U. S. DEPARTMENT OF AGRICULTURE

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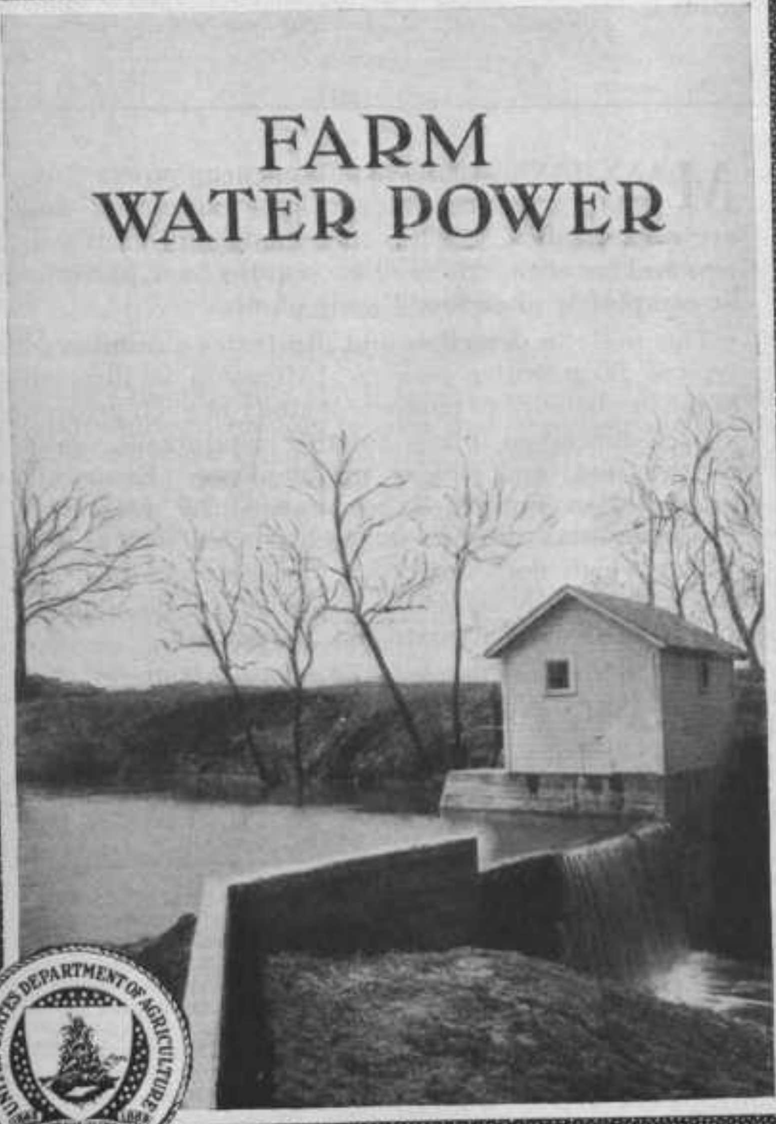
FARM WATER POWER



MANY HAVE TRIED to obtain cheap power from small streams. Some have succeeded and are well satisfied. Others have had indifferent success and for economic or other reasons have partially or completely abandoned their plants.

This bulletin describes and illustrates a number of typical farm water powers. Attention is directed to the importance of competent study of each project, a well-conceived plan, suitable equipment, good construction, and proper maintenance. Economic losses, often unnoticed, are caused by undersize line wires and inadequate or obstructed waterways. Water which does not reach a wheel, whatever its efficiency, and head which is lost in the channel to and from the wheel contribute no power.

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FARM WATER POWER

By **George M. Warren**, *Associate Hydraulic Engineer, Division of Agricultural Engineering, Bureau of Public Roads*

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INTRODUCTION

MANY PERSONS BELIEVE that the energy in flowing wells, hillside springs, running streams, and waterfalls can be easily and cheaply converted into useful power. Some consider it a simple matter to pipe the flow to an inexpensive water motor. Others see support for their belief in commercial power companies which are constantly extending their lines and supplying, at diminishing cost, electric current for both city and rural needs.

There is tendency to underestimate the quantity of water and the expense usually necessary to obtain worth-while amounts of power. Investigations by the Department of Agriculture indicate that numerous farm water-power plants have only partly met the expectations of their owners and that some plants have fallen into disuse. The main reasons why owners have not obtained greater success are:

(1) Failure to realize the technical nature of the undertaking and the importance of having full field data from which to make suitable designs and plans.

(2) Desire of owners to develop their own projects, to exercise their ingenuity, and to experiment with homemade equipment or old parts often obtained from a junk dealer.

(3) Overestimating the amount and constancy of the power obtainable from the natural flow of a stream.

(4) Inadequate channel capacity for the operation of the machinery near its rated speed and capacity.

(5) Using line wires too small for the distance, resulting in excessive drop in the voltage.

(6) Necessity of more attention and expense than was anticipated to keep channels and trash racks clear and machinery in good operating condition.

(7) Changes of farm ownership.

The amount of power that can be obtained from a stream depends upon the quantity of water applied to the water wheel or turbine, the height which the water falls in such application (called the head), and the efficiency with which this mechanical power is converted into electrical power and then distributed for use.

The output of the generator is expressed in kilowatts, one kilowatt being equal to 1,000 watts. The number of watts required by electrical appliances such as motors, washing machines, heating units, and lights are usually marked on the appliance or given in the literature describing them. The energy requirements of a few such appliances are given on page 22.


FIGURE 1.—Inexpensive overshot wheel and homemade counterweight rocker arm with draft wire for transmitting the power. Virginia

In this bulletin a number of typical water-power plants are first described. These descriptions will give the reader a general idea of the types of structures and equipment in common use, their cost, and what work the plants accomplish. The accompanying illustrations show how the equipment is installed. These descriptions are followed by a discussion of the design of farm water-power plants including the determination of the quantity of water available and the head, the making of power estimates, and construction details such as dams, water wheels, and the various accessory equipment. With the information contained in the following pages one should be able to determine the power possibilities in a given stream and just how he should proceed in order to obtain advantage from them.

TYPICAL PLANTS

Favorable natural conditions often make it possible to obtain a little power for pumping and like uses by setting up simple apparatus as shown in Figures 1 and 2. Sometimes it is feasible for a farmer to have his own hydroelectric plant. A homemade plant in Pennsylvania, built in 1924 at a total cost of $625 including line and house wiring, consists of an 8 by 2 foot steel overshot wheel costing $225 and a ½-kilowatt generator (second hand) which cost $5. The machinery is in a plain frame house 12½ feet square with concrete foundation and is run day and night on the discharge from a hilly drainage area of 1.9 square miles. A simple log dam (fig. 12, A) diverts water to the wheel.

A similar but more costly plant in which the machinery is started and stopped from the dwelling 800 feet away by means of a windlass and draft wires to the inlet gate is shown in Figure 3. A cross section of the dam is shown in Figure 12, C.

A plant installed under unusually favorable conditions by an Ohio farmer in 1927 is shown in Figure 4. Although the head is only 4 feet, this deficiency is offset by an abundance of water and the fact that the distance to the buildings is but 100 feet.

Parts of the works of old mills can sometimes be used to advantage as is shown in Figure 5.

Sometimes several farmers can cooperate and thus obtain the benefit of better construction and equipment than would be possible for one. A fireproof, mutually owned plant in Pennsylvania, built in 1923 to supply current to three farms having five families, is shown in Figure 6. A cross section of the dam is shown in Figure 12, F.

FIGURE 2.—Simple wooden flume and overshot wheel with chain drive to a pump lifting spring water to a mountain home. North Carolina

Another mutually owned plant in Pennsylvania, built in 1923 to supply current to six farms having nine families, is shown in Figure 7. A section through the turbine pit is shown in Figure 8 and a cross section of the dam is shown in Figure 12, G.

The plant shown on the cover page was built in Illinois in 1925 and cost $3,000 including the 2,000-foot power line of No. 4 gauge wire. This plant has a 15-inch vertical shaft turbine rated, under an 8-foot head and full gate, to make 229 revolutions per minute, to require 351 cubic feet of water per minute, and to produce 4.37 horsepower at the wheel. The method of stepping up the turbine speed is typical of similar farm plants and is shown in Figure 9.

Overshot wheels revolve much less rapidly than do turbines, and a different method of drive is employed to step up the speed. Ordinarily, a master spur wheel, which is keyed to the horizontal axle of the water wheel, meshes with a small pinion on a jackshaft to which is fastened a large iron or wooden pulley carrying a belt to a small pulley on the generator. This method of stepping up the speed, excepting substitution of chain drive for spur-gear drive, is shown in Figure 10.

FIGURE 3.—Hydroelectric plant built in Pennsylvania in 1925. Drainage area 2.4 square miles, head 6.9 feet, steel overshot wheel 6 by 2½ feet, generator one-half kilowatt, power house 13 by 15 feet. Cost of machinery $385, materials $325, labor $356, wire $64, miscellaneous $128, total $1,258. Estimated cost of current, including interest, depreciation, taxes, insurance, attention, and repairs, $174 per year

FIGURE 4.—Shop-made self-contained hydroelectric unit consisting of a 12-inch propeller-type turbine, 1-kilowatt generator, governor, and switchboard in a steel plate housing 2⅛ feet in diameter and 8 feet in height above the 6-inch I-beam supports. Drainage area 57.7 square miles. Cost of unit $775, materials $266, labor $100, wire $8, line and building wiring done under code regulations $80, total $1,229. Estimated cost of current per year, $152

Sometimes considerable money is spent, and only a small amount of power is obtained. In some instances plants have been partly built and equipped, and then power has been taken from a near-by commercial line. Figure 11 shows a plant in Pennsylvania which cost about $1,800 and was intended to supply current for two farms. Owing, however, to the small and variable discharges from the drainage area of 1.3 square miles, the lack of water storage, and the increasing need for current, use of the electrical equipment was discontinued and power was taken from a commercial line. The plant has a 7½ by 2 foot steel overshot wheel which, when the installation was inspected, was using 12 cubic feet of water per minute. This gave ample power for the operation of a very satisfactory domestic water system. The pump discharge was piped to the tops of two 10-room farm houses and thence to the barns and yards where watering troughs received the surplus. There were no storage tanks, and as the pump was run night and day the water was always cool and wholesome.

FIGURE 5.—Compact turbine plant in Massachusetts, built over the tailrace of an old rubble-face earth dam 18 feet wide on top (at tree). Drainage area 8 square miles, head 10 feet. Plant supplied current for lighting five rural houses

USE AND CARE OF PLANTS

Plants are generally run continuously. If electricity is generated, it is common practice to use the current for power during the day so as to have a better flow of current for lighting at night. Most owners burn yard or porch lamps throughout the night, and in cold weather some switch on a small electric heater. In addition to lamps the electric appliances in most common use are irons, vacuum cleaners, washing machines, pumps, refrigerators, and one or more small motors for miscellaneous use. Generators are direct-current machines and generally have a full-load voltage rating of 110 to 125.

Farm water-power plants require attention and repair, and while those items do not involve much expense they can not be ignored. Some owners visit their plants daily, some every other day, and others weekly. If the visit is merely for inspection or to oil or grease bearings it may not take more than 20 to 40 minutes, depending upon the distance. If ice or leaves interfere with wheel operation the visits must be more frequent. The cost of oil, grease, and repairs at one plant (fig. 7) was $13.27 in 1925, $5 in 1926, and $59.80 in 1927.

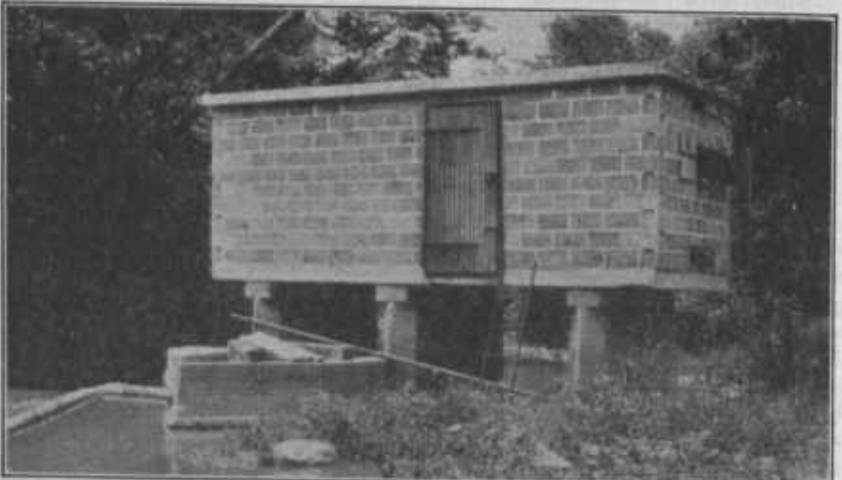

FIGURE 6.—Upstream side of a substantial concrete power house 7.7 by 20 feet, 6-inch roof slab, 8-inch block walls, 8-inch floor slab, supported above high water by three piers 17 inches thick built into and buttressing a concrete dam 129 feet long. Drainage area 43.9 square miles, head 7.7 feet. Cost of 24-inch turbine $310, 6½-kilowatt generator $400, materials $1,185, labor $750, wire $422, instruments and miscellaneous $385, total $3,452. Approximately one-half the cost was for the dam. Estimated cost of current per year, $469

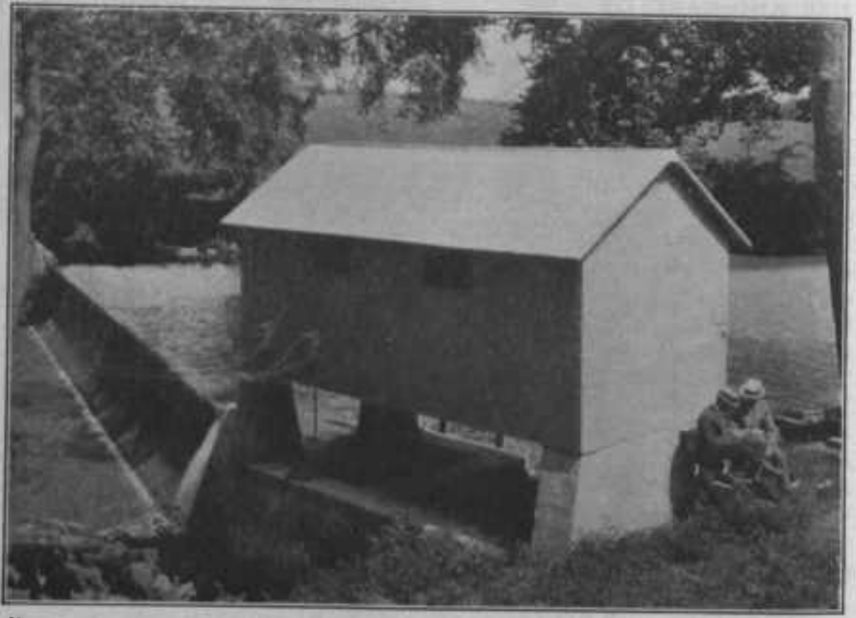

FIGURE 7.—Mutually owned plant built on the site of an old timber dam. Power house 8.6 by 20 feet, concrete dam 141 feet long, drainage area 51 square miles, head 7.5 feet. Cost of 27-inch turbine $393, 6-kilowatt generator $550, governor $460, materials $1,582, labor $1,000, wire $632, rent and supplies $250, instruments and miscellaneous $821, total $5,688. Approximately two-thirds of the cost was for the dam. Estimated cost of current per year, $754

PLANT DESIGN

Every farm water-power project calls for careful study. The power must be used as and when generated. It is true that surplus current is sometimes used to charge storage batteries for lighting purposes, but most farmers wish to avoid the purchase of large storage batteries because of their cost and comparatively short life. The hope of securing continuous power without the bother of storage batteries has been the main reason why many have undertaken development of water power. Owners frequently like to experiment, often using second-hand equipment and parts—a wheel bought here, and a shaft bought there. Although such experimentation is interesting and worthwhile results sometimes follow, it is generally better and cheaper to obtain the advice of men experienced in the design and installation of water-power equipment.

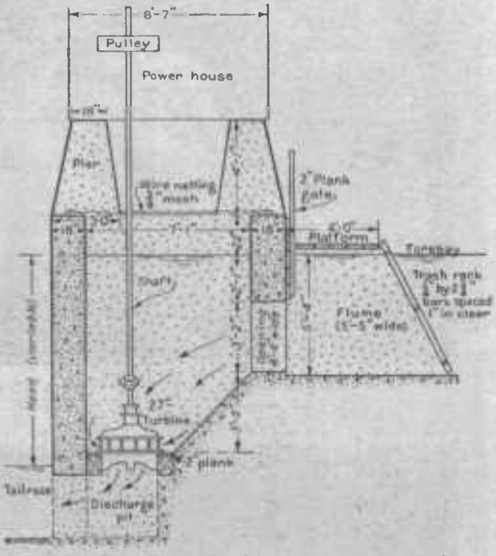

FIGURE 8.—Section through the turbine pit, flume, and trash rack of the plant shown in Figure 7. The wire netting which completely covers the pit is for the purpose of excluding débris at times of high water

WATER SUPPLY

The area of a drainage basin is only a partial index of the quantity and constancy of the discharge. But assuming similar relief and rainfall, the discharge from a large area is likely to be greater and more uniform than that from a small area. The run-off from some small areas is augmented by springs or seeps, and the discharge is well-sustained during droughts. In general, however, discharge fluctuates greatly with rainfall, and as rainfall usually runs from a small area quicker than from a large area, the former is likely to have the more varied and higher run-off per unit of area. The discharge from a typical hilly to mountainous drainage area of 22 square miles in New York during a year of nearly normal rainfall is summarized as follows: Maximum discharge, 30,120 cubic feet per minute on May 12; minimum discharge, 35.4 cubic feet per minute on October 21; mean daily discharge for the month of least run-off (October), 53 cubic feet per minute; mean daily discharge for the month (June) having the sixth smallest average, sometimes called the sixth driest, 529 cubic feet per minute; mean daily discharge for the year, 1,512 cubic feet per minute; number of days when the mean discharge was between 35.4 and 504 cubic feet per minute, 183 (one-half the time).

Very different discharges might occur another year or from a like area in another locality during the year considered. The figures emphasize the importance of obtaining as full information as pos-

FIGURE 9.—Quarter-twist belt drive from a 26 by 6 inch pulley on the vertical shaft of a 15-inch turbine to a smaller pulley on the generator

FIGURE 10.—Stepping up the speed of a 10 by 3 foot steel overshot wheel in New Jersey. The large sprocket wheel at the right is keyed to the axle of the water wheel outside the wall and is connected by chain drive with a small sprocket wheel on the overhead line shaft, which in turn is belted to a 7-kilowatt generator at the left

sible regarding the flow of a stream upon which power is to be developed. They also show that the occasional high discharges for brief periods, while swelling the figures for mean discharge, are worth little for power purposes unless there is liberal provision for storing a part of the flow.

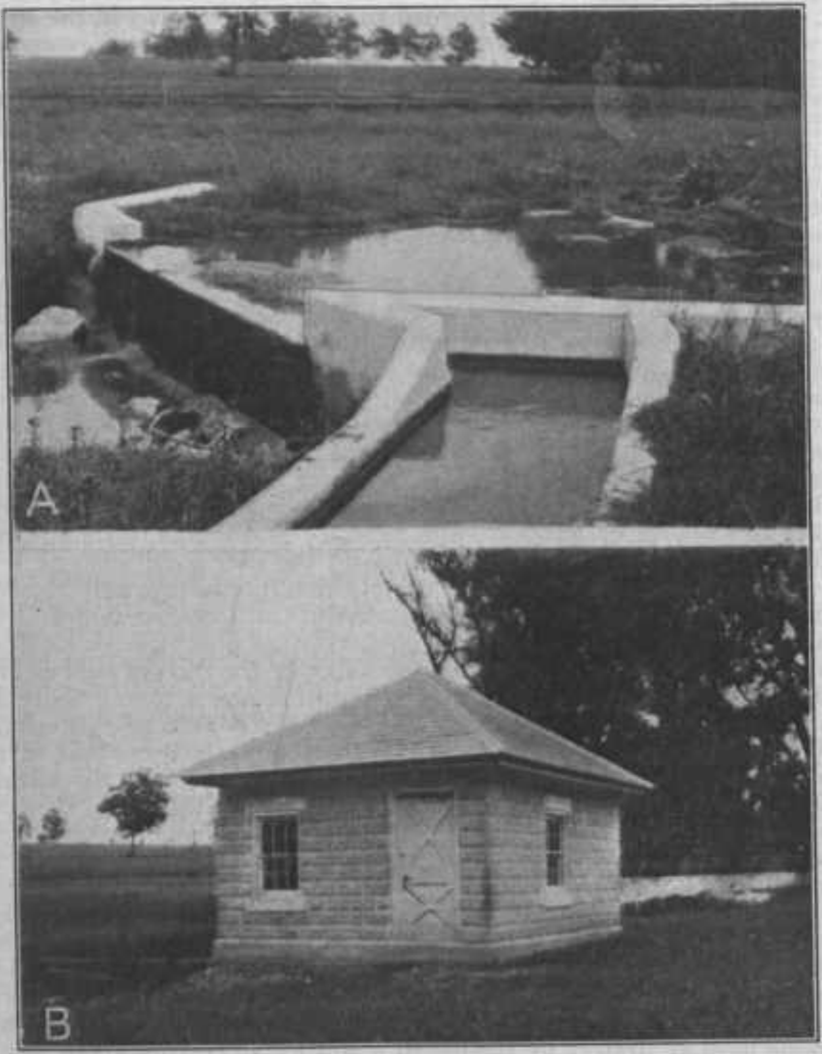

FIGURE 11.—Attractive, substantial plant in Pennsylvania which cost about $1,800 in 1917 and is now used only for driving a 2½ by 4 inch piston pump estimated to discharge 2¼ gallons per minute: A, Concrete diversion dam and entrance to flume 30 inches wide and 17 inches deep inside; B, cement-block power house 14 by 16 feet and concrete flume 225 feet long having a fall of 3½ inches

Decision as to wheel capacity is sometimes based on what may be termed the "middle-time flow" which means that flow, in a year of normal rainfall and run-off, which is exceeded on half of the days in the year and is not equalled on the remaining days. Assuming a wheel capacity equal to this middle-time flow and that there is no storage, waste of water, or variations in head, the result to be expected from an ordinary stream is about as follows: (1) A flow capable of driving the wheel to full capacity for 183 days of the year; and (2) an average flow of 50 per cent of the wheel capacity for the remaining 182 days of the year. This is equivalent to an average usable flow of 75 per cent of the wheel capacity for the whole year.

Many believe that the large demand for power comes in the spring when there is likely to be plenty of water. They therefore contend for the selection of a wheel of correspondingly large capacity. However, the principal uses of farm water power are for lighting, operating household appliances, and pumping. These uses call for some power every day, and except for lighting the seasonal variation is usually not large. In every instance consideration should be given to the amount of power needed and to how it is to be used, whether a large amount of power is required for a short time or a small amount of power for a long time.

Middle-time flow is a well-balanced compromise between the two extremes of stream discharge. It should not be confused with mean (average) discharge usually given in published records of stream flow. Mean discharge is usually larger than middle-time discharge and is obtained by summing the daily discharges for a year and dividing the sum by 365. Wheel capacity is sometimes based on the average daily stream discharge during that month having the sixth smallest average. This method, however, is less reliable than that based on middle-time flow. Where the flow is well sustained during the dry season or large storage capacity is possible, estimates may be based on a discharge which is nearer the average discharge.

Small discharges can be accurately determined by weir measurements as described in Farmers' Bulletin 813, Construction and Use of Farm Weirs. However, this method is not always convenient, nor are a few refined determinations as valuable for the purpose as are a large number of fairly accurate determinations covering daily discharges for one or more years. Large discharges are best determined by a competent hydraulic engineer, but a farmer can easily and quickly determine the approximate flow in the following manner: First, find the velocity of flow of the stream, and then, find the cross-sectional area of flow. The product of the two gives the rate of discharge at the time and place of making the test. These steps are explained as follows:

(1) Measure 50 to 100 feet along the bank of the stream where the bed is smooth, and of uniform width and depth. When there is no wind throw a chip of wood into the middle of the stream above the upstream point of measurement and note the exact number of seconds required for it to pass the measured distance. This can be done most accurately by the use of a stopwatch costing about $5. If the stream can be waded or is spanned by a low bridge, a still simpler 1-man method of making float tests is to attach one end of a measured length of ordinary fish line to a float and note the time required for it to move from the observer's position to the end of the line when fully payed out. As the midstream flow is usually swifter than that nearer the banks, make several tests from bank to bank and average the time. Divide the distance in feet by the average time in seconds, and multiply the result by 60 to get the average surface velocity in

feet per minute. As friction against the stream bed retards the flow, deduct 20 per cent (one-fifth) to approximate the average velocity of the entire cross section of flow.

(2) Determine the surface width of the stream and make measurements of the depth of the water at frequent intervals from bank to bank. Multiply the width of the stream in feet by the average depth in feet to get the cross-sectional area in square feet. This area, in a small stream having a round-shaped bed, is roughly two-thirds of the product of the surface width by the middle depth. These measurements must be made at the same time and place as the velocity measurements.

(3) Multiply the cross-sectional area of flow, in square feet, by the average velocity, in feet per minute, to get the discharge in cubic feet per minute.

POWER ESTIMATES

Water power is estimated from the quantity of water flowing and its vertical fall (head) from water surface to water surface at two points on the stream. The available power is frequently overestimated because of lack of water in dry times, unusable water in wet times, and loss of head in overcoming resistance to flow in the channel leading to and from the wheel. Wheels and generators of large capacity do not necessarily give a large amount of power. Unless there is sufficient water and head to drive the machinery at or near its rated speed it will not develop its greatest efficiency or power, and neither the operation nor the economy will be so satisfactory as could be obtained with smaller and less costly equipment run and loaded close to the manufacturer's rating. It is very important to distinguish between net or effective head referred to in manufacturer's power and speed tables, and total head as usually measured in the field. Effective head is the actual head at and on a wheel when running. Manufacturers in referring to head mean effective head, assuming full or nearly full gate opening and a well-installed wheel in good operating condition.

To find the total head, take the difference in level between the water surfaces at the proposed intake and outlet. The total head at a dam is the difference in level between the upper water surface and the surface at the lower end of the tail water. For short distances this difference may be determined with a carpenter's level or a farm level, but if the distance is more than 200 feet the head should generally be determined by an engineer or surveyor.

To estimate the theoretical or water horsepower, multiply the discharge (cubic feet per minute) by the total head (feet) and divide the product by 528. Example: What is the water horsepower of a flow of 264 cubic feet per minute having a total head of 8 feet? Solution: 264 multiplied by 8 equals 2,112; 2,112 divided by 528 equals 4 water horsepower. Dividing by 708 instead of by 528 will give the equivalent power in kilowatts. All of this power could not be realized because of unavoidable loss of head in waterways and frictional loss in machinery. In making preliminary estimates of farm water power it is unwise to assume that more than 50 per cent of the theoretical power will be realized at the switchboard. Thus under the conditions in the example about 2 horsepower or 1½ kilowatts would be available.

DAMS AND STORAGE

A dam serves two purposes: (1) To create head; and (2) to provide a storage basin for balancing irregularities of stream flow and increasing power possibilities. A discharge giving 2 horsepower continuously for 24 hours might, if stored and used in 12 hours, permit the use of a 4-horsepower wheel; if used in 6 hours, an 8-horsepower wheel. Farm dams seldom store much wet-weather flow because of the large cost of dams and the lack of flowage rights or difficulty in obtaining them. Continuous operation of a wheel at full capacity frequently exhausts a pond much quicker than anticipated. For example, a turbine using 725 cubic feet per minute would, in a 12-hour run, reduce the head of a 6-acre pond 2 feet if no inflow occurred. An old plant at South Troy, N. Y., illustrates the value of storage. One of the world's largest overshot wheels, 60 by 20 feet, was successfully operated from 1851 to 1897 on the yield of a hilly to mountainous watershed approximately 12 miles long, 3 miles wide, and containing 33.9 square miles. Within this area there are 11 lakes which furnished storage. The wheel normally made two revolutions per minute and required 4,500 cubic feet of water.

Figure 12 shows cross sections at the spillways of typical farm dams. Some of the sections could have been improved without adding to the cost of the dams, but each is probably strong enough for its location and intended purpose. Few of the spillway openings are sufficiently large to pass freshets. In the smaller dams the crest of the spillway generally was one-half to 1 foot lower than the top of the wings; in the larger dams the corresponding depth was 1 to 2 feet. Considerable leakage was observed at certain dams founded on rock; this might have been due to faulty bonding between the dam and rock or to failure to grout the seams beneath the foundation. A common fault is making wings too short at the land end. Unless both wings of a dam are built well into the earth or rock there is very likely to be a leakage around or beneath the ends and damage or destruction by undermining.

Farm dams are generally made of concrete mixed in the approximate proportion of 1 of cement to 6 of sand and stone combined, and reinforced with old steel pipe, rails, structural shapes, or scrap iron. Bankrun gravel was used in some of the dams inspected, but the concrete appeared to be oversanded and therefore of poor quality. Directions for making good concrete are contained in Farmers' Bulletins 1279 Plain Concrete for Farm Use, and 1480 Small Concrete Construction on the Farm.

In many of the States the design and construction of dams is regulated by law. Power of approval is vested variously in a department, commission, board, or State engineer. Different States have different requirements; for example, one State exempts dams where the drainage area is less than one-half square mile and the water is raised less than 5 feet above low water. Wherever State or other laws or regulations govern, the farmer should study these and build his dam to conform to them. The services of an experienced and reliable engineer are recommended as being most likely to result in obtaining a lawful and dependable dam.

CHOICE OF WHEELS

When working at full capacity and under favorable conditions there is no great difference, so far as efficiency is concerned, between overshot, turbine, and impulse wheels. Each should develop, at the wheel axle, 75 to 90 per cent of the water horsepower.

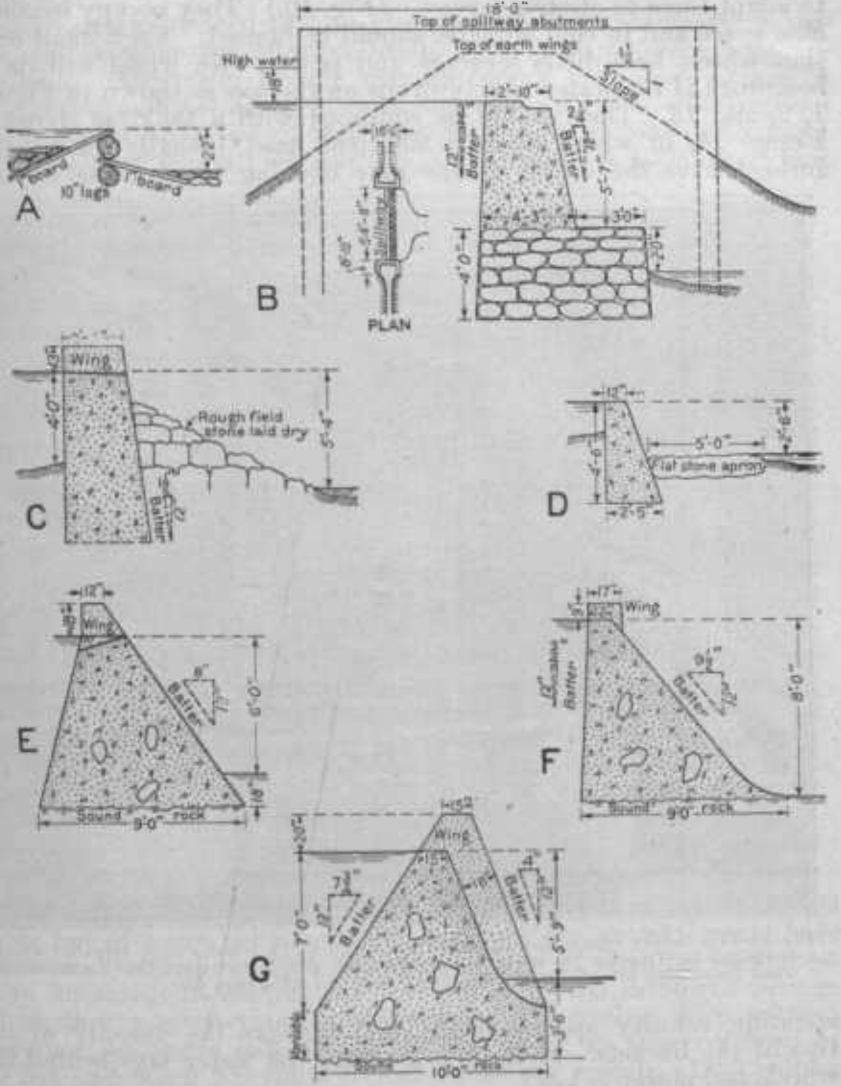

FIGURE 12.—Cross sections at the spillways of typical farm dams: A, Simple log and board dam for diverting a small flow into a headrace. B, Old earth milldam 335 feet long and having a concrete and rubble spillway 54 feet 8 inches long; the original spillway, 36 feet long, was too small and part of the dam was washed away. C, Dam shown in Figure 3. D, Simple concrete diversion dam with stone apron to prevent undermining by the overflow. E, Concrete dam 125 feet long founded on rock. F, Dam shown in Figure 6. G, Dam shown in Figure 7

Overshot wheels are adapted to small or moderate discharges under effective heads of 5 to 20 or more feet. They are simple, accessible, not easily clogged, and efficient under varying flow; their weight makes for steadiness of motion with load changes. They should never wade in the tail-water, and their slow speed usually requires stepping up, by means of gears and belts, 50 to 150 times to adapt them to electric service. (Fig. 10.) They occupy considerable space and in cold climates should be housed. Very small overshot wheels have little leverage and power. No wheel will do its best work if the water merely drops on the top as shown in Figures 1, 2, and 13. They should be equipped with a tank, as shown in Figure 14, in which there is sufficient head (usually 14 or more inches) over the center of the gate opening to give the water a spouting velocity approximately the same as the velocity of the tips of the buckets. If there is no tank the water lags behind the wheel, and power is lost.

FIGURE 13.—Faulty application of water to a small (3 by 1 foot) steel overshot wheel installed in Virginia in 1915. Cost of wheel, shaft, and gear, $60; shop-made steel frame and two pillow blocks, $35; 2½ by 4 inch pump, $60

Turbines are adapted to moderate or large discharges under effective heads from 4 feet upward. They are quiet, compact, and speedy and will run as long as water covers the turbine case and is higher than the tail-water, but with diminishing power as the head is lowered. Types and characteristics of turbines vary to meet the conditions and requirements. Each turbine does its best work when operating under specific conditions, being designed for a certain head, speed, and quantity of water. The power developed is approximately proportional to the quantity of used water, and that varies with the amount of gate opening. At half or quarter gate opening both the discharge and power are reduced in approximately like ratio from that at full gate. The speed at the turbine plants inspected was usually stepped up three to five times for electric service. (Fig. 9.)

Small, self-contained turbine electric units with automatic governor, and suitable for effective heads of 6 to 20 or more feet, are available. According to one manufacturer's catalogue ratings, a ¼-kilowatt unit having a 6-inch runner under a 7-foot effective head and using 64 cubic feet of water per minute (8 gallons per second) would have an over-all efficiency of 40 per cent. A 10-kilowatt unit having a 12-inch runner under a 21-foot effective head and using 539 cubic feet of water per minute (67.2 gallons per second) would have an over-all efficiency of 63 per cent. Units of sizes between these have intermediate efficiencies. According to the catalogue ratings of another manufacturer, a 1-kilowatt unit costing $600 without governor, having a ball-bearing runner under an effective head of 10 feet and using 100 cubic feet of water per minute (12½ gallons per second) would make 520 revolutions per minute and would have an over-all efficiency of 71 per cent; a similar 10-kilowatt unit costing about $900, under an effective head of 50 feet and using 221 cubic feet of water per minute (27.6 gallons per second) would make 1,165 revolutions per minute and would have an over-all efficiency of 64 per cent.

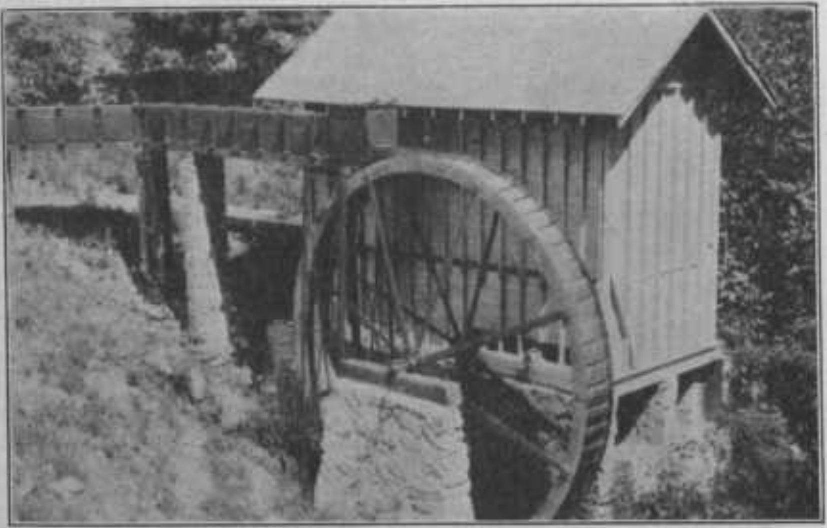

FIGURE 14.—Effective application of water to a 20 by 2 foot steel overshot wheel in North Carolina. Head in the open-top steel tank (2 by 3 by 2¾ feet deep) shoots the water through the gate opening (at bottom of right end) and down a 3-foot long inclined and tapered chute (trough), the lower end of which just clears the tips of the buckets approximately 10 inches short of a vertical line through the center of the wheel axle. The open flume to the tank is made of 1-inch boards lined with galvanized sheets and is 1½ feet wide (inside), 2 feet deep, and 82 feet long, graded to fall 2½ inches. It is supported by two 3 by 6 inch stringers on rubble piers 8 to 10 feet apart

Turbines of the propeller type are a comparatively late development in farm hydroelectric practice. As at present manufactured, they are adapted to medium or large discharges under effective heads of from 8 to 25 feet. However, the normal head at one plant (fig. 4) was only 4 feet. These turbines are small, quiet, and speedy, and are direct connected to the generator. The arrangement of the machinery in a typical unit is clearly shown in Figure 15. This unit is made in four stock sizes having capacities of one-half, 1, 3, and 5 kilowatts. According to the manufacturer's catalogue ratings a 1-kilowatt unit having a 12-inch inlet pipe, a 9-inch runner under an 8-foot head, and using 215 cubic feet of water per minute would have an over-all efficiency of 41 per cent; under a 14-foot head the rating is 120 cubic feet per minute. Another unit having no governor is shown in Figure 16. It has a capacity of 1 to 2½ kilowatts, varying with the head, and is equipped with an inlet valve controlled either by hand or by a distant pushbutton, and a switchboard with voltmeter, ammeter, rheostats, line switch, and fuses. The shipping weight of the unit is about 1,100 pounds, and the cost at the shop is approximately $750 which includes no switchboard wiring.

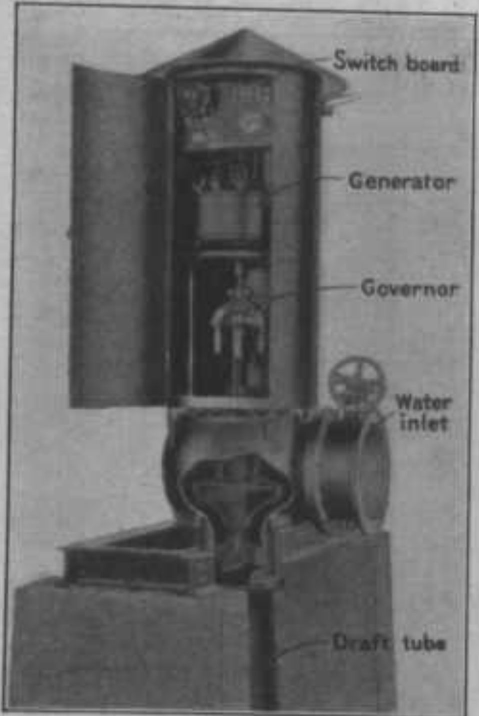

FIGURE 15.—Cut-away view of a power unit comprising a propeller-type turbine, generator, and governor connected to one vertical shaft

Impulse wheels are adapted to small, medium, or large discharges under effective heads from 20 feet upward. They are small, quiet, and speedy and are especially suitable for high heads where water can be delivered to the wheel by a comparatively small pipe. Figure 17 shows a power unit adapted to effective heads of 46 to 230 feet. It is made in four sizes varying in capacity from 150 watts to 20 kilowatts, in weight from 250 to 2,600 pounds, in floor space from 2 by 2½ feet to 3½ by 4½ feet, and in cost from $315 to $1,800. According to the manufacturer's rating, a typical unit adapted to 80 feet of effective head and costing $475 would use 13.2 cubic feet of water per minute (1.65 gallons per second), develop 1 kilowatt, and have an approximate over-all efficiency of 66 per cent.

Figure 18 shows two 3⅓ by 2⅓ foot steel pitch-back wheels for pumping water. A small underground flume at the far side of the pits delivers water to the buckets several inches below the tops of the wheels.

Figure 19 shows a 5 by 3 foot undershot wheel for pumping water. Wheels of this kind do not develop much power and cost approximately 25 per cent more than overshot wheels. A number of simple wheels are described in another bulletin [1] of the department.

HEADRACE AND TAILRACE

Most farm water powers are operated under small or moderate head, and it is very important to reduce the head losses as much as possible. These losses, including those in the wheel pit and tailrace which often are excavated with difficulty and subject to cave-ins and neglect, frequently are 20 to 30 per cent of the total head. A headrace or flume should be sufficiently large and clear to deliver at slow velocity the maximum quantity of water required at the wheel. A mean velocity in earth or rock channels of from 60 to 75 feet per minute (1 to 1¼ feet per second) is generally desirable. This velocity will ordinarily be approximated if headrace and tailrace are graded to fall 1 inch in 100 feet. The reader should bear in mind that velocity of flow is affected, not only by the amount of fall but

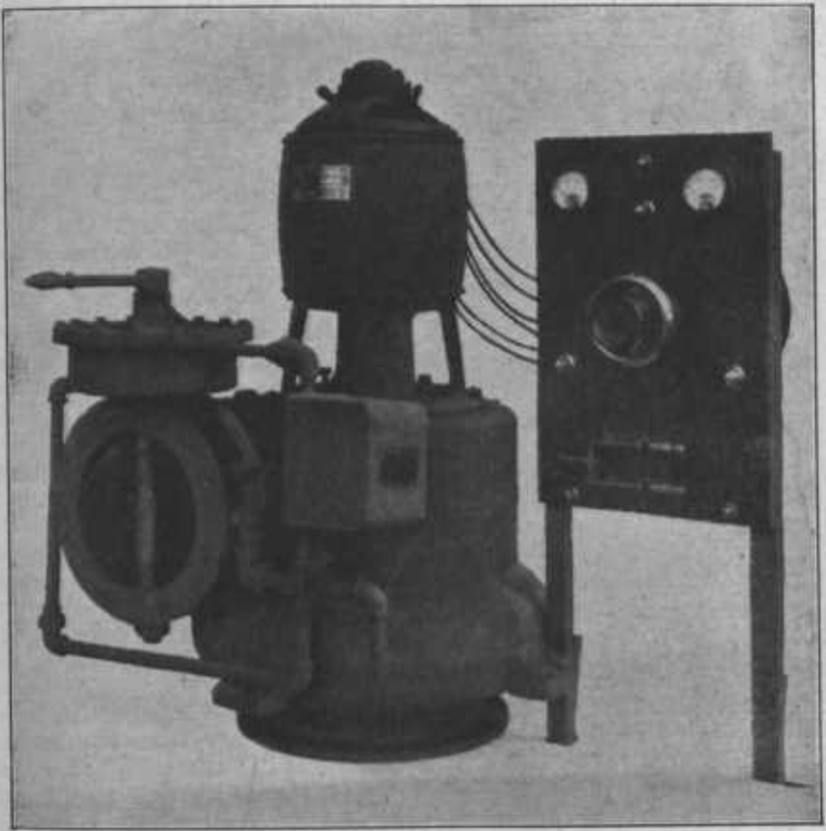

FIGURE 16.—A power unit comprising a vertical-shaft, propeller-type turbine and a generator and equipped with both hand and electrical control

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[1] Office of Experiment Stations Bulletin 146, Current Wheels: Their Use in Lifting Water for Irrigation. This bulletin can be obtained only by purchase from the Superintendent of Documents, Washington, D. C. Price, 10 cents.

also by the size of channel and quantity of flow, small canals or ditches requiring greater fall than large ones in order to produce a given velocity.

On the basis above outlined determination of the size of a canal at and below the flow line is a simple matter. Example: Assuming a mean velocity of 75 feet a minute, what size of canal is required for a turbine having a rated capacity of 600 cubic feet per minute? Solution: 600 divided by 75 equals 8, which is the cross-sectional area of flow in square feet. The most effective cross section would be half circular or U shaped with the width twice the depth. A canal of suitable dimensions, then, would be a half circle with a radius of 2 feet 3 inches, or a U shape of 4 feet average width by 2 feet average depth. Either section would have the required area of 8 square feet. The flow in most farm canals is much shallower than above indicated, but shoal sides favor the formation of ice and retard flow, grass and weeds take root, and débris collects. It is important to make canals deep and to keep them clear. Directions for ditching with plows and with dynamite are given in Farmers' Bulletin 1606, Farm Drainage. A velocity of 120 to 300 feet per minute (2 to 5 feet per second) is permissible in a short smooth pipe, flume, or penstock.

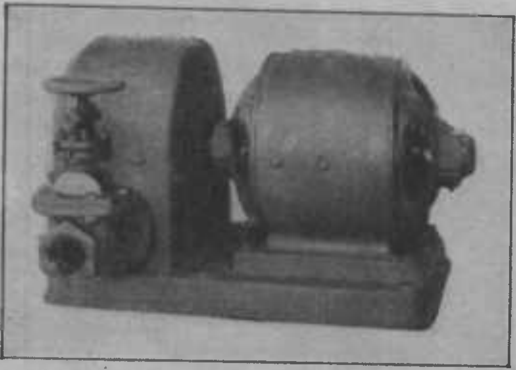

FIGURE 17.—A compact unit, comprising an overhung metal-housed impulse wheel direct-connected to a generator

A wheel pit should be the full depth and width recommended by the manufacturer of the wheel to be installed, and the wheel when running should be entirely clear of the tail-water. Even slight wading results in large loss of power. The draft tube of a turbine should extend at least 3 or 4 inches into dead water in the tailrace. The bottom of a tailrace should be graded evenly from the bottom of the discharge pit to the bed of the stream at the point of outlet. If so graded and if the tailrace is of ample width, the used water escapes with little surging and rise, and consequent loss of power.

TRASH RACKS

Leaves, twigs, sticks, and pieces of ice are likely to float along the shores of a stream and to be drawn into any open headrace or flume in which there is flow. A trash rack to intercept such matter is necessary in a turbine installation, but one is seldom installed at an overshot wheel. Eels were the principal cause of trouble at a North Carolina plant. The trash rack shown in Figure 8, which has a 1-inch clear spacing of the bars, is a typical one. A ½ to ¾ inch spacing is sometimes employed to strain out as much débris as possible. Whatever the spacing, care should be taken to have a large total area of opening so that flow shall not be much impeded and head lost. There are several ways of gaining area, but the simplest is to have the rack inclined instead of vertical. Inclination also facilitates the use of a rake for the removal of débris which then has a tendency to slide upward.

A garden rake or a manure rake is generally used to clear racks, but the work is much facilitated by using a regular trash rake with deep basket, and guards on the end teeth to prevent hooking under the spacing rods across the rack. In the fall, leaves are the chief cause of trouble and sometimes blanket a rack within an hour or two. An early morning inspection at one plant (fig. 7) showed the rack so matted with leaves that the normal head of 7.5 feet was reduced to 2.7 feet, and the power output was almost negligible.

FIGURE 18.—Two pitch-back wheels, in Pennsylvania, which make about six revolutions per minute and are connected by 8-inch cranks (16-inch stroke) to counterweighted steel triangles having draft wires to two pumps about 400 feet away. The left wheel cost $45 at the shop 15 years ago and the right wheel cost $75 recently

GOVERNORS

Few plants have governors to regulate delivery of water according to the load on the wheel. The lack of a governor renders a plant unresponsive to power needs. In the absence of a governor hand control is necessary, and the inconvenience discourages the use of large machines and appliances such as feed grinders, silage cutters, and ranges. Most plants operate on a more or less constant part-gate opening. Therefore the power developed is much below what the wheels are capable of developing. This condition prevails even when there is an abundance of water.

Governors are costly and do not always give the results expected. An automatic, fly-ball governor for a small overshot wheel costs approximately $100; for a medium-sized wheel, about $250. Two governors that were examined—one costing $25 (second-hand) and the other costing $460 were in disuse because of stripped gears or other breakage. It is not certain whether the damage was due to faulty installation of the governors or to some obstruction which prevented closure of the turbine gate when the load was reduced by cutting off electric motors and appliances. The latter cause seems the more probable. A turbine, although protected by a screen or trash rack, may become dirty and clogged, thus interfering with the action of the gate and reducing the discharge and power.

FIGURE 19.—Downstream side of a 5 by 3 foot undershot wheel geared to a 2½ by 4 inch triplex pump. The machinery cost $205 in 1914. Pennsylvania

A governor is a desirable accessory, provided it is properly installed and given the necessary attention.

WIRING

Power-line wires are often too small, resulting in excessive drop in voltage with attendant loss of illumination and slowing and heating of motors. It is strongly recommended that wiring[2] be done

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[2] A useful bulletin, Wiring the Farm for Light, Heat, and Power, is published and sold by the Committee on the Relation of Electricity to Agriculture, 1120 Garland Building, Chicago, Ill.

only by those duly qualified, and in conformity with the local or State regulations and the National Electrical Code.[3] A fair average charge for complete house wiring is $10 to $20 per room or $5 per outlet.

MANUFACTURERS' HELPS

The engineering departments of most manufacturers of water wheels are prepared to advise regarding hydraulic and electrical problems. Blue prints showing the proposed equipment and method of installation are usually furnished. Some manufacturers will send an engineer to investigate and a man to supervise erection and installation. Generally, manufacturers of water wheels and electrical equipment consider it good business policy to do all they can to supply equipment suited to local conditions and to have the equipment correctly installed. They give instruction regarding the erection, operation, and repair of their product. Generator and motor manufacturers furnish wire-connection diagrams and directions regarding the installation, lubrication, operation, and care of those machines, and the renewal of parts. Belt manufacturers advise regarding the choice, care, and repair of belts, and the size and spacing of pulleys. Information on belts and their care is given in the Department of Agriculture Yearbook, for 1928, p. 151–154.

DEPARTMENT HELPS

Requests to the department for advice as to proposed waterpower developments seldom are accompanied by information sufficient to make possible a satisfactory reply. Correspondents often state that there is water enough to fill an 8 or 10 inch pipe or that there is a lively creek 6 or 8 feet wide and a foot deep. Such information is worthless for estimating power unless the velocity of the water and other field data are also given. The department is not in a position to prepare designs, plans, specifications, or estimates of costs, but will give an opinion as to the probable value of a proposed development. Those asking for advice should supply as much as possible of the information outlined below:

(1) Name of stream and location of dam in such detail that it can be located closely on Government or State maps.

(2) Can use be made of an existing dam, headrace, tailrace, power house, wheel, or storage battery? If so, which?

(3) Minimum flow and middle-time flow of stream in cubic feet per minute. (P. 7 to 10.)

(4) Natural fall of the stream at the power site and the total fall it is feasible to obtain by constructing a dam. (P. 12.)

(5) Kind of dam, length, average height above the stream bed, and character of the foundation.

(6) Will water be conveyed to the wheel by a ditch, flume, or pipe? Give its length in feet.

(7) If the plant is for electric service give the distance from the power house to the farm buildings.

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[3] Persons having real use for the code may obtain copies from the National Fire Protection Association, 60 Batterymarch Street, Boston, Mass., or the National Board of Fire Underwriters, 85 John Street, New York City.

(8) What is the least amount of power (total watts required for appliances in actual use at one time) that will give satisfactory service? The requirements of some appliances, at full capacities and average efficiencies, are approximately as follows: Lamps of average capacity, 40 watts each; coffee percolator, 400 watts; bread toaster, 500 watts; 6-pound flatiron, 550 watts; ¼-horsepower motor, 288 watts; ½-horsepower motor, 518 watts; ¾-horsepower motor, 746 watts; 1-horsepower motor, 966 watts. Example: Six 40-watt lamps and a ¾-horsepower motor at full load would require 986 watts.

(9) If not for electric service, state fully the kind and size of machinery to be driven.

(10) Submit a pencil sketch clearly showing the location of buildings, ordinary and high water shore lines, dam, and power plant.

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