the wear and slip increase.

A rotary pump is adapted to service where there are two lifts or where the lift is very variable. At the Salt River Valley Experiment Farm a rotary pump of 100 gallons capacity lifts water from a well, about 35 feet to the ground surface or to an elevated tank, as required.

Vertical rotary pumps with long shafts have been built and marketed, but they have not proved satisfactory in service.

RECIPROCATING PUMPS

Small single-acting reciprocating, or plunger, pumps are common, being in use with windmills or gasoline engines at thousands of house wells in Arizona. Plunger pumps of large capacity are impractical, because of the slow speed. Forty strokes per minute are about the limit for low lift, and 30 strokes per minute for lifts of 80 to 90 feet. At 30 strokes, about fifty gallons per minute can be obtained from a 6-inch cylinder with a single-acting pump, that is, with a single piston and one line of pump rods. Such pumps can be used, in conjunction with small, low, earth reservoirs, for the irrigation of home gardens.

The stroke of a plunger pump, for irrigation, should be about twice the diameter of the cylinder for lifts up to 50 feet, and the ratio should increase as the lift increases. The cylinder should be of brass or brass-lined. The discharge pipe should be a trifle larger than the cylinder. Hard-wood pump rods are preferable to pipe rods, and the rod couplings should be heavy forged straps with copper rivets, with threaded joints. At each joint there are a pin and a socket with a square shoulder on each.
In putting the rods together, they are screwed up until the shoulders butt tightly.

Double-acting plunger pumps have two lines of pump rods, one within the other, and two pistons in the working barrel (cylinder). One rod ascends while the other descends. Several makes of double-acting pumps have overlapping strokes and constant discharge without pulsation or shock. Other makes, though double-acting, do not have overlapping strokes, and are merely two single-acting pumps; they are greatly overrated. Pumps with overlapping strokes, of capacities up to 600 gallons per minute, are on the market, but they are expensive, and seldom are justifiable for irrigation pumping, except on high lift for high-priced crops like citrus fruits. They have good efficiency, but the cost of maintenance is high, especially if the water contains sand. The Experiment Station installed one of 100 gallons capacity, at the Sulphur Spring Valley Drip-Farm, on a lift of 90 feet, the reason for its selection being that it had to be placed in an 8-inch bored well.

The mechanical features of plunger pumps require discrimination on the part of a purchaser. The gears, the valves, the bearings, the leathers, the kind of metal, the machining, the lubrication—all should be investigated. An extra set of leathers should be kept on hand.

**AIR LIFT**

Pumping by means of compressed air is found occasionally in pump irrigation districts. Its great advantage is that heavy draught can be made on wells of small diameter, wells too small for a vertical turbine pump. Heavy draught, however, means greater drawdown and increased lift and cost. There are no moving parts in the well to get out of order, only the air line of small pipe and the discharge column, but on the other hand there is an air compressor to operate and maintain.

It is admitted that air lift is of low efficiency, and in general it should not be adopted for pump irrigation. One air-lift plant alone, tested by the Irrigation section, showed fair efficiency.

**BUCKET PUMPS**

Pumps of this type are impractical for irrigation service. However, as one saddened Arizona farmer remarked, “the buckets can be salvaged and used for hog troughs.”

**FREAK PUMPS**

Pumps that have no merit whatsoever appear on the market occasionally. There are always some good talking points. Not infrequently the most extravagant claims are made for a new pump. "Twice the water with
half the power" is a fetching slogan. Many of the statements printed in red ink make perpetual motion look like a wasteful process.

A letter of protest was addressed to a manufacturer, stating that the Arizona Agricultural Experiment Station considered it to be a duty to endeavor to protect pump irrigators from imposition. The reply, far from admitting the obvious errors of the prospectus, reiterated the statement that "where the lift is under fifty feet we absolutely guarantee to handle water with 50 percent less power than any pump manufactured, and where the lift exceeds fifty feet we guarantee to handle water with 65 percent less power." The reply proved that the writer was both ignorant and reckless.

The standard pumps, both centrifugal and others, have been brought to their present degree of perfection through slow evolution. Their merits are known. It is far better to purchase machinery that is already proved than to experiment with untried machines on the strength of glittering promises.

**PIPING**

Suction and discharge pipes of centrifugal pumps should be of such sizes that the velocities of the ascending water will not be more than 5 or 6 feet per second. If the discharge is carried through a considerable length of pipe from the well to a tank, the velocity in the pipe should not be over 4 feet per second. The following sizes are recommended.

<table>
<thead>
<tr>
<th>Discharge (Grt. per min.)</th>
<th>Diam of pipe (Inches)</th>
<th>Discharge (Grt. per min.)</th>
<th>Diam of pipe (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>4</td>
<td>1000</td>
<td>8</td>
</tr>
<tr>
<td>400</td>
<td>5</td>
<td>1350</td>
<td>10</td>
</tr>
<tr>
<td>700</td>
<td>7</td>
<td>2000</td>
<td>12</td>
</tr>
</tbody>
</table>

Valves have been discussed on page 102. If there is a gate valve in the discharge line, it is desirable to close it before shutting off the power.

Every pump should be protected by a strainer on the lower end of the suction pipe. The passages through the strainer should be small enough to prevent the entrance of anything that cannot pass through the pump readily. The total area of passageways should be so great that the loss of head will be small, and this is especially important for suction lift. The top of the strainer should be submerged at least 4 feet, to prevent the intake of air in downward whirling water.

Elbows in the pipe line should be what are known as long-turn elbows.

The discharge should be at low velocity and at a level no higher than is required.
Several pump manufacturers issue excellent instruction books, covering the installation, operation, and care of their pumps. A purchaser of a pump should obtain such a book and should observe the instructions faithfully.
In power contracts and in the purchase of transformers, motors, and auxiliary equipment, the farmer encounters many electrical terms which are new to him. It is desirable that he have a fair conception of the meaning of the terms which he must use. One often hears such questions as the following: Can the number of cycles be changed in a transformer? What is a volt? Single-phase? Load factor? To meet this demand for information the following explanation of terms in common use is offered:

**Voltage.**—Electric current can be thought of as flowing along the wires. But what causes it to flow? There must be a pressure. This electric pressure is called the voltage. The unit used to measure electric pressure is the volt. Just as water flows through a water wheel under a pressure that is measured in feet, so the electricity flows through an electric motor under a pressure that is measured in volts. If the head on a water turbine is increased 10 percent, the power is increased 10 percent. Similarly, in the computation of power consumed in a motor, the applied voltage is one of the factors determining the amount of power consumed.

**Current.**—The quantity of electricity flowing in a wire is quite different from the voltage or pressure. The quantity, or rate of flow of electricity is called the electric current and corresponds to the quantity of water per second flowing through the water wheel or through a pipe line. The quantity of water is measured in cubic feet per second, while the electric current is measured in units called amperes. An ampere is a unit of current.

There are two kinds of electric current—direct current and alternating current. The direct current may be thought of as always flowing in one direction, while the alternating current dances back and forth like a shuttlecock with rapid "alternations" of direction. Alternating current is used almost exclusively for long distance transmission of power.

**Frequency.**—This term is applied to alternating current, and refers to the number of alternations per minute. The current commonly used throughout the United States has 7200 alternations per minute. The current generated by the Salt River Valley Water Users' Association, however, has only 3000 alternations per minute.

**Cycles.**—This is another way of designating the frequency. A cycle consists of two alternations, or rather of two electric impulses, one in each
direction. Therefore 7200 alternations per minute equal 3600 cycles per minute or 60 cycles per second. Similarly, 3000 alternations per minute equal 25 cycles per second. In one case, the current is called 60-cycle current, and in the other case it is called 25-cycle current.

**Power.** — The power depends upon both the current and the voltage or pressure, just as the power of a water wheel depends upon both the quantity of water per second and the pressure head. The electric power varies directly with both the number of volts and the number of amperes.

**Watt and kilowatt.** — These are the units of power used in connection with motors and electric lighting. The kilowatt equals 1000 watts. The watt is a small unit; the kilowatt, being larger, is better adapted to measure the power of motors. A kilowatt equals almost exactly one and one-third horsepower. It is usually written kw.

**Work.** — Speaking more exactly, it is work and not power that is bought, measured, and paid for. Power is the rate of doing work. Work depends upon the rate and also upon the duration of time, that is, the number of hours. However, the term power is often used to mean work.

**Kilowatt-hour.** — This is the unit of work. It is the work done by a kilowatt in one hour. The cost of electric power service is based on the number of kilowatt-hours consumed. The meter placed near each pumping plant measures the number of kilowatt-hours. The abbreviation is kw-hr.

**Resistance.** — There is a resistance to the flow of electric current in a wire, and this resistance causes a loss or waste of power. It is analogous to the friction loss of water flowing in a pipe line. The unit of resistance is one ohm. The resistance of different materials varies tremendously. Copper has very little resistance, and is therefore an excellent conductor of electricity.

**Insulation.** — Some substances such as glass, rubber, and porcelain, have resistances so great that practically no electric current can flow or even leak through them. These substances are used for insulators, and by means of them, the current can be kept in the wire circuit.

**Single-phase.** — The simplest arrangement is to have two wires only. The two wires form a complete circuit. If an alternating current is transmitted over this circuit, it is called a single-phase current. Let the two wires be designated as No. 1 and No. 2.

**Two-phase.** — If another wire (No. 3), is strung alongside, and a similar current is transmitted over the completed circuit formed by No. 2 and No. 3, at the same time that the circuit through No. 1 and No. 2 is active,
then the combined current in the three wires is called a 2-phase current.\footnote{Four wires are used for 2-phase current ordinarily, but this is for other reasons.}

Three-phase.—If a third current, similar to the other two, is being transmitted in the closed circuit formed by No. 1 and No. 3 wires, then the combined three currents are called a 3-phase current. One advantage of the 3-phase current is that only three-fourths as much copper is required to transmit a definite amount of power as with a single-phase current. Motors, except some of very small size, are so wound as to utilize the three similar, equal currents simultaneously. Such motors are called 3-phase motors. They are positive in starting, while single-phase motors are not unless especially equipped.

Load factor.—If all pumping plants on a transmission line are operated for eight hours through the middle of the day, and are idle the other 16 hours of the day, then the transmission wires must be comparatively heavy and costly. If the same service, that is, the same total daily demand for power, is distributed equally over the 24 hours, then much smaller wires can be used. In the first case, the average load for each 24 hours is only one-third of the load during the hours of pumping, and the load factor is said to be one-third, or 33 percent. In the second case, the load factor would be 100 percent. The load factor is the ratio of the average load to the maximum load, or to the nominal load for which the system must be kept in readiness to serve. A high load factor is desired for many reasons, and this requires that the load be distributed as evenly as possible over the 24 hours, and without high "peaks."

Power factor.—Alternating current, particularly in induction motors, is of such a character that a part of the current does no work. This part is sometimes called the wattless current, yet it helps to use the capacity of transmission wires and of transformers and is subject to losses. A low power factor means that the wattless current is excessive. Induction motors have a favorable power factor when carrying a load of more than about two-thirds of the rated capacity, but have a low power factor when loaded lightly.

Transformers are rated in kilovolt-amperes (written kv.-a.), which include both the real power and the effect of the wattless current. If the number of kilovolt-amperes is multiplied by the power factor, the result is the number of kilowatts of real power.

Torque.—This refers to the leverage exerted by the motor to turn the shaft. It is expressed by the pounds pull at one foot radius. It is of greatest importance when starting the motor or when the load is thrown on suddenly.

Primary power.—Guaranteed power, available at all times.
MOTOR DRIVEN PUMPING PLANTS

Secondary power.—Power that is not guaranteed, but is available according to conditions.

MOTORS

Of the several types of motors, the squirrel-cage induction, 3-phase motor, is the most suitable for farm pumping plants. It has many advantages over slip-ring motors. The rotating part, called the rotor, has no windings of wire, but has copper bars insulated but slightly, or not at all, from the iron core and spider. There are no slip-rings nor commutator nor brushes—nothing that requires attention. The windings or coils are built in the stationary part, which is called the stator.

A 3-phase motor (or a 2-phase motor) tends to start promptly when the circuit is closed. A single-phase motor does not have this tendency, and special devices are required for starting.

A horizontal motor is built with a heavy cast-iron base. If for belt drive, the motor rests on slide rails to permit easy adjustment of the belt tension. A “complete motor” includes pulley, starting compensator, slide rails and base or adjustable base; a “bare motor” does not include them. This distinction should be understood by a purchaser.

VOLTAGE

For pumping service, either 220-volt or 440-volt motors should be used. The former is perhaps preferable. If it is selected, the same circuit can be used for lighting. Motors with high voltage, such as 2200 volts, although they are used to some extent in pumping plants, are not desirable, particularly in pits or where the motor cannot be kept entirely dry at all times. Even low voltages, such as 220 volts or 110 volts, may be dangerous under some unusual conditions, but not nearly so much so as high voltages. Precaution is required at all times to protect the insulation of electric machines and of all wiring, and to protect the attendant from the current. As one means of protection to the attendant, the motor frame should be grounded to the well casing.

SPEED

With present practice in building centrifugal pumps, speeds of from 720 to 1750 revolutions per minute are most used. If the motor is to be direct-connected to the pump, it must have the same speed as the pump. Motor speeds offer small choice, particularly with 25-cycle current. For motors of less than 50 horsepower, speeds of 1450 (25-cycle) or 1750 (60-cycle) revolutions per minute are possible, and are used considerably for high lifts. But in general the 720 speed will be most used with 25-cycle current, and the 870 and 1160 speeds with 60-cycle current. The
480 bpeed is too low except for very large low-head pumps. The motor speed must be selected first, and then the pump must be designed for that speed.

It should be explained that motors run a little slower when loaded than when running idle. This reduction of speed is called the slip. It seldom over 4 or 5 percent. Thus, a 4-pole motor, with 25-cycle current, has a (synchronous) no load speed of 750 revolutions per minute, but with full load its speed will be about 720 revolutions per minute. With a partial load the speed will be intermediate between 750 and 720. The synchronous speeds and the approximate speeds at full load are shown in the accompanying table.

<table>
<thead>
<tr>
<th>No of poles</th>
<th>60 cycles</th>
<th>25 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No load</td>
<td>Full load</td>
</tr>
<tr>
<td>2</td>
<td>1800</td>
<td>1740</td>
</tr>
<tr>
<td>4</td>
<td>1200</td>
<td>1160</td>
</tr>
<tr>
<td>6</td>
<td>900</td>
<td>870</td>
</tr>
</tbody>
</table>

**RATING**

The heavier the load a motor carries, the hotter the motor becomes, and the capacity of a motor depends wholly upon how much heat it can stand. In general, motors have been rated by the load which they can carry without a rise of temperature greater than 40°C. (72°F.), the test to be made in a surrounding air temperature of 104°F. The motors are so built and with such insulation in the windings that ordinarily they can stand safely a 25 percent overload for two hours, but the windings should never be subjected to a temperature above 190°F. A special method of rating was adopted a few years ago, based on a rise of temperature of 50°C. (90°F.) at full load, with no overload guarantees. Some motors were built and sold on that basis, but more recently manufacturers have abandoned it entirely.

In buying an old motor, it is important to know whether it is a 40° or 50° motor. In many cases this can be ascertained from the name plate. A 60-h.p. 50° motor is about equivalent to a 50-h.p. 40° motor.

The efficiency of a motor is quite uniform from two-thirds of the rated load to full load. There is no reason why a motor should not be used in service at full load continuously, provided good air ventilation is maintained, but on account of the high midsummer heat in the Arizona pumping districts, motors should not be overloaded.

The rating is guaranteed usually for a range of voltage of 10 percent above or below normal voltage.
STARTING

Very small motors are usually started by merely closing a switch, but every motor of over 5 horsepower is provided with a compensator, also called an auto-starter. The handle on the auto-starter has three positions. To start the motor, the handle should be moved from the neutral to the "starting" position, where it should be held until the motor starts and comes up to normal speed; then the handle should be thrown quickly to the "running" position. Many operators do not hold the handle on the starting position long enough; however, it should never be held there over 15 seconds, because of the injury that would be done to the transformers.

When the motor is started for the first time after being connected to the line, there will be uncertainty as to the rotation. If the motor starts to rotate in the wrong direction, it should be stopped at once, and two of the connecting wires should be reversed on the terminals.

The auto-starter contains a low-voltage release. Therefore, if for any reason the line becomes "dead," or the voltage drops dangerously low, the starting switch will be released automatically and will return to the neutral position. It then becomes necessary to start the motor again in the usual manner. In most cases the auto-starter contains, also, an overload release, which trips out the starter when the motor becomes overloaded. Many auto-starters have a push-button or a trip lever by means of which the operator can stop the motor; in other cases the motor is stopped by moving the starting handle back to the neutral position.

Automatic compensators, which start the motors again after a brief interval after the current comes on again, are on the market. They are of great service where one operator has the care of many pumping plants. They can be so adjusted that only one motor will start at a time.

LUBRICATION

Horizontal motors have oil-ring bearings and the oil level should be kept quite constant by adding occasionally a small amount of special "motor and dynamo oil." Although this is required only at infrequent intervals, yet the oil level should be examined often. Vertical motors generally, and some horizontal motors, have ball bearings. "Motor and dynamo oil" is used for vertical motors, but horizontal motors with ball bearings are lubricated with grease.

FOUNDATIONS

A horizontal motor should be set rigidly on a concrete foundation, though small motors are set sometimes on heavy timbers. The dimensions for the concrete foundations should be such that a ledge of a few inches will be left on each side of the motor base. The depth of the concrete should be from 1 to 3 feet, depending on the size of the motor.
concrete proportions should be as follows: 1 part cement, 3 parts clean sand, and 5 parts broken stone, or 1 part cement to 5 parts clean gravel. Anchor bolts should be set accurately by means of a template, and a piece of 2-inch pipe should be placed around each anchor bolt. The template should be so placed that the motor shaft will be exactly parallel to the pump shaft, if the pump is of the horizontal type. If pump and motor are direct-connected on the same cast-iron base, then the concrete foundation must be of proper size to support the entire machine. The concrete should be left to harden several days before the motor is placed on it. The motor must be bolted down securely. It should run without vibration.

DRIVE

Motor and pump may be direct-connected by a flexible link or bushing type coupling, or they may be connected by belt, or by gears. The direct connection has decided advantages, but it is not always feasible. It cannot be used unless the yield of the well and the drawdown have been measured, and not unless there is reasonable assurance that the yield and the lift will continue fairly constant.

If the belt drive is used, then good belting, preferably rubber, should be purchased. Leather belting is not advisable for use in pumping plants. If the alignment and the tension are fairly good, a new belt takes care of itself, but old belts often give much trouble and should be replaced with new ones. The tension should be in the under side of the belt, and the slack in the top side. For quarter-turn belts, the pulley centers should be 15 to 22 feet apart, depending on the size of the motor, and the fall from the center of the driving pulley to the center of the pump pulley should be from 8 to 12 inches. A rule that has been used by the Southwest Cotton Company is the following: The top of the motor pulley should be higher than the top of the pump pulley by \( \frac{1}{2} \) inch for each foot between centers.

The rule for determining the width of belt is as follows: The belt will transmit 1 horsepower per inch width for each 1000 feet per minute of belt speed.

The use of idlers ordinarily has not been considered desirable, because of the loss of power.

SECOND-HAND MOTORS

Good judgment is required in the purchase of second-hand motors and it is well to require guarantees. If the motor has been used in the vicinity, its history of use and abuse is probably known. "Rebuilt" motors are sometimes merely repainted motors. Rewinding costs 50 percent or more of the cost of a new motor. Second-hand motors are likely
to be of old types, and less efficient than new types. A difference of only 2 percent in efficiency means larger power bills and offsets a considerable difference in the cost of the motors. Before a motor is rewound to
a different voltage or is reconnected for 3-phase current, inquiry should be made of the manufacturer concerning the particular motor, stating its serial number, and asking if it is feasible to make the change.

**HOUSING**

Ordinary motors are not built for service out-of-doors. They must be protected from rain and dust storms. They should be well housed, but with provision for free ventilation when they are in operation. The house should be fireproof. The walls of a pump house should be of adobe or brick on a concrete base, or of galvanized iron. The roof and doors should be of galvanized iron. Small direct-connected vertical units can be housed very simply, as shown in Fig. 20.

If a motor is set down in a well pit, it should not be left idle for more than 3 or 4 weeks at a time, as it is likely to absorb too much moisture in

**TABLE VII—APPROXIMATE WEIGHTS AND RETAIL PRICES OF 3-PHASE, HORIZONTAL, SQUIRREL-CAGE MOTORS, COMPLETE.**

<table>
<thead>
<tr>
<th>H.P.</th>
<th>60-cycle</th>
<th>25-cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.P.M.</td>
<td>Weight</td>
<td>Price</td>
</tr>
<tr>
<td>60</td>
<td>440</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>375</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>
a damp location. Motors are obtainable with special moisture-proofed insulation, but at slightly higher cost.

Rust must be prevented. If the paint wears off, the motor should be repainted. Exposed bright metal parts should be slushed with grease if the motor is left idle.

WEIGHTS AND PRICES

A general survey of the prices of squirrel-cage motors will be of much service in a new electrical district. Table VII gives the approximate weights and retail prices of three-phase horizontal motors including pulleys and slide rails, of various capacities and speeds, for both 60-cycle and 25-cycle current. The prices for 220-volt and 440-volt motors are the same throughout the table except for the 60-cycle, 40 h.p. and 50 h.p. motors; for those cases the 440-volt motors cost about 5 percent less than shown in the table. The prices given include freight in carload lots to Casa Grande. Much lower prices can be obtained by collective buying so as to get jobbers' discounts.

The prices of vertical motors are somewhat higher than those given in Table VII. In the case of 25-cycle motors, the difference is from 10 to 15 percent, and for 60-cycle motors, it is from 20 to 25 percent.

TRANSFORMERS

The purpose of the farmer's transformers is to transform the small current of high voltage to a larger current of low voltage. The great advantage of alternating current lies in the ease of transforming it from low to high voltage for transmission over long distances and then from high to low voltage at the points of use. The high voltage on the transmission line reduces the weight and cost of the copper wires; the low voltage in the pump house reduces the difficulties of insulation and, also, the element of danger.

LOCATION

Transformers are placed on a pole or on a high platform supported by two poles, in order to prevent persons from coming in contact with the high voltage wires. Sometimes small transformers are placed on a single pole well set in the ground, but always it is preferable to have two poles and a platform. For high-voltage wires, cedar poles 40 feet long should be used. The platform should be at least ten feet above the ground, and no ladder should be attached to it. The poles, below the platform, can be wrapped with barbed wire. No inexperienced person should climb up to the transformer platform.

Transformers of great capacity such as those at central power plants are set sometimes on foundations close to the ground, and then enclosed
Fig. 18.—Three substations in the Santa Cruz Valley, showing variety of equipment and mounting. The transformers should be mounted on a high platform. The disconnects and fuses on the pole at the right are very inferior to the automatic circuit-breaker shown at the left. The series resistance shown at left reduces the surge in case of lightning. The horn gap, which is used in all three installations, is a poor type of lightning arrester.—Photo by W. E. Bryan.
MOTOR DRIVE PUMPING PLANTS

in high impenetrable fencing. Transformers at pumping plants should never be set on the ground.

CONSTRUCTION

The transformer is an enclosed metal tank containing two coils of wire and a laminated iron core. There are no moving parts whatever. In one type, the coils surround the core; in another type, the core surrounds the coils. Core and coils are immersed in a special transformer oil. One coil is connected to the transmission line, the other to the motor. The change of voltage is proportional to the number of turns of wire in the coil. Thus, to transform a 11,000-volt current to 220-volt current, the primary coil must have 50 times as many turns as the secondary coil. There is a little additional drop in voltage as the load increases. Both transformers and motors must be designed for the frequency and voltage of the transmission line on which they are to be operated. Usually, there is an extra tap from the middle of the low-tension coil, so that a circuit with half the regular voltage can be taken off.

On account of the line loss, the voltage available on a long transmission line decreases slightly as the distance from the source of supply increases. Near the end of main feeder lines, or of lateral lines, the voltage may be too low for satisfactory operation of motors. For such cases, transformers with two extra taps on the high-tension coils can be purchased. They give 5 and 10 percent higher voltages respectively at the motor. A purchaser should make sure that the capacity of the transformers that he is buying is not lowered by the use of the extra taps. The practice is not generally encouraged by some manufacturers, but it provides for flexibility, which is very desirable in large transmission systems. If the voltage is not over 10 percent below normal, the motor will operate satisfactorily, but if there is a possibility that the voltage may be as much as 10 percent below normal, then transformers with the extra taps should be purchased.

CONNECTIONS

To transform a 3-phase current, one 3-phase transformer can be used, or three separate equal single-phase transformers. The latter arrangement is preferable at pumping plants. Thus, three 10-kva single-phase transformers should be used for a 25-horsepower motor. The single-phase transformers are much easier to handle than an equivalent 3-phase transformer, being lighter in weight. The cost is practically the same in the two cases. The single-phase transformers are wired to each other and to the transmission line as though they were plated together to form a triangle. This arrangement is called the delta connection.

If one of the single-phase transformers is damaged, due to lightning or other cause, it can be disconnected and the other two can be operated for
a time "on open delta," until a new transformer can be obtained or the damaged one repaired. If there is but little excess capacity, they should be used, perhaps, only 2 or 3 hours at a time on open delta, and in hot weather only at night or when there is a strong breeze.

Another alternative is to install two larger single-phase transformers for permanent service. This practice is not to be recommended, however. A transformer has only 86 percent as much capacity on open delta as it has when connected regularly in delta. There is another system of connecting three transformers, called the Star or Y-connection, but it is inferior to the delta connection for farmers' substations.

TABLE VIII—APPROXIMATE WEIGHTS AND RETAIL PRICES OF STANDARD SINGLE-PHASE TRANSFORMERS.

11,000 volts to 220 or 440 volts
(Three equal transformers required in a set for three-phase currents)

<table>
<thead>
<tr>
<th>Capacity (Kw.-a)</th>
<th>60-cycle</th>
<th>25-cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kg.</td>
<td>Lbs.</td>
<td>Dollars</td>
</tr>
<tr>
<td>2.5</td>
<td>330</td>
<td>125</td>
</tr>
<tr>
<td>5</td>
<td>510</td>
<td>160</td>
</tr>
<tr>
<td>10</td>
<td>760</td>
<td>210</td>
</tr>
<tr>
<td>15</td>
<td>780</td>
<td>210</td>
</tr>
<tr>
<td>25</td>
<td>1240</td>
<td>340</td>
</tr>
</tbody>
</table>

Note: These transformers include two extra taps, with full capacity on the 10 percent tap.

RATING

Transformers are rated, not in kilowatts, but in kilovolt-amperes, usually written kv.-a. The kv.-a. would be equal to the kilowatts, if the power factor were 100 percent, as indeed it is in a circuit furnishing power for electric lighting. But for induction motors the power factor is always considerably less. One kv.-a. per motor horsepower is the general rule for determining the minimum size that can be used. If the power factor is 90 percent and the motor efficiency is 85 percent, then exactly one kv.-a. is required for each horsepower performed by the motor. Transformers are rated at 55°C. rise in temperature. In selecting the size of transformers required for a plant, a capacity of from 1 to 1.2 kv.-a. per horsepower of motor output should be allowed.

WEIGHTS AND PRICES

The weights and costs of transformers are dependent upon the voltage and the ratio of transformation. Hydroelectric power is transmitted usually at very high voltage, and the cost of transformers, therefore, is relatively high.

The approximate weights and approximate retail prices of transformers of standard sizes are given in the accompanying table. The prices include
freight in car load lots to Casa Grande. Manufacturers should add a 7.5 kv.-a. size to the list of stock sizes.

LIFE

Transformers should be inspected every few months to make sure that the supply of oil is being maintained. A little oil must be added occasionally. If a transformer has a leaky case, oil must be added oftener. Transformer oil is a specially prepared oil, free from acids, moisture, and impurities. No other oil should be used. The oil should be tested for moisture several times each season in a special testing apparatus, one of which should be available in each electrical district. For 11,000 volts, the amount of water must not exceed one part in 2000 parts of oil by volume, and for 44,000 volts, it must not exceed one part in 100,000. Fine dust in the oil is as injurious as moisture, and the sediment and slime produced by long continued heating of a transformer must be removed occasionally.

The length of life of a transformer depends not only upon the care and attention given to it, but also upon the construction — the material used for insulation, the means provided for effective radiation of the heat generated within the transformer, and other details of construction. A good transformer in irrigation service, properly cared for and not overloaded, should last 20 years. Transformers are subject to damage by lightning during the summer rainy season. Usually, in such cases the primary coil is injured. A set of new primary coils for a transformer costs about one-half as much as a new transformer. If a small transformer is burned out, it is economy to abandon it and to install a new one.

AUXILIARY ELECTRICAL EQUIPMENT

In addition to the motor and transformer, the farmer must provide a disconnecting switch and lightning arresters on the transformer platform and poles; a metering equipment; and all the wiring between the transmission line and the motor. The transformer platform and poles and the equipment thereon is called the farmer's substation.

SWITCHES

The purpose of a switch is to disconnect the circuit so that the flow of electricity is cut off. A switch is “closed” to permit the current to flow, and is “opened” to shut off the current. There may be more than one switch at a pumping plant, depending upon the type of installation.

A disconnecting high-voltage switch between the transmission line and the transformers is indispensable. It is placed high up on one of the poles of the substation. A common type is a three-pole switch with long air-break blades. An example of this type is shown in Fig. 18. For
Fig 19—Diagramatic sketch of the electrical connections at a pumping plant. The "ground" wire, which is shown as terminating abruptly, is carried down one of the poles and connected to the well casing. A 3-phase meter is shown, and there is no air-break switch nor fuses.
installations smaller than 50 kVA, these switches are built by some manufacturers into a combination with fuses and lightning arresters. A much better type, however, is the closed-case, automatic oil switch, or circuit-breaker, such as the Kelman, shown in Fig. 17. The circuit-breaker is mounted on the side of one of the poles. All disconnecting switches are operated from the ground.

An air-break switch is opened readily when there is no "load" on the wires, but if opened when the pumps are running, long hot arcs follow the blades, and the contacts may be burned considerably; in an oil circuit-breaker, the arc is quenched instantly by the oil. Furthermore, in case of short-circuit or heavy overload of any kind, the oil circuit-breaker opens automatically before damage can be done; the air-break switch does not give this protection.

On the Litchton project in Maricopa County, where oil circuit-breakers have been used, not a single transformer has been burned out, while at Marinette and at Goodイヤ, the loss of a transformer has been a frequent occurrence.

Oil circuit-breakers, of the type that cannot be tied or held in on an overload, should be used at all pumping plants. The air-break switches that are now in use at many substations should be replaced by automatic oil switches. This is true especially for all voltages higher than 6000 volts.

In many installations a knife switch is placed between the transformer and the auto-starter. This permits of opening the circuit at that point if work is to be done on the motor or auto-starter. It is convenient to use also if the motor and compensator are in the well. A knife switch, with three blades, or "poles," is shown in Fig. 20. For a single-phase motor, a two-pole switch is used. A starting switch must have sufficient carrying capacity for the current and must be insulated sufficiently for the voltage. Therefore, in purchasing a knife switch, the voltage and the number of amperes per wire should be stated.

A knife switch is accompanied usually by a fuse block, with one fuse for each wire. In case of short-circuit or heavy overload, the fuses are expected to melt out quickly, thus breaking the circuit before injury is done to the motor. A[n,o, the fuses should prevent serious arcs, in case the switch is opened on full load or on overload. In buying fuses a size should be selected which has about 25 percent greater capacity (amperes) than the normal current for the motor, except for small motors which have no starting compensator, in which case 60 to 80 percent excess capacity should be provided.

Safety enclosed knife switches with fuses concealed beneath the cover are preferable to bare switches, and the electric wiring laws of some
require the enclosed switches to be used. The cost is very little more than the combined costs of separate switch and fuse block.

Fuses introduce new dangers, however; if one fuse of a set burns out, the motor may run single-phase with consequent damage to it or to a transformer. In some cases, the blowing of a fuse has thrown transmission lines out of service.

Table IX gives the approximate number of amperes per terminal of electric motors. It will be found convenient in determining sizes of switches, and fuses required, and the proper sizes of wiring.

**Table IX—Approximate Amperes per Terminal of 3-Phased Motors at Full Load.**

<table>
<thead>
<tr>
<th>H. P.</th>
<th>220 Volts</th>
<th>440 Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>7½</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>41</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>54</td>
<td>27</td>
</tr>
<tr>
<td>25</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>30</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>105</td>
<td>53</td>
</tr>
<tr>
<td>50</td>
<td>128</td>
<td>64</td>
</tr>
</tbody>
</table>

The starting compensator of a motor performs the functions of a switch, inasmuch as it is used always to start the motor, and it can be used to stop the motor by means of a trip or push button, or in some cases by moving the starting handle to the neutral position.

An automatic circuit-breaker and a compensator are sufficient without an intermediate knife switch. Also, if a circuit-breaker is used, there is no necessity for any fuses on either the high-tension or low-tension side of the transformers.

**Lightning Arresters**

Lightning presents the greatest difficulty to the operation of transmission lines. If it strikes on or near a line, it causes a sudden, short-lived current of exceedingly high voltage. If it strikes the farmer's substation itself, something is sure to be damaged and the pumping plant put out of commission. If the lightning strikes some distance away and runs in on the line, as often happens, the transformer and motor will be protected if suitable lightning arresters have been provided. An arrester shunts the heavy current to the ground, but is so constructed as to prevent the loss or escape of the regular normal current. An arrester is required on each of the three wires of a circuit.

The horn gaps and choke coils, often used alone as lightning arresters on pumping plants, are inadequate, and manufacturers will not guarantee
transformers and motors unless better protection is used. Sometimes series resistance is used with the horn gap. This consists of a stick, or a frame carrying four, six, or eight carbon or carborundum sticks. It is connected on the "ground" to shorten and reduce the surge of current. This does not increase the protection to the transformer, however. For 11,000 volts, the gap should be about one inch.

Fig. 20.—A small pumping plant. The vertical motor is direct-connected on a 350-gallon pump, with a lift of 85 feet. The metal house is open at bottom and ventilated at top. The starting compensator is placed just above the motor. The meter and knife switch and fuse block are mounted in a box bolted to a post that is a few feet away from the motor. The lead wires are enclosed in a metal conduit, which is grounded.

There are several ingeniously constructed forms of effective lightning arresters, designed for different conditions of service. The higher the transmission voltage, the more expensive are the arresters required. One of the most practical arresters for voltages up to 15,000 volts is the auto-valve. This consists of an elongated porcelain jar containing a spherical gap and a series of carbon disks separated by means of thin rings of mica to form short air gaps, and immersed in oil. The compression chamber arrester has a series of brass cylinders with short gaps between them and is her-
metrically sealed so that the compression of the heated air may blow out the arcs. The autovalve is designed to discharge at twice the normal voltage, while an air gap may require eight or ten times the normal voltage.

The “ground” wire connects the lightning arresters to the ground. It is not sufficient to run this wire down into dry dirt. The wire, or cable, should be of stranded copper, of large size, and should be connected with the well casing or should be continued into the well to below the water level.

In some installations smaller lightning arresters are placed on low-voltage line, to provide additional protection to the motors. This is not essential, however, if the substation is close to the well.

METERS

A meter is required to measure the quantity of power delivered to the pumping plant. Usually a 3-phase meter is installed on a 3-phase circuit. This is preferable to the older practice of using two or three single-phase meters. They may be connected to the circuit on the low-voltage side, that is, between the transformers and the motor, or on the high-voltage side, that is, between the transmission line and the transformers. In the latter case, the power consumption shown by the meter readings includes the power that is absorbed or lost in the transformers and will be from 2 to 5 percent greater than if the meters are placed on the low-tension side. If the contract stipulates that the power shall be measured on the high-voltage side, the meters must be connected on that side. Sometimes, however, the meters are placed on the low-voltage side but are adjusted to “overread” an amount which is estimated or presumed to take care of the transformer losses, or the power consumption as read is increased by a small percentage. If connected to the high-tension side, meter transformers are required, at least for the current connections. The cost of two potential transformers and two current transformers is about $300. This expenditure can be saved if the parties to the contract agree to measure the power on the low-tension side, with proper allowance for transformer losses.

In many cases the metering equipment is furnished by the agency from which the power is purchased. Meters should be tested and adjusted every year, or at least as often as once in 2 years.

Minimum charges oftentimes are based on the maximum demand instead of on the rated power of the motor. Special meters can be purchased, which, besides integrating the total amount of power used, also show the maximum demand for power that occurs between successive visits of inspection.
WIRING

All wiring must be designed and constructed with safety as the foremost consideration. It must be properly insulated at all points, and connections should be soldered and wrapped. It is not advisable for a farmer to attempt to do his own wiring, but he should understand it in a general way and in emergencies he may be obliged to make some changes.

A table of sizes and capacities of wires that are required for installations up to 50 horsepower is given in Table X. If the lead wires are unusually long, then larger wires than indicated by the table may be advisable.

**Table X—Sizes, Weights, and Carrying Capacities of Copper Wire, Bare and Rubber-Insulated.**

<table>
<thead>
<tr>
<th>Gauge No.</th>
<th>Weight</th>
<th>Carrying capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown and Sharpe gauge</td>
<td>Lbs. per 1000 feet</td>
<td>Bare</td>
</tr>
<tr>
<td>1</td>
<td>252.8</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>200.5</td>
<td>125</td>
</tr>
<tr>
<td>3</td>
<td>159.0</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>126.1</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>100.0</td>
<td>80</td>
</tr>
<tr>
<td>6</td>
<td>79.3</td>
<td>70</td>
</tr>
<tr>
<td>7</td>
<td>62.9</td>
<td>54</td>
</tr>
<tr>
<td>8</td>
<td>49.9</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>39.6</td>
<td>38</td>
</tr>
<tr>
<td>10</td>
<td>31.4</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>24.9</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>19.7</td>
<td>25</td>
</tr>
<tr>
<td>13</td>
<td>15.6</td>
<td>23</td>
</tr>
<tr>
<td>14</td>
<td>12.4</td>
<td>20</td>
</tr>
<tr>
<td>16</td>
<td>7.8</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>4.9</td>
<td>5</td>
</tr>
</tbody>
</table>

The transmission line and all wiring to the transformers are of bare wire, usually copper. All wiring between the transformer platform and the motor must be of insulated or covered weather-proof wire.

If the motor is placed with the pump in the well pit or in any other place that is likely to be wet or where there may be dripping water, then the wires leading to the motor must be enclosed in galvanized or black iron conduit.

Insulators used for supporting the wire are made of porcelain or glass. Insulators for high voltages are especially designed. A two-cape porcelain insulator is rated usually as safe for voltages up to 15,000 volts. Pin insulators are placed above the cross-arms, and suspended type insulators are placed below the cross-arms. Short-circuits are caused occasionally by birds alighting on pin insulators.
As an aid to those designing substations at pumping plants, the accompanying list of material is suggested for a pumping plant requiring a motor of from 15 to 50 horsepower.

**Material List for 2-Pole Substation.**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Cedar poles, 8&quot; top, 40' long, treated</td>
<td></td>
<td>$38.00</td>
</tr>
<tr>
<td>Transformer platform —</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Stringers, 3&quot; X 12&quot; X 12' long</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Galvanized machine bolts, 3/4&quot; X 20'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plank walk, 2&quot; X 8&quot; X 10'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Bracket supports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Galvanized machine bolts, 5/8&quot; X 4 1/2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized carriage bolts, 1/2&quot; X 4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stringer above transformers, 4&quot; X 4&quot; X 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized machine bolts, 5/8&quot; X 15&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Insulators and pins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross arms below circuit-breaker —</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Pieces, 3/4&quot; X 3/4&quot; X 4' 6&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized machine bolts, 5/8&quot; X 13&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Braces, 1/2&quot; X 1 1/2&quot; X 2 1/4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Lag screws, 3/4&quot; X 3/4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized carriage bolts, 1/2&quot; X 5&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Insulators and pins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bracket for oil circuit-breaker —</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 — 3/4&quot; X 3 3/4&quot; X 3' 8&quot;</td>
<td></td>
<td>$2.00</td>
</tr>
<tr>
<td>2 — 3/4&quot; X 3 3/4&quot; X 2' 1&quot;</td>
<td></td>
<td>$1.20</td>
</tr>
<tr>
<td>1 — 3/4&quot; X 3 3/4&quot; X 3' 4&quot;</td>
<td></td>
<td>$0.80</td>
</tr>
<tr>
<td>2 Braces, 1 1/4&quot; X 1 1/4&quot; X 3' 4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Galvanized machine bolt, 5/8&quot; X 17&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Galvanized machine bolts, 5/8&quot; X 11&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Lag screws, 5/8&quot; X 3 3/4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized carriage bolts, 5/8&quot; X 5&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Insulators and pins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Automatic oil circuit-breaker —</td>
<td></td>
<td>$80.00</td>
</tr>
<tr>
<td>Bracket for operating handles —</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Arms, 3/4&quot; X 3 3/4&quot; X 2' 10&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Brace, 1/2&quot; X 1 1/2&quot; X 1' 6&quot;</td>
<td></td>
<td>$0.35</td>
</tr>
<tr>
<td>1 Brace, 1 3/4&quot; X 1 3/4&quot; X 2' 4&quot;</td>
<td></td>
<td>$0.16</td>
</tr>
<tr>
<td>2 Sliding handles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Bearing block with strap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized machine bolts, 5/8&quot; X 1&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized carriage bolts, 1/2&quot; X 8&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized carriage bolts, 5/8&quot; X 5&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Lag screw, 5/8&quot; X 3 3/4&quot;</td>
<td></td>
<td>$0.06</td>
</tr>
<tr>
<td>Switch pole hook</td>
<td></td>
<td>$1.50</td>
</tr>
<tr>
<td>Lightning arresters and supports —</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Cross arm, 3/4&quot; X 3/4&quot; X 8&quot;</td>
<td></td>
<td>$0.90</td>
</tr>
<tr>
<td>1 Galvanized machine bolt, 5/8&quot; X 1&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Galvanized carriage bolts, 3/4&quot; X 5&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Lag screws, 5/8&quot; X 3 3/4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Autovalve arresters, 12,000 volt.</td>
<td></td>
<td>$75.00</td>
</tr>
<tr>
<td>3 Choke coils</td>
<td></td>
<td>$3.00</td>
</tr>
</tbody>
</table>
Cross arms for transmission line terminals—
   2 Cross arms, 3\(\frac{3}{4}\)" X 3\(\frac{3}{4}\)" X 8\(\frac{3}{4}\) ft. ........... 1.80
   2 Braces, 1\(\frac{1}{4}\)" X 1\(\frac{1}{2}\)" X 3\(\frac{3}{4}\) ft. ........... 0.80
   1 Galvanized machine bolt, 5\(\frac{1}{8}\)" X 17" ....... 0.14
   2 Galvanized carriage bolts, 5\(\frac{3}{8}\)" X 5" ............ 0.10
   2 Lag screws, 5\(\frac{1}{2}\)" X 3\(\frac{1}{2}\)" X 3\(\frac{1}{2}\)" ............. 0.12
   3 Galvanized double arming bolts, 5\(\frac{3}{8}\)" X 17" ............. 0.72
   3 Eye nuts ........................................ 0.45
   1 Galvanized machine bolt, 5\(\frac{3}{8}\)" X 17" .............. 0.14
   2 Galvanized carriage bolts, 5\(\frac{3}{8}\)" X 5" ............ 0.10
   2 Lag screws, 5\(\frac{1}{2}\)" X 3\(\frac{1}{2}\)" X 3\(\frac{1}{2}\)" ............. 0.12
   3 Galvanized double arming bolts, 5\(\frac{3}{8}\)" X 17" ............. 0.72
   3 Eye nuts ........................................ 0.45
   3 Insulators ........................................ 0.40
   3 Insulators and pins .................................. 0.40
   3 Brass hot-line connectors ............................. 2.50

100' Guy wire, 5\(\frac{1}{8}\)" galvanized steel strand ............ 1.50
40 square washers, 2" X 2" X 3\(\frac{1}{2}\)" .................. 0.50
225' No hard-drawn copper wire .......................... 4.50
50' Ground wire, galvanized strand ...................... 0.30
10' Ground wire cover, 1\(\frac{1}{2}\)" half-round .................. 0.30
24 Pole steps, 5\(\frac{1}{2}\)" diameter, 12" long ................. 1.80
Labor and miscellaneous extras .......................... 100.00

Total ................................................. $ 380.54

3 Single-phase transformers .................................. 20.00

Total, including transformers .................................. 380.54

STANDARDIZATION

Inasmuch as the selection of the motor and substation is likely to be left to the individual farmer, it is to be expected that a great variety of makes and styles will be found in an electrical district. Through dealing with many salesmen, and with outside firms and agencies by correspondence, the electrical equipment of the many pumping plants will be variously designed.

Under the electrical district law it is possible for the electrical district to install and own the farmers' substations. One objection to this plan is that it increases the size of the bond issue of the district. Furthermore, there is an advantage in making each power user responsible for his substation.

It is far better to adopt standard types and makes, and to standardize the pumping plants and substations throughout. If that is done the public soon becomes familiar with the limited but uniform equipment and is less likely to cause unnecessary troubles for themselves and others. A short-circuit at a pumping plant may throw out an entire transmission line, and perhaps 15 miles or more of line must be inspected before the damage is located, and before the line can be used again.

If the electrical equipment is standardized, it becomes more practicable to maintain a central warehouse with a line of parts for renewals, and with spare units, both motors and transformers.

Furthermore, electrical goods can be purchased at much lower cost, if purchased in large orders, and in carload shipments. Probably 30 or 40
percent can be saved in the first cost through standardization and collective buying.

There appear to be five ways in which the electrical equipment can be supplied to the farmers of an electrical district. First, the electrical district itself can go into the business of a supply house, though this may require an amendment to the Electrical District Act. Enough profit should be charged on the equipment sold to the power users to cover all overhead costs of the supply department, and the credit of the district should not be allowed to anyone.

Second, a separate organization can be formed, preferably incorporated, and the water users who desire to obtain the advantages of the organization, can be required to own stock in it in proportion to the size (horsepower) of their plants. A competent electrical engineer should be engaged as manager. Such an organization could arrange credit terms.

Third, arrangements may be made, in some cases, for the corporation or other agency from whom power is purchased to receive orders and to furnish and install the equipment for the pumping plants. The Salt River Valley Water Users' Association obtains very low prices from electric machinery houses.

Fourth, dependence can be placed on local supply houses, who must have electricians in their employ. Each individual contract should be for the necessary equipment installed and tested. The supply houses should be located within the electrical district, and should be equipped to give service after the equipment is in operation.

Fifth, each power-user may arrange the purchase and installation of his equipment through correspondence and through salesmen. This method is not to be recommended.

For small districts, the third or fourth method is perhaps the best solution, due consideration being given to the proper standardization of equipment by the directors of the electrical district before any orders are placed. In case of large districts, the second and third methods should be given consideration. The first three methods would give the purchasers the advantages of collective buying.

The third method should give good results, provided satisfactory arrangements can be made with the power company. Several conditions should be required, including the maintenance of a warehouse at one or more places within the district and the availability of electricians when they are needed.

In any case there are many advantages in standardization of equipment. When a new district is organized, the directors or a special committee should study the alternative types of construction and of equipment, should obtain costs thereon, and should adopt standards. Efforts should be made to have all purchases conform to the standards of the district.
COOPERATIVE PUMPING

The practice of each small landowner having his own pumping plant is, in general, very costly. The individual pump irrigator glories in his independence and in his ability to pump and irrigate when he pleases. Equipment catalogues, too, encourage the farmer to overestimate the value of an exclusive water supply. But usually the farmer pays dearly for this privilege. The individual ditches of the earliest settlers soon gave way to community ditches; in like manner it is possible to effect economy in the cost of pumped water by means of cooperative pumping plants.

The principle of cooperative pumping is applicable especially to small groups of neighbors so situated as to use the water from one well, and near enough that the losses of water by seepage in the ditches will not be excessive.

It is unfortunate that so many farmers measure the cost of pumped water by the price of gas oil or the price of electric current. An analysis of the cost of pumped water shows that in most cases the largest item of cost is the "fixed charges." The fixed charges consist of the interest on the investment, the depreciation in value, the general maintenance of the plant and equipment, the taxes, and also the insurance if the plant is insured. These fixed charges are just as truly a part of the cost of pumping as are the monthly bills for electric power. It is to be noticed, however, that the fixed charges do not depend at all upon the number of acres irrigated; the interest, taxes, and even the depreciation go on continuously, whether the plant is used much or little. The way to reduce the fixed charges per acre irrigated is to keep the plant in operation and to irrigate as large an acreage as possible from one plant.

The farmer should realize that each hour of idleness of the plant increases the cost of irrigating each acre of land. Pumping plants should be operated 24 hours per day at least 20 days per month through the months of maximum irrigation from May to September.

A few farmers have an acreage under irrigation sufficiently large to utilize their pumping plants fully. The majority of farmers, however, because of small acreage in their farms, or because of lack of capital to farm a large area, or because the capacities of their pumping plants are unnecessarily large, do not operate their plants more than one-third or one-half as many hours as the plants are capable of being operated.

There are several ways in which the use of a pumping plant can be increased. If a farmer has considerable unused land, he can lease the

\[1\text{Ball. 74, Ariz. Agr. Expt. Sta, p. 439.}\]
unused portion, with water, to some one else. Or, a farmer can sell water to one or more neighbors who do not have pumping plants. Or, several neighbors can form a mutual company and buy or establish a pumping plant that will serve them all.

The importance of fixed charges can be emphasized by a partial analysis of the cost of pumped water on an average farm in the Cusi Grande Valley. For this purpose the following assumptions are made:

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of farm</td>
<td>320 acs</td>
</tr>
<tr>
<td>Area under plow</td>
<td>60 acs</td>
</tr>
<tr>
<td>Lift, including downhill</td>
<td>60 ft</td>
</tr>
<tr>
<td>Discharge of pump</td>
<td>675 gph</td>
</tr>
<tr>
<td>Interest and sinking fund on bond</td>
<td>10%</td>
</tr>
<tr>
<td>Cost of power per kw-hr</td>
<td>55 cents</td>
</tr>
<tr>
<td>Investment in well, 150 ft in depth</td>
<td>$1,400</td>
</tr>
<tr>
<td>Investment in pump, motor, and subst</td>
<td>$2,800</td>
</tr>
<tr>
<td>Fixed charges on well</td>
<td>9%</td>
</tr>
<tr>
<td>Fixed charges on equipment</td>
<td>14%</td>
</tr>
<tr>
<td>Duty of water at pumping plant</td>
<td>1.5 gpm</td>
</tr>
</tbody>
</table>

The itemized cost of the pumped water per acre of land, as close as a can be estimated, is as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost per ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest and sinking fund on bond</td>
<td>$1.60</td>
</tr>
<tr>
<td>Other expenses of electrical district</td>
<td>$3.75</td>
</tr>
<tr>
<td>Electric power</td>
<td>$0.64</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>$0.23</td>
</tr>
<tr>
<td>Attendance and repairs</td>
<td>$0.61</td>
</tr>
<tr>
<td>Fixed charges on pumping plant, including well</td>
<td>$0.86</td>
</tr>
<tr>
<td></td>
<td>$1.52</td>
</tr>
</tbody>
</table>

The fixed charge on transmission line and pumping plant aggregate $10.55, which is 59 percent of the total cost of the pumped water. The direct charge for power is only 37 percent of the total. The analyses of many pumping plants show acre costs less favorable than those given above, the causes being less acreage, or larger investment, or lower plant efficiency than those assumed.

Fixed charges so large as those shown in the analyses are burdensome and are the cause of many failures in pump irrigation. But they are unnecessary and indefensible. There is a way to reduce them. The plant should be used to irrigate a larger acreage. The capacity of the plant is adequate for 100 acres, or even 140 acres. If the plant is used for 120 acres, it will be operated about 20 days of 24 hours through each of the summer months. This leaves ample time for occasional repairs. If the fixed charges are divided among 120 acres, the total cost is reduced to about $12.50 per acre.

It is not to be expected that the cost of pumped water, with a lift of 60 feet, will be as low as the cost of most gravity supplies. However,
It is unfair to make a comparison with the costs in the Salt River Valley, inasmuch as that Valley has derived great benefit through the United States Reclamation Act and, furthermore, that Valley has developed and markets hydroelectric power, the profit from which reduces the annual cost to the water users about $2 per acre. A similar project, without assistance from the Reclamation Fund and without any power business, would cost about $5 per acre per year for fixed charges and $2 or $3 more for operation and maintenance. The charge in the Salt River Valley in 1923, for 3 1/2 acre-feet of water, was $4.20.

The ultimate difference in the value of irrigation water supplies in two different irrigation systems is reflected in the value and selling price of the lands under the two systems. If a purchaser of a pump-irrigated farm has bought his farm at the right price, or has developed it at a low cost, then the higher annual cost of water supply is not a handicap.