RURAL ELECTRIFICATION BY POWER DEVELOPMENT OF A SMALL STREAM

THESIS FOR THE DEGREE OF B. S.

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Water-power electric plants
Tuttle

Rural Electrification by Power Development of a Small Stream

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THESIS

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INTENT

The purpose of this thesis is to furnish Michigan agriculturists, and others interested, (golf course proprietors, and persons with country homes), with a source of information upon the question of the desirability and possibility of rural electrification by the use of small hydro-electric plants. The nature of the problem demanded a thorough investigation of rural transmission line construction so, that there is included for the sake of comparison considerable data upon this type of installation.

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INTRODUCTION

That rural electrification is going to be a necessity in the next few years is very evident. There are three eminent facts to confirm this, confronting one in our economic and social situation today. The public utility companies and manufacturers of electrical appliances have reached a point where they can more than supply the demands of industry, and are looking for a new field. The manufacturers have applied electricity to industry to the point where they must turn some of their applied science research facilities into new channels, with agriculture offering a huge and profitable opportunity.

Manufacturing and marketing industries, in fact almost every field except agriculture, have so shortened hours of labor by the use of electrical power, and at the same time have so raised the standards of living, that conducting a farm with manual labor as the chief source of energy cannot compete, all things considered, with lives led by persons in other fields.

It is true that farming is more healthful and in many ways furnishes a cleaner, more wholesome environment than th the city. However, the necessity for working to the point of physical exhaustion each day leaves little time for the enjoyment and consciousness of this better environment.

The farm can be and is being made the best of all places in the world to live. To do this, life on the farm, and particularly in the farmhouse, must be relieved of its exhausting drudgery, by the installation of electric power.

Then the Monday morning would be welcome, when the electrically driven milking machines have milked the cows; the electrically driven separator has skimmed the milk; and the electrically driven churn has made the butter; while in the house the washing machine is automatically doing its work, allowing breakfast to go on. This compares favorably with a blue Monday, when the milk comes into the house from the barn with the separating to do; pans and buckets to be washed; the churn waiting for attention; the wash water on the stove; the wash tub and its back-breaking device, the washboard, cluttering the house; the kitchen full of steam; cooking in progress; and usually one tired and discouraged woman in the midst of this confusion. Blue is such a day, indeed.

Again it is certain that in not such a far-off day we must give the farmer a better lot; we must give this vital element in our civilization, the man who furnishes us with our bread and butter, a square deal, eliminating some of his muscular labor and long hours, making the farm an attractive place to live, and as profitable as other businesses.

This may be best accomplished by adding electrical power to the farmer's working force. In order to do this, two procedures might be followed; one, to use a system such as is used in our cities where one large generating plant furnishes energy to a great number of users over a more or less large area; the other, to use individual plants generating electrical energy for each individual user, such as gasoline motor generator sets, and small hydro-electric plants.

The expense connected with the electrification of a farm is the big obstacle to its accomplishment. For that reason, the economy and cost comparison of three types of installation in general use, are particularly stressed. In the same light, the routine of deciding upon a particular installation for particular projects is minimized, since the manufacturers of small plants have had a great deal of experience along this line and are ready to furnish reliable information concerning any specific installation.

CONCLUSIONS

1. If it is possible, the ordinary farm can be electrified more economically and efficiently from a central source via transmission lines and transformers, than by any other method known at present.

2. In order that it may be possible to economically build transmission lines and install transformers, there must be a minimum of four customers to the mile, with five customers to the mile allowing for more reasonable rates.

3. Any place where there are less than four customers to the mile (barring unusual electrical loads) or where for some other reasons, such as would be found upon a country estate or golf course, it would be reasonable and ideal to install a small hydro-electric plant, provided several general physical conditions are approximated. These conditions are :

(a) A sufficiently large "year-round flow' coupled with a head* of water to develop necessary power.

(b) The electric l load must be close enough to the source of power so that it may be conducted to this load at a reasonable cost and with a reasonable loss of power.

(c) The topography of the land upstream from the afore mentioned head must be such that any rise in the upstream water levels will not cause damage to other parties or immediate valuable land.

(d) The site of the proposed power plant should be such that the height and length of dam required for the creation of a head are reasonable.

(e) The site should be such that the power can be developed without too great an outlay for equipment.

4. In the event that neither a local plant, or a transmission line is available, there are sveral systems designed to furnish lights to rural homes. The most important is the motor generator - battery arrangement - and its cost is such that it would be more profitable to invest in the highly perfected oil-burning lamps produced today.

* A head of water is the difference between elevations of water surfaces at any two points.

CENTRAL STATION POWER

There are several reasons why the usage of centrally generated power is the most suitable for rural electrification. First, it leaves the matter of handling the electricity in the hands of men who make it their business, the problem of choosing the correct plant to suit his needs and then having it installed and properly maintained being quite an issue to the ordinary farmer. It also eliminates the chance for the shutdown of the power for any length of time, a large station having auxiliary units to insure their supply. A small, privately operated plant is susceptible to a breakdown and usually takes a long time and possible skilled labor to repair it.

The most important reason for the use of transmission lines and transformers is the fact that where conditions are such that a transmission line may be installed, it renders service much cheaper than either the motor generator system or the small hydro-electric plant. (In the very special cases where there exists relatively large demands for energy and also a goodly supply of potential energy in a stream which could be developed, this conclusion would not, of course, hold.)

Below, in tabular form, is a survey of the costs of the various methods for furnishing electricity.

RURAL LINE CONSTRUCTION

(Costs of line construction vary considerably with the type of land passed through. The figures following take this

fact into consideration.)

Variation of rural energy costs with load:

	Cost per kilowatt-hour in cents					
Kilowatt-hours per month	25	75	100	300	500	750
Large companies.......	19.8	8.0	5.9	4.7	4.1	3.9
Small companies.......	15.2	8.5	6.1	4.7	4.3	3.9
Medium companies......	13.5	8.3	6.4	5.5	5.0	4.4
Mid-West (average)....	24.7	7.5	5.7	4.6	4.0	3.8

Distribution costs per mile:

	Average	Maximum	Minimum
Right-of-way & clearing	$50.42	$50.46	$00.00
Poles and fixtures.....	784.51	1400.00	551.76
Conductors.............	437.70	741.30	264.00
Overhead costs.........	157.67	507.30	111.24
Total (primary & secondary)	$1430.30	$2699.06	$927.00
Transformers & installation	230.50	107.00	177.95
Services & installation	58.50	36.00	31.80
Meters & installation	59.05	24.00	33.08
Overhead costs	37.80	18.84	19.26 66
Grand total...............	$1806.33	$2874.90	$1168.09

(This material is from the "Electrical World", Vol.100, pages 509 and 820.)

MOTOR GENERATOR COSTS

Cost per kilowatt-hour.............................$.27

Kilowatt-hours used per month...................... 30

Energy cost per month..............................$8.10

(This material is from C.R.E.A. Bulletin, Vol.VII - No.1,

published by the Committee On The Relation Of Electricity To Agriculture.)

SMALL HYDRO-ELECTRIC PLANTS

(The cost of energy from the source varies greatly. The figures here are a fair average for the plants considered here.)

Service & installation....................	$ 450.00
Wheel & generator.........................	800.00
Wiring....................................	100.00
Dam.......................................	300.00
Total.....................................	$1650.00

This data brings out the relative cost of the three systems. At $1850.00 per mile of rural line construction, with five customers to the mile, the investment charged to each individual is $370.00. In order for public utilities to maintain and perpetuate their equipment and pay a fair rate of interest on their investment of capital, it has been found that they must receive revenue amounting to twenty percent of their investment. This would demand that each user pay $74.00 per year for the privelege of using current. Actually, this figure proves to be a very close approximation. Statistics from 30,000 New England farms receiving electrical power showed a total investment in equipment amounting to sixteen million dollars. The revenue for 1930 was three million, one hundred and twenty thousand dollars, equalling the necessary twenty percent interest rate and at the same time amounting to only sixty dollars per year per customer, or five dollars per month. Using

sixteen hundred dollars for the cost of an average small water wheel and generator installation, it is found that six percent of this(which is the amount of interest the invested sum world earn) amounts to ninety-six dollars each year. This is more than the charges from a central generating system, and has in it no allowances for upkeep, depreciation, and labor. The motor generator set is applicable only as far as lighting goes, making comparisons with other systems useless. However, the data given shows that this method of furnishing lights is more expensive than furnishing lights and power by a central station. Also, in this setup the cost of wiring the house (amounting to one hundred and fifty dollars) has been omitted and would necessarily be added to the first cost of the plant. Here again it would seem to be disadvantageous to install an individual power plant. Experience has shown that they fall into disuse in favor of a highly perfected oil or gasoline burning lamp.

The figures quoted concerning central power generation are based upon conditions such that there will be four customers to a mile of line construction. Experiment has shown that ordinarily unless there are at least this many customers to use the energy supplied, the line losses become a relatively large percent of the total energy furnished, reflecting back to the farmer in such high rates per unit of electricity that electrification under such a condition becomes uneconomical.

The question of rates and amount of electrical energy used, although it is a broad field, should be touched on here to further clarify the position of the utility companies as sources of rural power. To a certain extent, the public utilities must charge its users a fixed amount to pay for their investment, no matter how much electricity the farmer uses. If the farmer uses sufficient current, he could bring his charge per kilowatt-hour down very low. To do this, the rural load must be built up by the application of electricity to many agricultural processes. On the other hand the utility companies must construct their lines for as small an expense as possible, to encourage use of electricity by allowing low rates.

The statistics upon "Variation of cost of energy with load" throw much light upon the subjec t, there being such a large discrepancy between the unit charges on the 25 kilowatt-hours and on the 300 or more kilowatt-hours.

SMALL HYDRO-ELECTRIC PLANTS

The laws of Michigan place no restrictions upon the construction of dams upon private non-navigable streams, except that a means must be supplied for fish to pass over or through a dam. The state conservation commissioner is the inspector of such things, and is required to furnish plans for such.

About the lower peninsula of Michigan and over most of the United States, the character of most small streams is such that their development for power is unlikely. Although electrical energy could be readily attainable from this source, it is a luxury which could not ordinarily be undertaken in a strictly economical sense. If the land is of such quality that it will not pay to finance a transmission line, it is as far as the agricultural industry is concerned; that is, the land is too poor to support the investment necessary to install a hydro-electric plant.

Another disadvantage common to this particular locality is that the streams give insufficient heads without flooding large areas of very good grazing land. In a recent bulletin of the United States Department of Agriculture they publish the following statement, based upon investigation of existing plants:

" Many persons believe that the energy in flowing wells, hill-side 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 a diminishing cost, electric current for both city and rural needs.

' There is a tendency to underestimate the quantity of water and the expense usually necessary to obtain worthwhile 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 channel and trash racks clear and machinery in good operating condition.

(7) Changes of farm ownership."

As a luxury, a small hydro-electric plant is an extremely useful addition to a home outside the city. The dam and plant may be made so as to be a valuable scenic addition to the land. An overshot wheel especially lends a picturesque beautyto the landscape) At the same time, the owners of such places being in a financial position to make this improvement as a luxury, there is no question of its economy.

In the pages following, the planning of a specific plant and electric service for a Michigan farm is given. The stream is an ordinary fast-flowing, trout stream called Honey Creek.

STREAM FLOW

In considering stream flow, the minimum flow is the important point. Upon it depends the size and elevation of the flume, the size of the water wheel, and the capacity of the generator. The maximum flow is considered in the design of the spillway. In this respect, the spring freshets from melted snow must be allowed for, and the spillway designed to carry the largest possible flow.

The farmer will know, usually, the general trend of stream flow, and if he has lived upon the site for a number of years, will probably have a good idea of the water level during the dry summer months when low flow conditions occur. If the stream drys up to a rivulet in the summer, it has little value from the standpoint of water power.

Provided this is not the case, the problem becomes to find what the flow is during the dry period. There are several ways to accomplish this. Two methods employed are the Weir method, and the cross-section velocity method. Both of these methods are discussed in detail in numerous publications * and will not be discussed here.

In determining the stream flow of Honey Creek it was impossible to investigate the flow during the dry months, which would have been the best procedure. Instead, the stream flow was measured during the spring months, giving the upper curve shown in Fig. 1; then an approximate curve was plotted for the

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* The U.S. Department of Agriculture farmer's bulletin No. 1430,

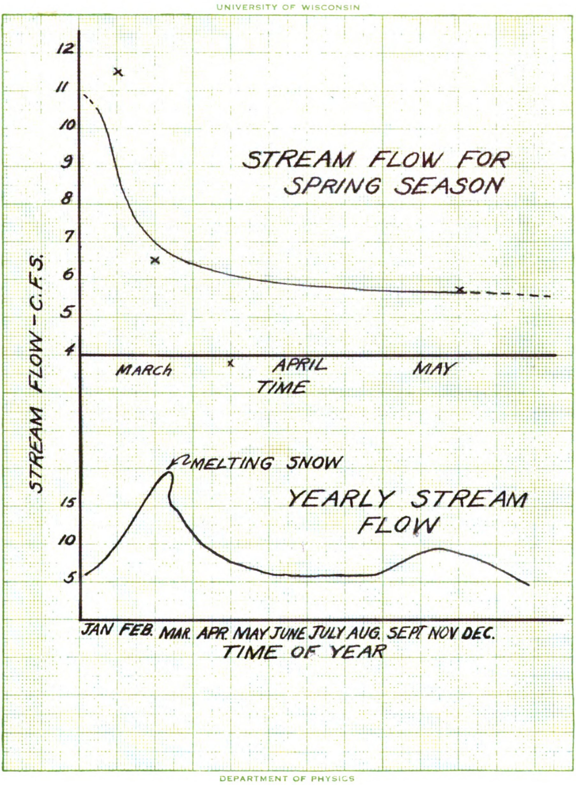
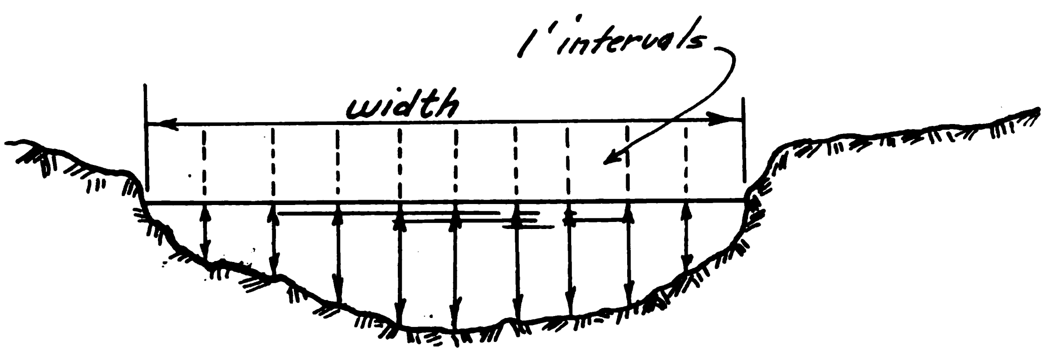

UNIVERSITY OF WISCONSIN
STREAM FLOW FOR SPRING SEASON
STREAM FLOW - C.F.S.
12
11
10
9
8
7
6
5
4
MARCH
APRIL
MAY
TIME
MELTING SNOW
YEARLY STREAM FLOW
15
10
5
JAN FEB. MAR. APR. MAY JUNE JULY AUG. SEPT NOV DEC.
TIME OF YEAR
DEPARTMENT OF PHYSICS

Fig. 1

entire year upon a basis of a past knowledge of the stream and from the fact that the watershed contained a great deal of woodland and swamp land, the stream receiving most of its water from springs.

By use of these two curves of Fig. 1, an accurate estimate of minimum stream flow may be made, the flow in mid-summer, as shown by the graph, measuring from one to two cubic feet per second less than at the time the flow was measured.

In measuring the stream flow itself, a place was chosen where the stream ran quietly, without rapids, for some distance. At this point, a course eighty feet long was laid out and the average cross-section taken, as shown by the sketch, by stretching a tape across the stream at several points throughout the eighty feet, and measuring the depth of water at each foot of width.



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gives an accurate description of both these methods. A copy may be obtained for 5¢ by writing the U.S. Dept. of Agriculture.

There would be an advantage in doing the construction work planned here, in late summer when the water is low; in addition, a check could be made on the summer flow at this time.

DAM

Under fortunate circumstances such as would exist where already there are dams from an old sawmill, or one made to facilitate logging operations, it would be necessary only to repair the existing structure and install a power plant.

In this case, however, no such favorable circumstance existed, and at some point on the stream a dam site had to be selected. To best accomplish this selection, the accompanying topographic map was made. In making the survey for the map, the difference in elevations was the important element; therefore, a chain of bench marks* were laid out and then elevations were set accurately by running levels over them until completing a circuit and arriving back at the first bench mark. The determined elevation agreed with the real elevation as set at the beginning of the survey. It was quite evident, also, from physical inspection, that there were only a few sites where power might be developed advantageously. Consequently, only a few readings were taken between these positions; viz,, enough to set the thread of the stream and the contour lines

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*A bench mark is a point which is in no danger of a change of its elevation, and which elevation has been accurately set. These bench marks are reference points from which are determined the relative elevations of the other points on the topographic map.

back to the edge of high ground.

The site selected, as shown on the map, was chosen because of its nearness to the farm buildings and because of the small area which would be flooded by the contemplated dam. The design of the dam itself was governed largely by the materials available. The ground about the site of the dam is covered with the remains of a "glacial tilt"*. Erosion has carried all else away until only granite and igneous rocks remain, as shown in the elevation of the dam. Because of the amount of this rock available, a masonry base was decided upon for the spillway, with a concrete section above it, as shown on the sectional view of the drawings.

The stream bed itself, at this point, is covered with rocks and boulders which in turn rest upon a rock formation. More than likely this rock is sandstone, but the load it is subjected to in this cas e is not sufficient to cause any settling of the dam. Care must be taken, however, to prevent the water from flowing beneath it. To do this, a trench one foot, six inches deep must be either blasted or picked out along the upstream face and poured with concrete and medium-sized stone.

The concrete in this dam shall be the standard 1:2:4 mix (1 part of Portland cement, 2 parts of clean, coarse sand, and 4 parts of bank-run gravel which has been washed and screened to remove dirt, silt, and sand.). The cement mortar shall contain 1 part of Portland cement to three parts of clean, coarse sand. If the opening of the trench in the bed rock re-

* A glacial tilt is the material left by a drifting glacier,

veal any fissures or seams, these should be filled with the cement mortar.

In building a dam of this sort, a great deal of expense is not incurred, the big item being labor, which was not included in the estimated cost ($200.00). The danger of failure due to the poor foundation, or water cutting around the end of a spillway, is considerable. If the dam is no larger than the dam shown in the encluded drawings, the structure can be built according to accepted practise. If the head of water is greater, however, the services of an engineer are needed.

THE WATER WHEEL

In choosing a wheel for any particular situation, the available head and quantity of flow are the determining factors. There are three general types of installations which would give the desired amount of electrical energy for rural use:

1. A head from eight to twenty feet with moderate or medium discharge. Small, self-contained turbine generator units, with automatic governors are to be desired.
3. A very high head and small or large discharge. Here a pelton or impulse wheel should be used.
3. A five to twenty foot head with sufficient water to generate four horsepower, and the use of an overshot wheel.

The third type of installation is the most important and most favorable. Under good conditions all three wheels would work with equal efficiency. However, the first two are more susceptible to clogging and do not work so well under

varying loads. This fault may be remedied, but requires the addition of an intricate governor. The overshot wheel is more accessibale, will not clog, and renders steady performance under varying load. Also, if by some chance, the flow of water is diminished, its efficiency will increase slightly, whereas the other wheels lose in efficiency.

In the plant desifned here, an overshot wheel was chosen for the above reasons. The buckets of this wheel must be designed to carry the dry-weather flow of the stream when running with full load on the line. This problem is outside the scope of this paper, but it cannot be brought too emphatically to point that either a reliable manufacturer of water wheels should be allowed to furnish a wheel, or someone who is experienced in the design of such wheels consulted before building one. In the event that this advice is not heeded and a wheel is installed hit-or-miss fashion, the efficiency of extracting energy from the water will be materially lowered, probably down to thirty percent. This loss of power, due to economy in the selection of the wheel, devaluates the rest of the investment.

GENERATOR AND LINE CONDUCTORS

The generator for a small stream power plant should have as low a full load speed as possible. There is a limit to this, however , because the lower the speed of the generator, the more expensive the generator becomes. In the generation of alternating current, the expense of a generator to run on an over-shot wheel is almost prohibitive.

The best solution to the entire problem of converting the energy into electricity, at the load, appears to be the use of a 125-volt D.C.generator, rated speed 750 revolutions per minute. By using wire large enough to eliminate "copper losses"* in transmitting the energy to the buildings, this type of generator will run standard 110-volt services.

Seven hundred and fifty revolutions per minute may be conveniently obtained from the water wheel through a system of gears. Here again, the services of either an engineer or manufacturers of hydraulic equipment are needed. Otherwise the wheel and generator will not be correctly balanced and the efficiency of the system will be very low.

The question of the size of wire is very important. There is very little difference in the prices of weather-proofed wire of varying sizes, but the energy loss varies as the square of the cross-sectional area.

Upon May 15, the prices of copper wire were as follows:

<u>Weather-proof wire</u>

No.4, wt. 164# per 1000 ft; lots of 100-500#...$30.86 per cwt.

No.6, wt. 112# per 1000 ft; lots of 100-500#...$21.16 per cwt.

* "Copper Loss"-- The energy dissipated as heat due to

Prices of copper wire (continued)

Cost of 1000 ft. of No.4 wire............ $9[illegible].40

Cost of 1000 ft. of No.6 wire............ $92.[illegible]0

There is only a difference of forty cents per thousand feet in the cost. The resistances of the two wires follow:

Resistance of No.4 wire in ohms.......... 0.[illegible] per 1000 ft.

Resistance of No.6 wire in ohms.......... 0.4[illegible] per 1000 ft.

It will be noted that one resistance is almost twice as much as the resistance of the other, while the costs are practically the same. (These prices were quoted by Western Electric Company)

SUMMARY OF THE PROJECT

The dam as shown is rather a conservative, substantial structure and it is probable that the entire plant would give satisfactory service for many years. At the present time the land could not support such an investment. The actual current delivered to the building would be approximately two kilowatts, which would necessitate the making of a schedule for the usage of the current, to keep from overloading the generator.

The "actual energy"* delivered to the wheel is a good deal more than this amount mentioned above; but the wheel, generator, and line conductors have efficiencies of 8[illegible]%, 90%, and 95% respectively, and lose a total of 30% of the total available energy.

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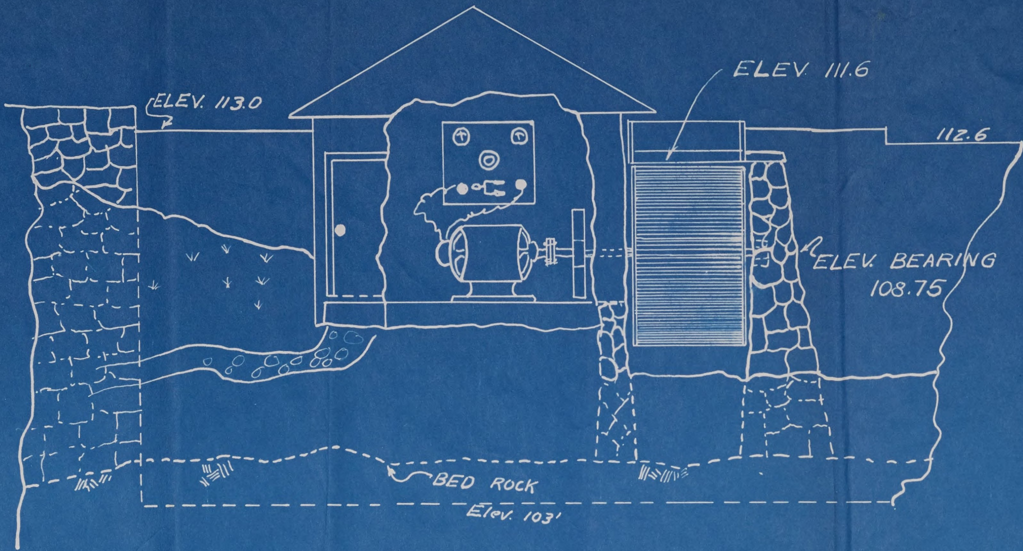
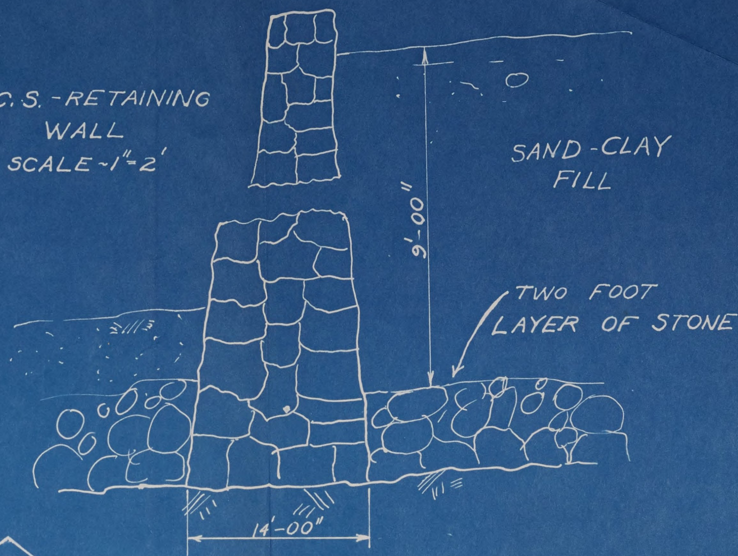
* "Actual energy" is the energy of the water. To determine this, refer to U.S. Agricultural Bulletin No. 14[illegible]0.

Pocket has:
3 Plan

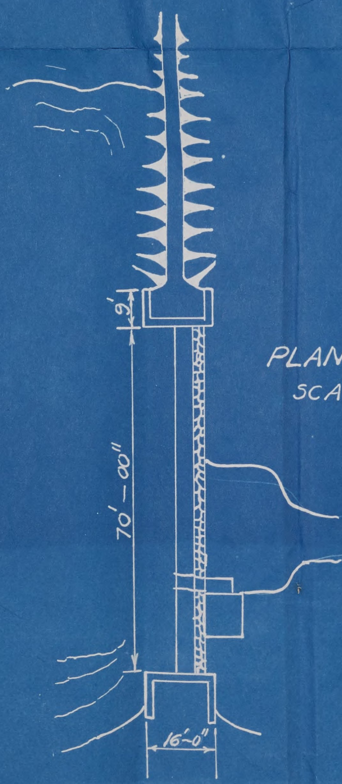


FRONT VIEW-SPILLWAY
SCALE-1"=3'

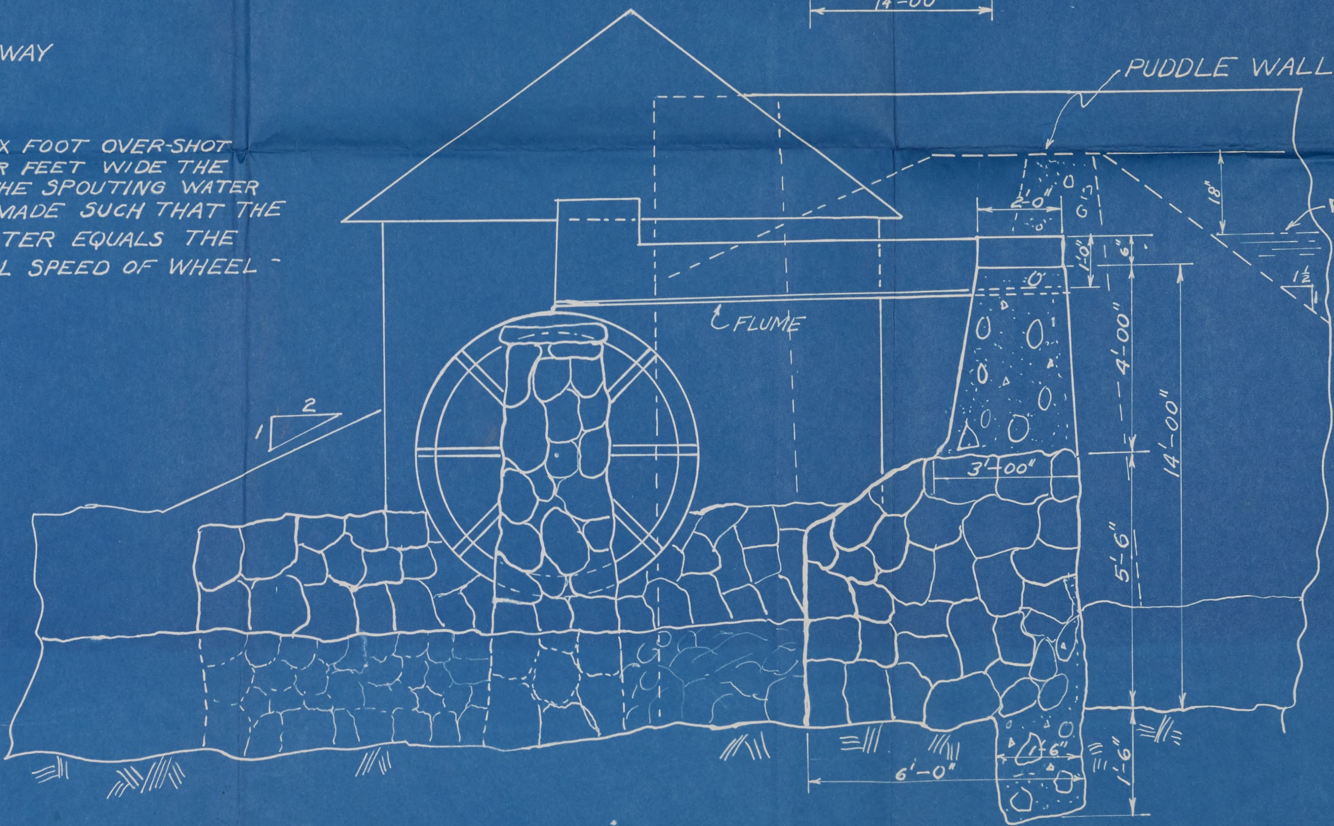
C.S.-RETAINING
WALL
SCALE-1"=2'



NOTE: A SIX FOOT OVER-SHOT
WHEEL, FOUR FEET WIDE THE
HEAD ON THE SPOUTING WATER
MUST BE MADE SUCH THAT THE
VEL. OF WATER EQUALS THE
PERIPHERAL SPEED OF WHEEL



PLAN-VIEW
SCALE-1"=20'



SECTION of SPILLWAY
SCALE - ½" = 1'

HONEY CREEK POWER PLANT
CIVIL ENG. DEPT. M.S.C.
JUNE, 1934 G.W. STONEBRAKER