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Small Michell (Banki) Turbine: A Construction
Manual

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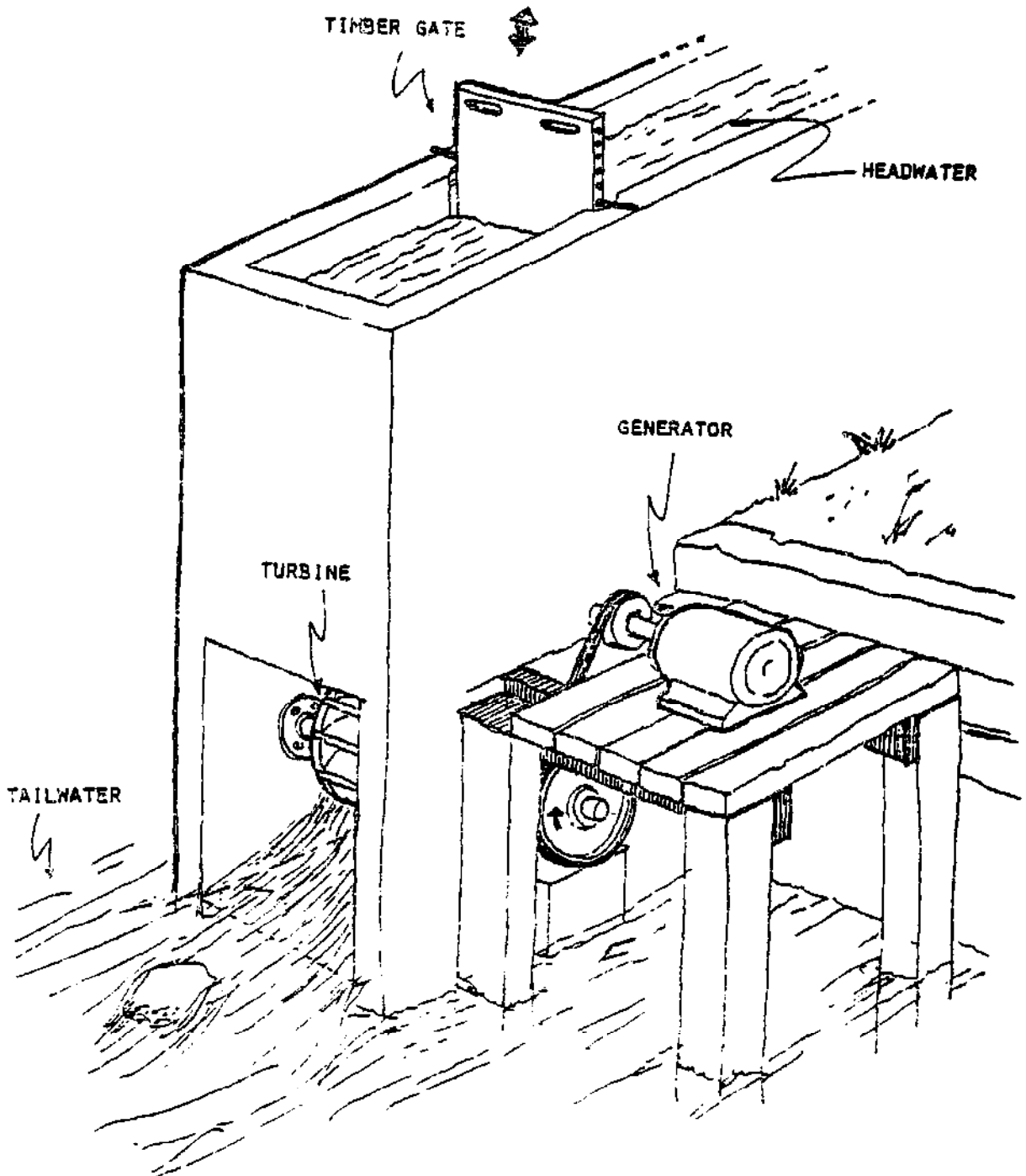
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Small Michell (Banki) Turbine: A Construction Manual

W. R. Breslin



a **VITA** publication

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MICHELL (BANKI) TURBINE CONSIDERATIONS

APPLICATIONS: AC OR DC ELECTRIC GENERATION--AGRICULTURAL MACHINERY OPERATIONS, SUCH AS, THRESHERS, WINNOWER, WATER PUMPING, ETC.

SKILLS/LABOR/TIME:

Construction time and labor resources required to complete this project will vary depending on several factors. The most important consideration is availability of people interested in doing this project. The project may in many circumstances be a secondary or after work project. This will of course increase the time necessary to complete the project. The construction times given here are at best an estimation based on limited field experience.

Skill divisions are given because some aspects of the project require someone with experience in metalworking and/or welding. Make sure adequate facilities are available before construction begins.

SKILLED LABOR -- 40 hours
UNSKILLED LABOR -- 40 hours (depending on site conditions)
WELDING -- 8 hours

SPECIAL CONSIDERATIONS:

Advantages:

- Very efficient and simple to build and operate
- Virtually no maintenance
- Can operate over a range of water flow and head conditions

Disadvantages:

- Requires certain amount of skill in turbine construction
- Special governing device needed for AC electric generation
- Welding equipment with cutting attachments needed
- Electric grinding machine needed
- Wood bearing will have to be replaced periodically

COST ESTIMATE:* \$150 - \$600(US) including materials and labor.

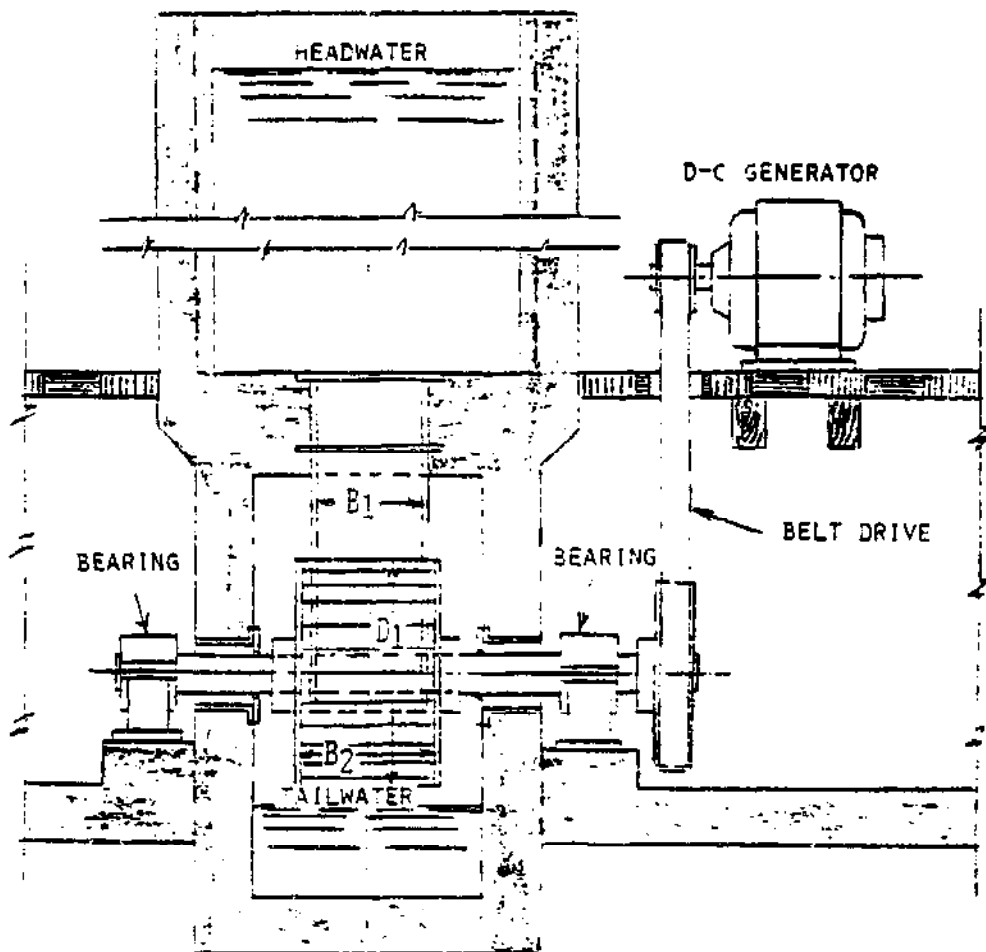
*Cost estimates serve only as a guide and will vary from country to country.

I. INTRODUCTION

The Michel or Banki turbine is a relatively easily constructed, highly efficient means of harnessing a small stream to provide enough power to generate electricity as well as a number of mechanical devices.

The turbine consists of two main parts--the runner or wheel and the nozzle. Curved horizontal blades are fixed between the circular end plates of the runner. Water passes from the nozzle through the runner twice in a narrow jet before it is discharged into the tail race. Once the flow and head of the water site have been calculated, the blades of the 30cm diameter wheel presented here can be lengthened as necessary to obtain optimum power output from the available water source.

The efficiency of the Michell turbine is 80 percent or greater. This, coupled with its adaptability to a variety of water sites and power needs, its simplicity and low cost, make it the most suitable of all water turbines for small power development. The turbine itself provides power for direct current; a governing device is necessary to provide alternating current.

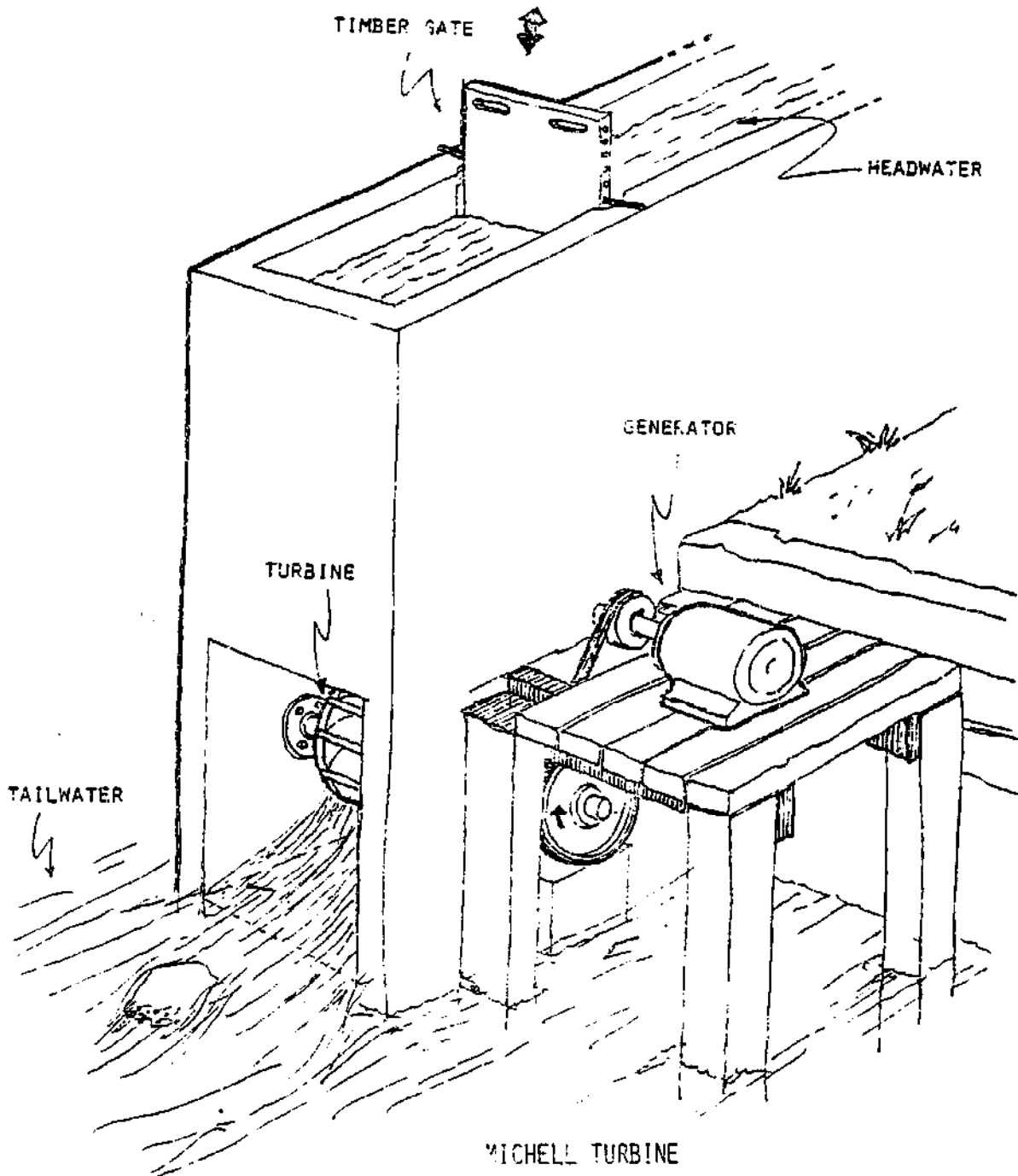


ARRANGEMENT OF A MICHELL (BANKI) TURBINE
FOR LOW-HEAD USE WITHOUT CONTROL (B)

Both of the main parts of the Michell turbine are made of plate steel and require some machining. Ordinary steel pipe is cut to form the blades or buckets of the runner. Access to welding equipment and a small machine shop like those often used to repair farm machinery and automotive parts is necessary.

The nature of the turbine avoids the need for a complicated and well-sealed housing. The bearings have no contact with the water flow, as they are located outside of the housing; they can simply be lubricated and don't need to be sealed.

Figure 15 shows an arrangement of a turbine of this type for low-head use without control. This installation will drive an AC or DC generator with a belt drive.



MICHELL TURBINE
OVERALL VIEW

MICHELL (BANKI) TURBINE

DICTIONARY OF TERMS

- Alternating Current** - Electrical energy that reverses its direction at regularly recurring intervals known as cycles.
- Bearing** - Any part of a machine in or on which another part revolves, slides, etc.
- Direct Current** - Electrical current proceeding from one point to another in time or space without deviation or interruption.
- Head** - The height of a body of water, considered as causing pressure.
- Headwater** - The average height of a water source of a stream.
- Net Head** - Height of a body of water minus the energy losses through friction of a pipe or water channel.
- Penstock** - A conduit or pipe for conducting water.
- Rolled Earth** - Compaction of soil achieved through the use of a steel or heavy wood cylinder rolled over the soil several times.
- Tailrace (Tailwater)** - The average height of the water source at the point it is utilized.
- Turbine** - A rotary engine actuated by the reaction or impulse or both of a current of fluid (such as water) subject to pressure and usually made with a series of curved vanes on a central rotating spindle.
- Weir** - A dam in a stream or river to raise the water level or divert its flow.

II. PRE-CONSTRUCTION CONSIDERATIONS

Development of small water power sites currently comprises one of the most feasible areas for application of alternative energy technologies. If water power is needed to produce only mechanical energy, for example, for powering a grain thresher, it may be easier and less expensive to construct a waterwheel or a windmill. However, if an electrical generator is needed, the Michell turbine, despite relatively high initial costs, may be feasible and indeed economical under one or more of the following conditions:

- access to transmission lines or to reliable fossil fuel sources is limited or non-existent
- cost of coal, oil, other fuels is high
- available water supply is constant and reliable, with high head (50-100 meters) relatively easy to achieve
- need exists for only a small dam built into a river or stream and for a relatively short (less than 35m) penstock (channel) for conducting water to the turbine

If one or more of the above seems to be the case, it is probably a good idea to look further into the potential of a Michell turbine. However, the final decision is going to require consideration of a combination of factors, including site potential, expense, and purpose.

SITE SELECTION

This is perhaps the most critical factor. For the amount of power which can be obtained, the expense of installation, and even, by extension, the applications for which the power can be used may be determined by the quality of the site.

The first consideration in terms of site is ownership. Installation of an electricity generating unit, for example one that needs a dam and reservoir, in addition to the site for the housing, can require access to a lot of land. In many developing countries, large lots of land are few and it is likely that more than one owner will have to be consulted. If ownership is not already clearly held, the property questions must be investigated, including any rights which may belong to those whose property borders on the water. Damming, for example, can change the entire water table and/or water usage patterns in the area and is a step to be taken only after careful consideration.

If ownership is clear, or not a problem, a careful analysis of the site is necessary in order to determine 1) the feasibility of the site for use of any kind and 2) the power obtainable from the site.

Site analysis consists of collecting the following basic data:

- Minimum flow
- Maximum flow
- Available head
- Pipe line length (length of penstock required to give desired head)
- Site sketch (with elevations, or topographical map with site sketched in)
- Water condition (clear, muddy, sandy, acid, etc.)
- Soil condition (the size of the ditch and the condition of the soil combine to affect the speed at which the water moves through the channel and, therefore, the amount of power available)
- Minimum tailwater (determines the turbine setting and type)
- Air temperature (minimum and maximum)

Appendix I contains more detailed information and the instructions needed to complete the site analysis including directions for: Measuring head, flow, and head losses. These directions have been geared so that they can be carried out in field conditions without a great deal of complex equipment.

Once such information is collected, the amount of power available can be determined. Power, expressed in terms of horsepower or kilowatts (one horsepower equals 0.7455 kilowatts), is going to be lost when it is transmitted from the generator to the place of application and because of turbine and generator inefficiencies. For a small water power installation of the type considered here, it is usually safe to assume that the net or useful power (power actually delivered for heating, lighting, etc.) will be only half of the available gross power.

Gross Power, or power available directly from the water, is determined by the following formula:

GROSS POWER

Gross Power (English units: horsepower) =

$$\frac{\text{Minimum Water Flow (cubic feet/second)} \times \text{Gross Head (feet)}}{8.8}$$

Gross Power (metric horsepower) =

$$\frac{1,000 \text{ Flow (cubic meters/second)} \times \text{Head (meters)}}{75}$$

NET POWER (available at the turbine shaft)

Net Power (English units) =

$$\frac{\text{Minimum Water Flow} \times \text{Net Head}^* \times \text{Turbine Efficiency}}{8.8}$$

Net Power (Metric units) =

$$\frac{\text{Minimum Water Flow} \times \text{Net Head}^* \times \text{Turbine Efficiency}}{75/1,000}$$

*NET HEAD is obtained by deducting energy losses from the gross head. These losses are discussed in Appendix I. A good assumption for turbine efficiency when calculating losses is 80%.

Remember that while some sites appear to lend themselves naturally to being harnessed for producing electrical power, there are a far greater number of sites which can be used if work is done to make them suitable. For example, a dam can be built to direct water into a channel intake or to get a higher head than the stream provides naturally. (A dam may not be required if there is sufficient head or if there is enough water to cover the intake of a pipe or channel leading to the penstock.)

Dams may be of earth, wood, concrete, or stone. Appendix II provides information on construction of small dams. If a dam is needed, or if there seems to be some question concerning need for a dam, it is always wise to consult an expert.

EXPENSE

Closely related to site considerations is cost. It should be clear from the previous discussion that some sites are going to require investing a great deal more money than others. Construction of dams and penstocks can be very expensive, depending upon, for example, the size and type of dam, and upon the length of the channel required. Add to these construction expenses, the cost of the electrical equipment--generators, transformers, transmission lines--and related costs for operation and maintenance and the cost, without financial support, can be prohibitive.

Any discussion of site or cost, however, must be done in light of the purpose for which the power is desired. It may be more possible to justify the expense for one purpose but not for another.

APPLICATION

Before going into a longer discussion of potential for application of turbine-produced power, a discussion of alternating (AC) and direct current (DC) is necessary. A turbine can produce both, but both types of current cannot always be used for the same purposes and one requires installation of more expensive equipment than the other.

ALTERNATING OR DIRECT CURRENT

Two factors to consider in deciding whether to install an AC or DC power unit are (1) the cost of regulating the flow of water into the turbine for AC and (2) the cost of converting motors to use DC electricity.

The demand for power will vary from time to time during the day. With a constant flow of water into the turbine, the power output will sometimes be greater than the demand for power. Therefore, either excess power must be stored or the flow of water into the turbine must be regulated according to the demand for power.

In producing AC, the flow of water must be regulated because AC cannot be stored. Flow regulation requires governors and complex valve-type shut-off devices. This equipment is expensive: in a small water power site, the regulating equipment would cost more than a turbine and generator combined.

The flow of water to a DC producing turbine, however, does not have to be regulated. Excess power can be stored in a storage battery. Direct-current generators and storage batteries are low in cost because they are mass-produced.

DC power is just as good as AC for producing electric light and heat. But for electrical appliances, such as farm machinery and household appliances having AC motors, DC motors must be installed. The cost of converting appliances must be weighed against the cost of flow regulation needed for producing AC.

Flowing water tends to generate automatically a picture of "free" power in the eyes of the observer. But there is always a cost to producing power from water sources. Before proceeding, the cost of developing low-output water power sites should be checked against the costs of other possible alternatives, such as:

- Electric Utility - In areas where transmission lines can furnish unlimited amounts of reasonably priced electric current, it is often uneconomical to develop small and medium-sized sites. However, in view of the increasing cost of utility supplied electricity, hydro-electric power is becoming more cost-effective.
- Generators - Diesel engines and internal-combustion engines are available in a wide variety of sizes and use a variety of fuels; for example, oil, gasoline, or wood. In general, the capital expenditure for this type of power plant is low compared to a hydro-electric plant. Operating costs, on the other hand, are very low for hydro-electric and high for generated power.

- Solar - Extensive work has been done on the utilization of solar energy for such things as water pumping. Equipment now available may be less costly than water power development in regions with long hours of intense sunshine.

If it seems feasible to pursue development of the small water power site, it is necessary to calculate in detail whether the site will indeed yield enough power for the specific purposes planned.

While a 30cm diameter wheel has been chosen for this manual because this size is easy to fabricate and weld, the Michell turbine has a wide range of application for all water power sites providing head and flow are suitable. The amount of water to be run through the turbine determines the width of the nozzle and the width of the wheel. These widths may vary from 5cm to 36cm. No other turbine is adaptable to as large a range of water flow.

TABLE III
SMALL HYDRAULIC TURBINES

	TYPES		
	Impulse or Pelton	Michell or Banki	Centrifugal Pump Used as Turbine
Head Range (feet)	50 to 1000	3 to 650	Available for any desired condition
Flow Range (cubic feet per second)	0.1 to 10	0.5 to 250	
Application	high head	medium head	
Power (horsepower)	1 to 500	1 to 1000	
Cost per Kilowatt	low low	low	
Manufacturers	James Leffel & Co. Springfield, Ohio USA 45501 Drees & Co. Werl, Germany Officine Bubler Taverne, Switzerland	Ossberger-Turbinenfabrik 8832 Weissenburg Bayern, Germany Can be do-it-yourself project is small weld and machine shops are available.	Any reputable dealer or manufacturer

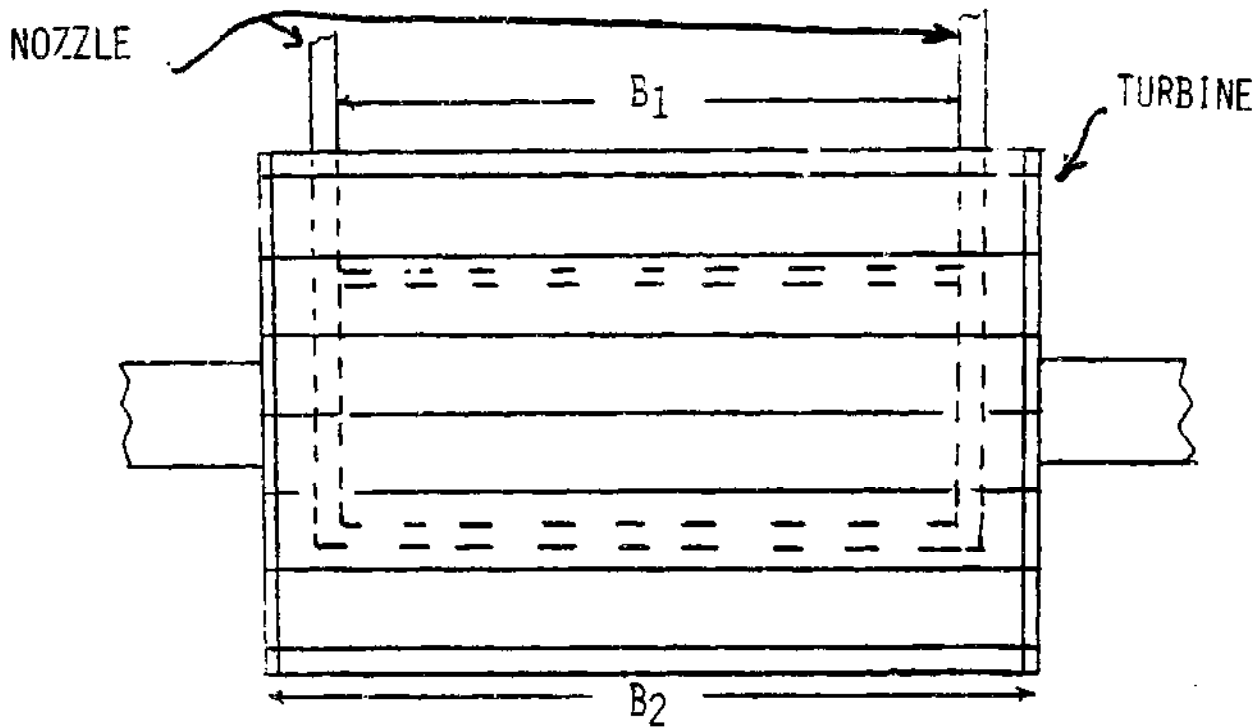
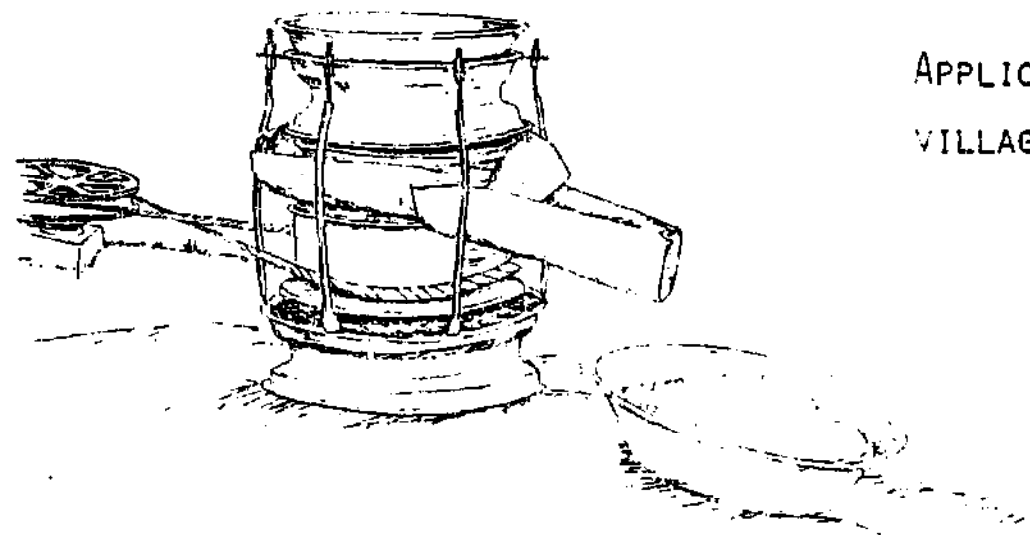


FIGURE 14. Front View - Turbine and Nozzle

It seems useful to provide an example of the decision-making process which must be gone through to determine the size of the turbine needed.



APPLICATION:

VILLAGE PEANUT HULLER

- Power enough to replace the motor for a 2-1/2 HP 1800 revolutions per minute (rpm) peanut thresher
- Gross power needed is about 5 HP (Roughly twice the horsepower of the motor to be replaced assuming that the losses are about 1/2 of the total power available.)
- Village stream can be dammed up and the water channeled through a ditch 100 feet long.

- Total difference in elevation is 25 feet
- Available minimum flow rate: 2.8 cubic feet/second
- Soil of ditch permits a water velocity of 2.4 feet/second (Appendix Table II gives $n = 0.030$)
- Area of flow in ditch = $2.8/2.4 = 1.2$ square feet
- Bottom width = 1.2 feet
- Hydraulic radius = $0.31 \times 1.2 = .37$ feet

Calculate results of fall and head loss. Shown on nomograph as 1.7 feet for 1,000 feet. The total for 100 ft. ditch is:

$$\frac{1.7}{10} = .17 \text{ feet (a negligible loss)}$$

Fall remaining is approximately 25 feet.

Power produced by turbine at 80% efficiency = 6.36 horsepower

$$\text{Net power} = \frac{\text{Minimum water flow} \times \text{net head} \times \text{turbine efficiency}}{8.8}$$

$$\frac{2.8 \times 25 \times .80}{8.8} = 6.36 \text{ horsepower}$$

Formulas for principal Michell turbine dimensions:

$$\begin{aligned} (B_1) = \text{width of nozzle} &= \frac{210 \times \text{flow}}{\text{Runner outside diameter} \times \sqrt{\text{head}}} \\ &= \frac{210 \times 2.8}{12 \times \sqrt{25}} = 9.8 \text{ inches} \end{aligned}$$

$$\begin{aligned} (B_2) = \text{width of runner between discs} - (B_1) &= 1/2 \text{ to } 1 \text{ inch} \\ &= 9.8 + 1 \text{ inch} = 10.8 \text{ inches} \end{aligned}$$

Rotational speed (revolutions per minute) =

$$\begin{aligned} &\frac{73.1 \times \sqrt{\text{head}}}{\text{Runner outside diameter (ft.)}} \\ &\frac{73.1 \times \sqrt{25}}{1} = 365.5 \text{ rpm} \end{aligned}$$

The horsepower generated is more than enough for the peanut huller but the rpm is not high enough.

Many peanut threshers will operate at varying speeds giving different kg output of hulled peanuts. So for a huller which gives maximum output at 2-1/2 HP and 1800 rpm, a pulley arrangement will be needed for stepping up speed. In this example, the pulley ratio needed to step up speed is $1800 \div 365$ or approximately 6:1. Therefore an 18" diameter pulley attached to the turbine shaft, driving a 3 inch pulley on a generator shaft will give us 1800 ± rpm.

TOOLS AND MATERIALS

Although materials used in construction can be purchased new, many of these materials can be found in the form of scrap at junk yards.

Materials for a 30cm diameter Michell turbine:

- Steel plate 40cm X 10cm X 6.5mm thick
- Steel plate 6.5mm thick (quantity of material depends on nozzle width)
- 10cm diameter water pipe for turbine buckets*
- 2 blocks hardwood (e.g., oak, lignum vitae or substitute) for bearings
- Chicken wire (1.5cm X 1.5cm weave) or 25mm diameter steel rods
- 6cm diameter or larger pipe 16cm long (to be used to enclose the wood bearings).
- 4 Hub Flanges for attaching end pieces to steel shaft
- 4.5cm diameter solid steel SHAFT
- 2 - 4.5cm diameter pillow or bush bearings for high speed use
- 8 - nuts and bolts appropriate size for hub flanges

*Measurements for length of the pipe depends on water site conditions.

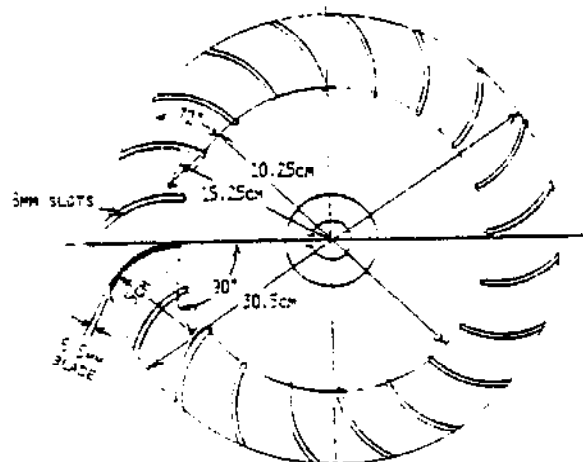
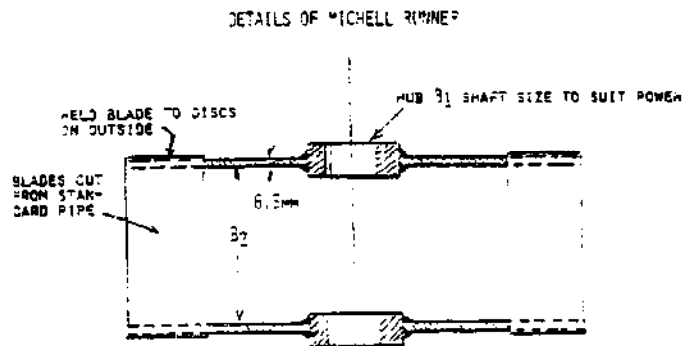
Tools:

- Welding equipment with cutting attachments
- Metal file
- Electric or manual grinder
- Drill and metal bits
- Compass
- Pencil
- T-square (template included in this handbook)
- Hammer
- C-clamps
- Work bench
- Protractor

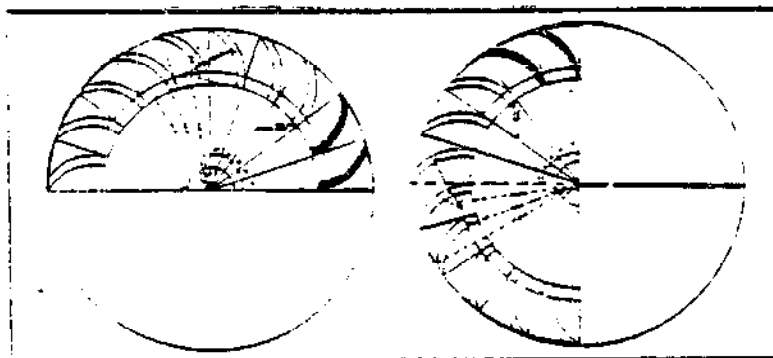
III. CONSTRUCTION

PREPARE THE END PIECES

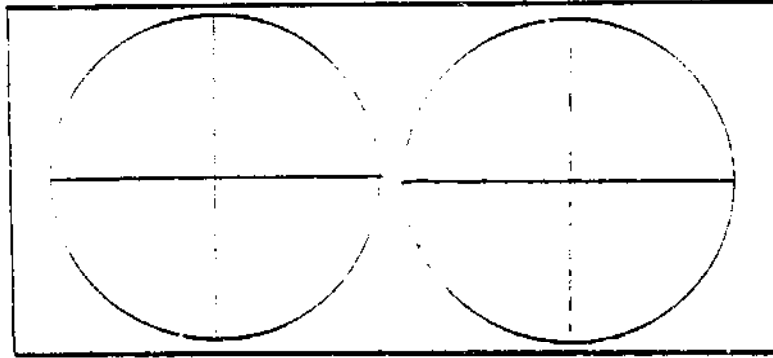
- Use 6.5mm thick plate steel. An actual size template for a 30.5cm turbine is provided at the end of this book. Two of the bucket slots are shaded to show how the buckets are installed.



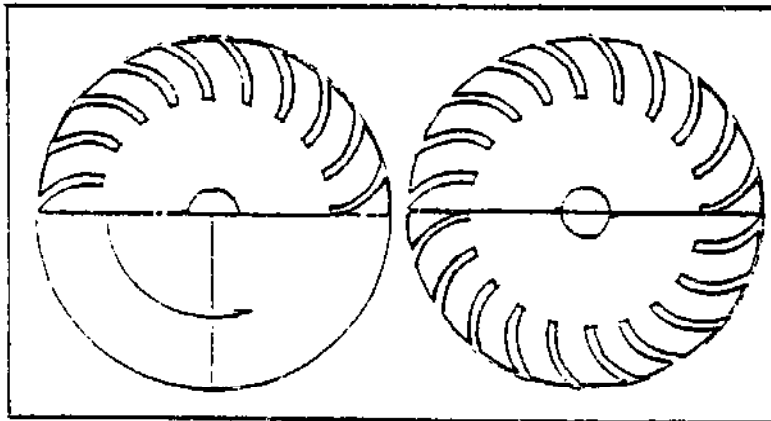
- Cut out the half circle from the template and mount it on cardboard or heavy paper.
- Trace around the half circle on the steel plate.



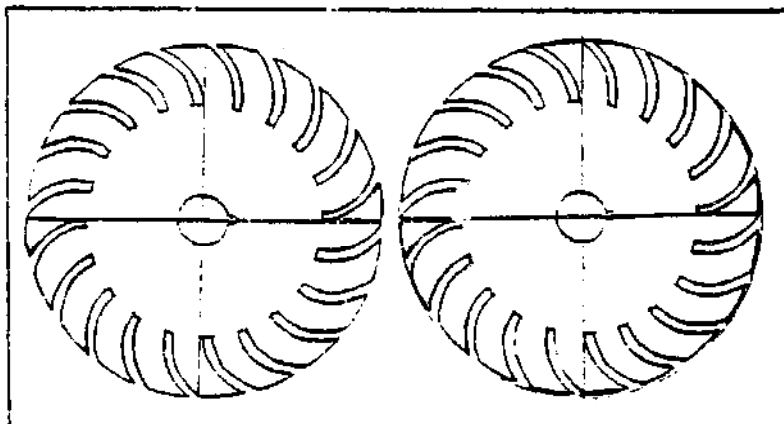
— STEEL PLATE 40cm x 100cm



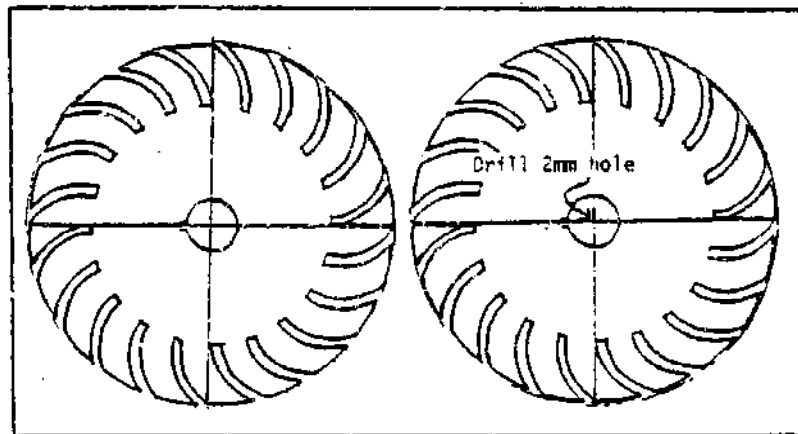
- Turn the template over and trace again to complete a full circle.
 - Make two circles on the steel plate in this way.
 - Cut out the bucket slots on the template so that there are 10 spaces.
 - Place template on the steel plate and trace in the buckets.*
- *All buckets should be oriented counterclockwise.



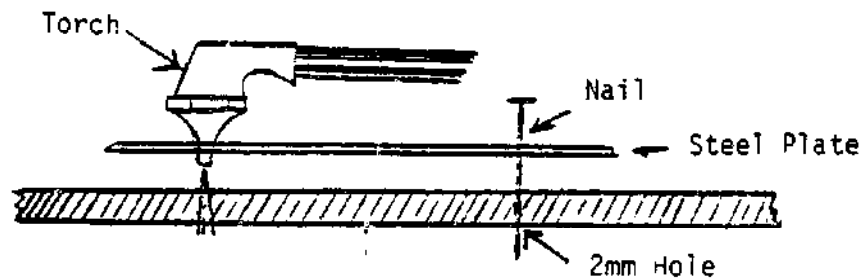
- Repeat the tracing process as before to fill in the area for the shaft.



- Drill a 2mm hole in the steel plate in the center of the wheel where the X is formed. The hole will serve as a guide for cutting the metal plate.



- Take a piece of scrap metal 20cm long by 5cm wide and drill a hole near one end the width of the opening in the torch.
- Drill a 2mm diameter hole at the other end at a point equal to the radius of the wheel 15.25cm. Measure carefully.
- Line the 2mm hole in the scrap metal up with the 2mm hole and attach with a nail (see illustration). This attachment makes it easy to cut a perfect circle.
- Cut the end plates as shown using the torch.



CUTTING THE END PLATES

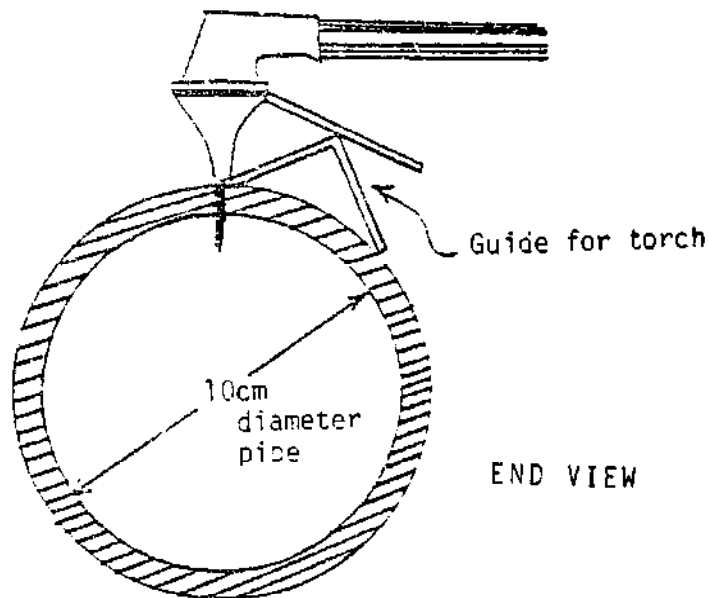
- Cut the bucket slots with the torch, or if you prefer, use a metal saw and file them out that way.
- Cut out a 4.5cm diameter circle from the center of the wheel. This prepares for the axle.

CONSTRUCT THE BUCKETS

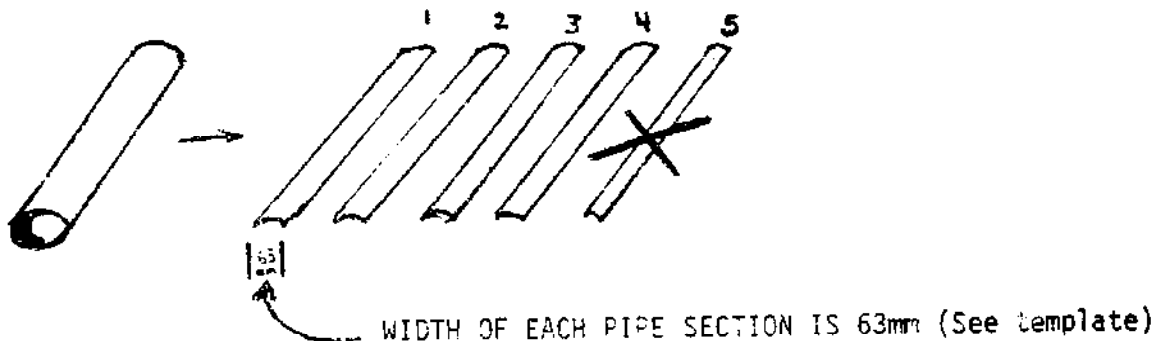
Calculate the length of buckets using the following formula:

$$\text{Width of Buckets Between End Plates} = \frac{210 \times \text{Flow (Cubic feet/second)}}{\text{Outside Diameter of Turbine (inches)} \times \sqrt{\text{Head (ft.)}}} + (3.0\text{cm})$$

- Take a 10cm diameter pipe once the bucket length has been determined and cut to the lengths you require.
- Cut pipe length-wise using a piece of angle iron to serve as a guide as shown in illustration. (Bucket measurements given in the template in the back of this manual will serve as a guide.)



- Cut four buckets from each section of pipe. A fifth piece of pipe will be left over but it will not be the correct width or angle for use as a bucket.

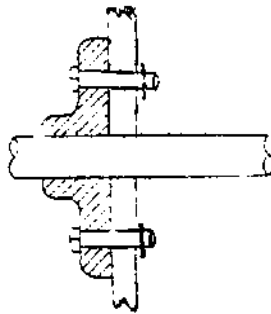


- File each of the buckets to measure 63mm wide. (NOTE: Cutting with a torch may warp the buckets; a few sharp raps with a hammer will straighten out warp.)

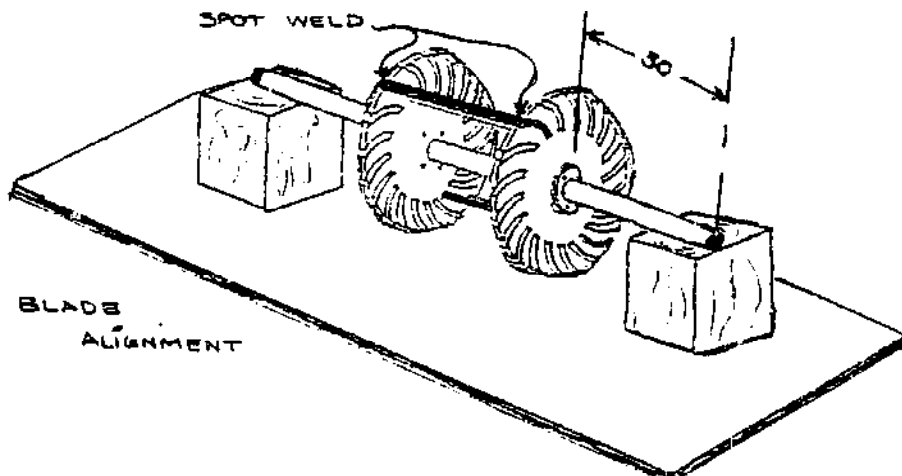
ASSEMBLE THE WHEEL

- Cut a shaft from 4.5cm diameter steel. The total length of the shaft should be 60cm plus the width of the wheel.
- Place the 4.5cm diameter metal hubs on the center of each wheel, matching the hole of the hub with the hole of the end piece.
- Drill four 20mm holes through the hub and end piece.
- Attach the hubs to each end piece using 20mm diameter X 3cm long bolts and nuts.

HUB ATTACHMENT
EDGE VIEW

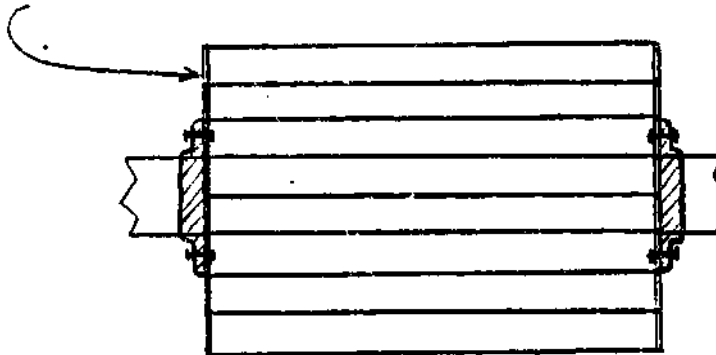


- Slide shaft through the hubs and space the end pieces to fit the buckets. The distance from each end piece to the end of the shaft should be 30cm.
- Insert a bucket and align the end pieces so that the blade runs perfectly parallel with the center shaft.
- Spot weld the bucket to the end pieces.

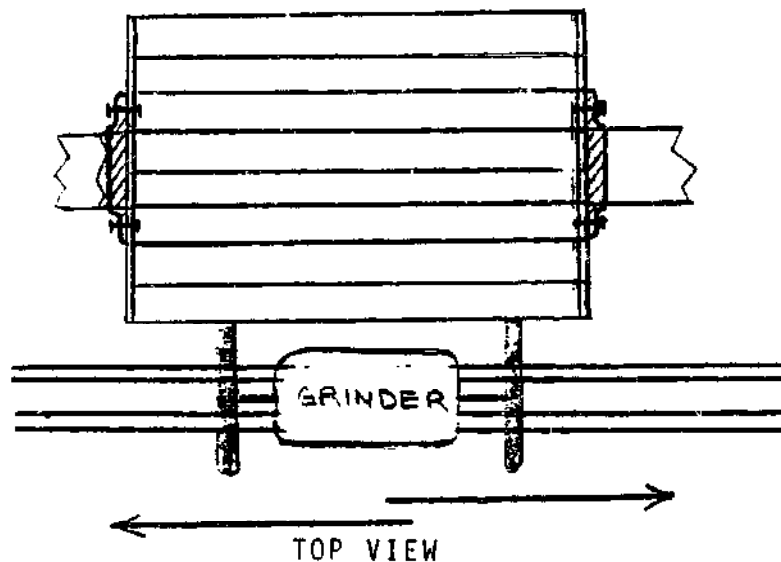


- Turn the turbine on the shaft half a revolution and insert another bucket making sure it is aligned with the center shaft.
- Spot weld the second bucket to the end pieces. Once these buckets are placed, it is easier to make sure that all the buckets will be aligned parallel to the center shaft.
- Weld the hubs to the shaft (check measurements).
- Weld remaining buckets to the end pieces (it is much easier to weld the bucket from the outside of the wheel than from the inside.)

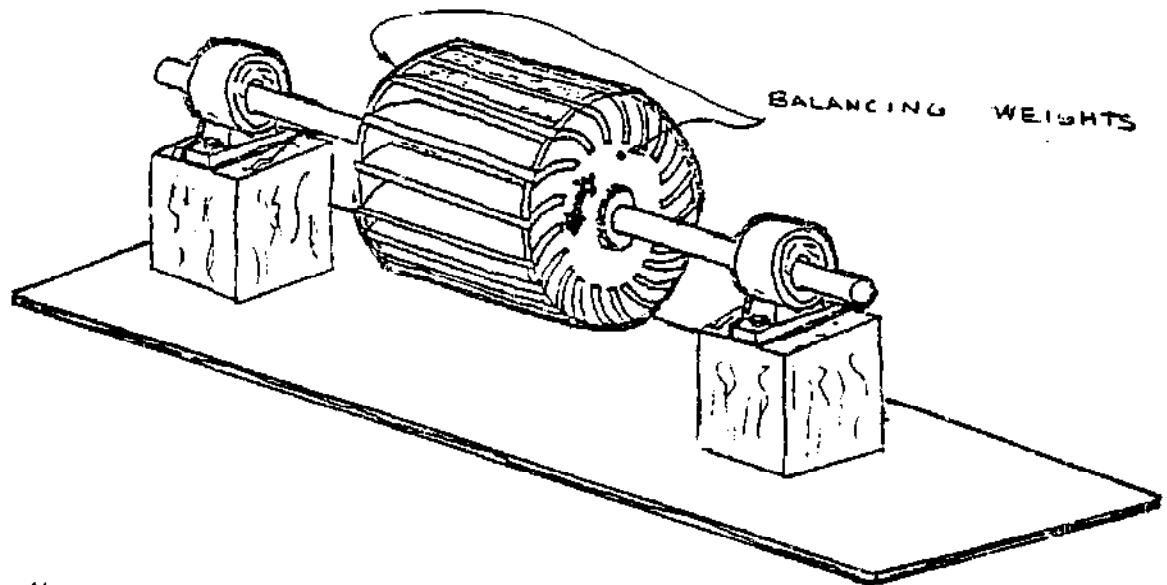
WELD BUCKETS FROM OUTSIDE



- Mount the turbine on its bearings. The bearings should be either pillow or bush bearings for high-speed applications. It is possible to fabricate wood bearings, but because of the high speed such bearings would not last. Each bearing should be clamped to the workbench so that the whole thing can be slowly rotated as in a lathe. The cutting tool is an electric or small portable hand grinder mounted on a rail and allowed to slide along a second rail, or guide. The slide rail should be carefully clamped so that it is exactly parallel to the turbine shaft.



- Rotate the turbine slowly so that the high part of each blade comes into contact with the grinder. Low parts will not quite touch. This process takes several hours and must be done carefully.
- Make sure the bucket blades are ground so that the edges are flush with the outside of the end pieces.
- Balance the turbine so it will not roll on its edges; it may be necessary to weld a couple of small metal washers on the top of either end of the turbine. The turbine is balanced when it can be rotated in any position without rolling.



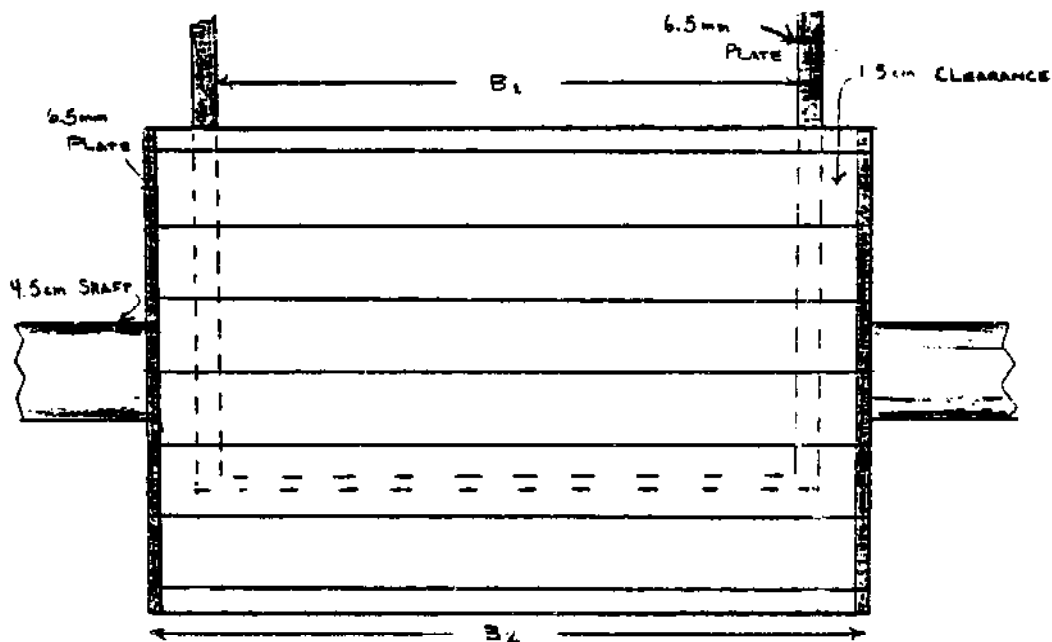
TURBINE NOZZLE

- Determine nozzle size by using the following formula:

$$\frac{210 \times \text{Flow (cubic feet/second)}}{\text{runner outside diameter (inches)} \times \sqrt{\text{head (ft.)}}}$$

The nozzle should be 1.5cm to 3cm less than the length of the buckets between the discs.

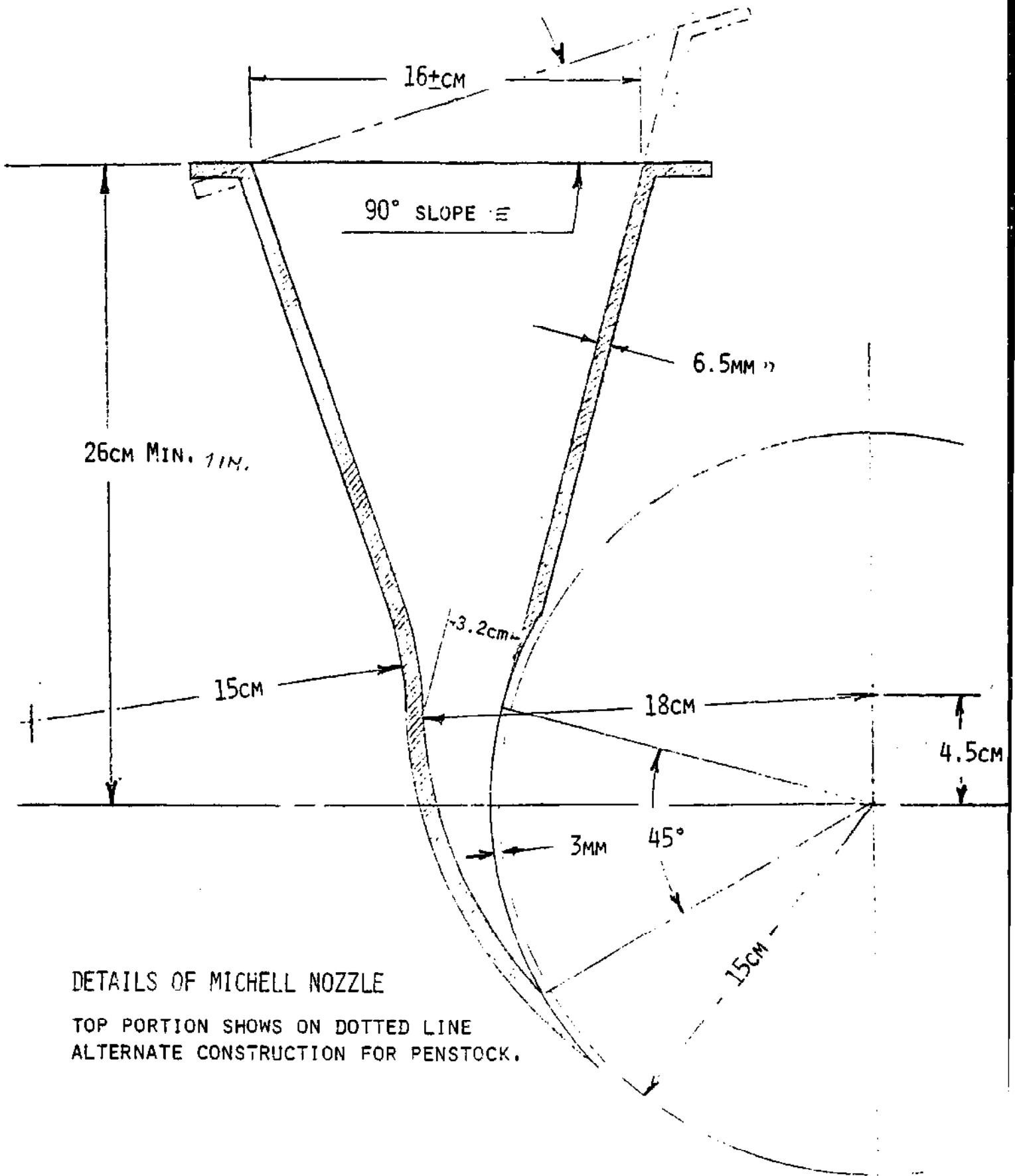
The following illustration shows a front view of a properly positioned nozzle in relationship to the turbine.



FRONT VIEW - TURBINE AND NOZZLE

- Use 6.5mm steel plate for construction of the nozzle.
- Cut curved sections of the nozzle from 15cm (outside diameter) steel pipe if available.
- Make sure that the pipe is first cut to the correct width/dimensions of the nozzle as calculated previously.
- Bend steel plate to the necessary curvature if 15cm pipe is unavailable. This process will take some time and ingenuity on the part of the builder. One way of bending steel plate is to sledge hammer the 6.5mm plate around a steel cylinder (or hardwood log) 15cm in diameter. This may be the only way to construct the nozzle if 15cm steel pipe is unavailable.

The following diagram provides minimum dimensions for proper turbine installation.

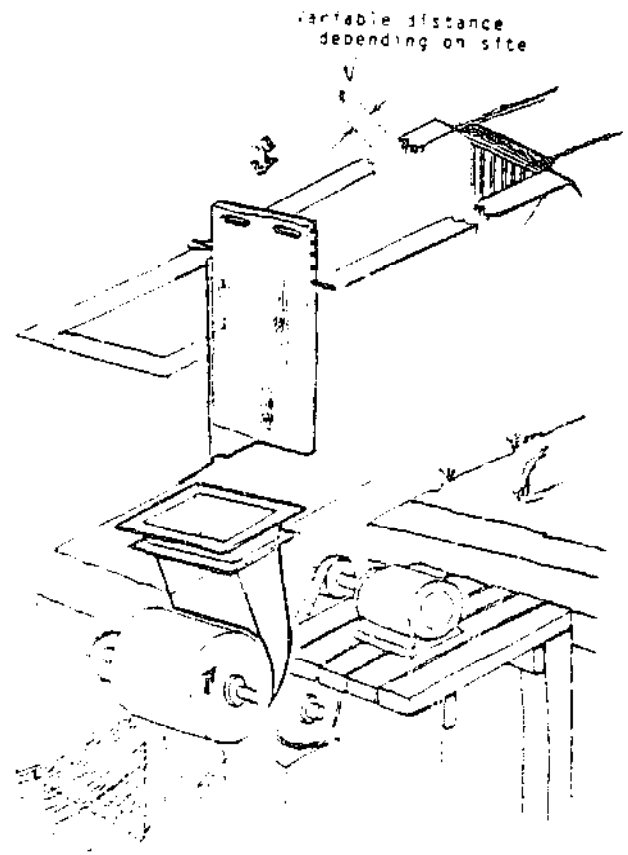
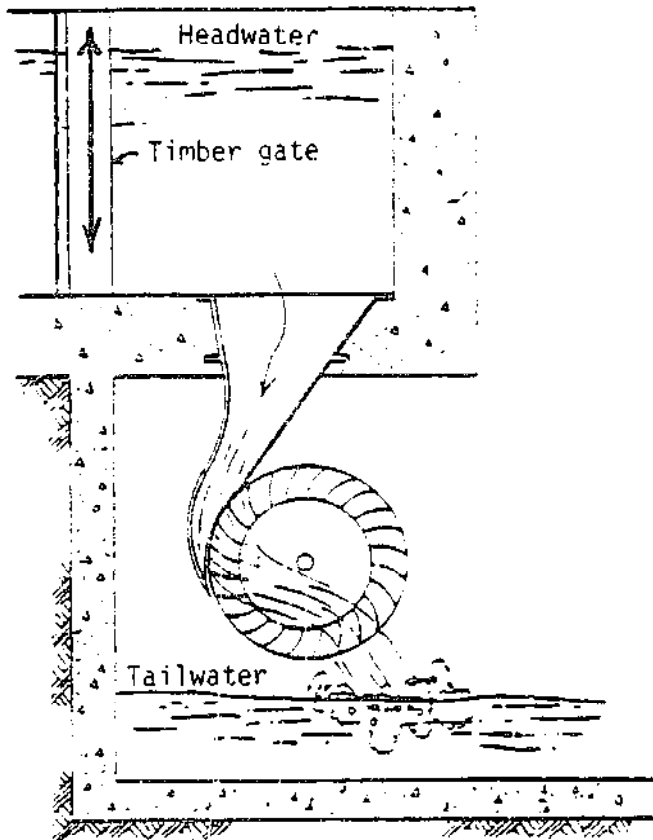


DETAILS OF MICHELL NOZZLE

TOP PORTION SHOWS ON DOTTED LINE
 ALTERNATE CONSTRUCTION FOR PENSTOCK.

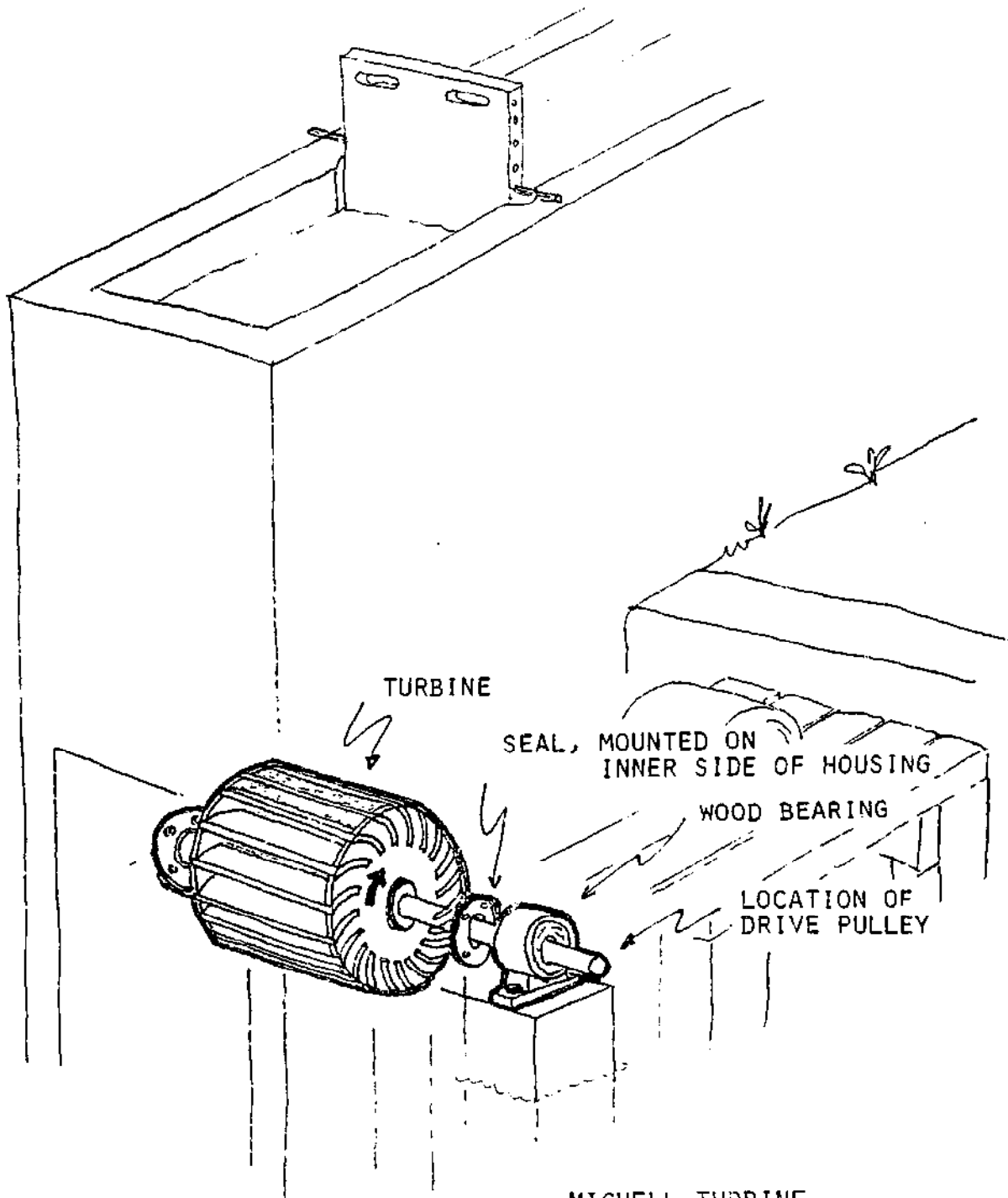
TURBINE HOUSING

- Build the structure to house the turbine and nozzle of concrete, wood, or steel plate. The illustrations here show a side view and front view of a typical installation for low head use (1-3 meters).



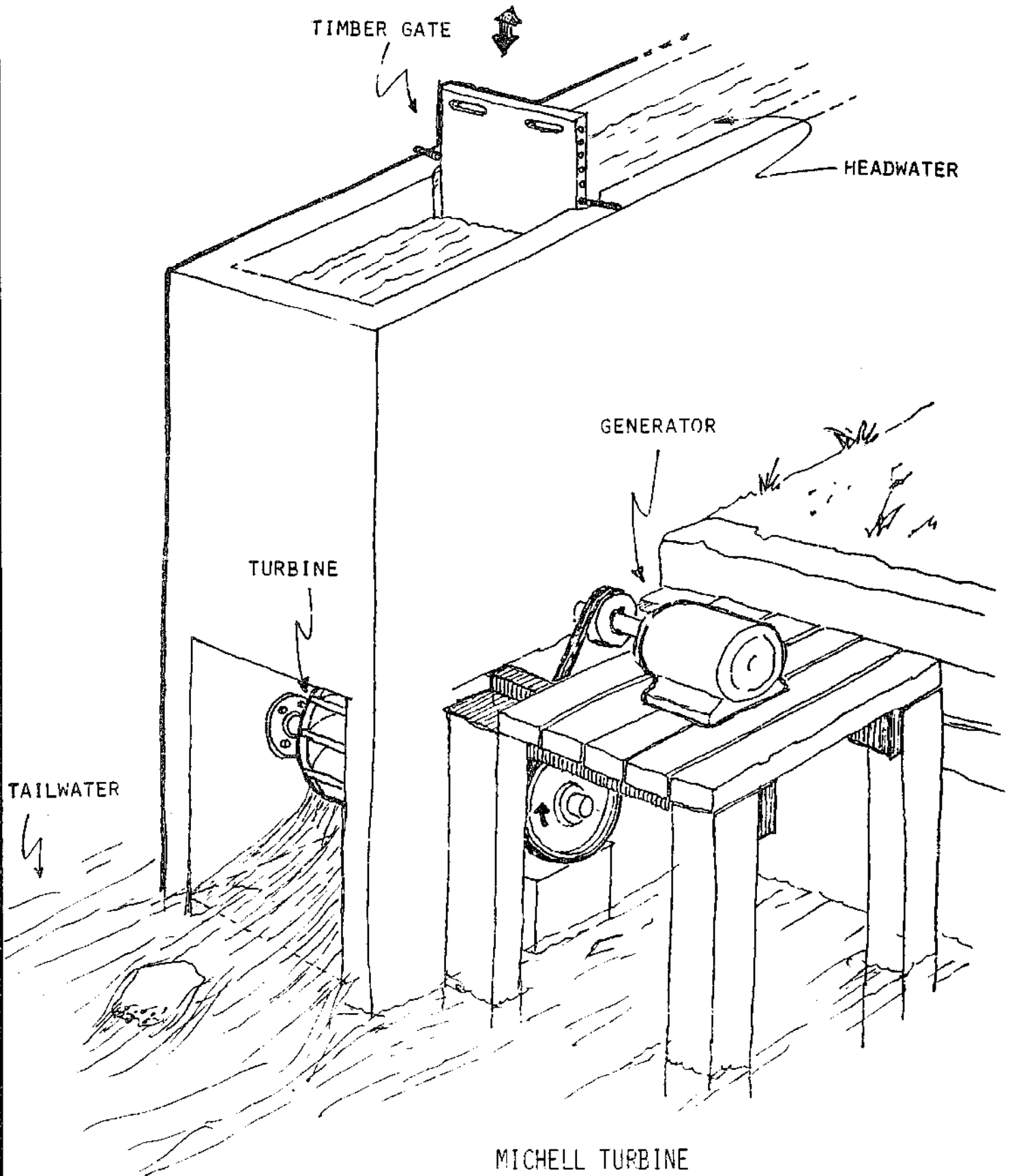
MICHELL TURBINE
Exploded view of
nozzle and timber gate.

- Attach the nozzle to the housing first and then orient the turbine to the nozzle. This should insure correct turbine placement.
- Make the foundation to which the bearings will be attached of hardwood pilings or concrete.
- Move the turbine, with bearings attached, to the proper nozzle/turbine measurements and attach the bearings to the foundation with bolts.
- Locate the bearings on the outside of the turbine housing.
- Fashion water seals, using 6.5mm steel plate drilled .3mm longer than turbine shaft, (4.53cm) (one for each side) and weld to the inside of the turbine housing between the housing and shaft. Some water will still come through the housing but not enough to interfere with efficiency.



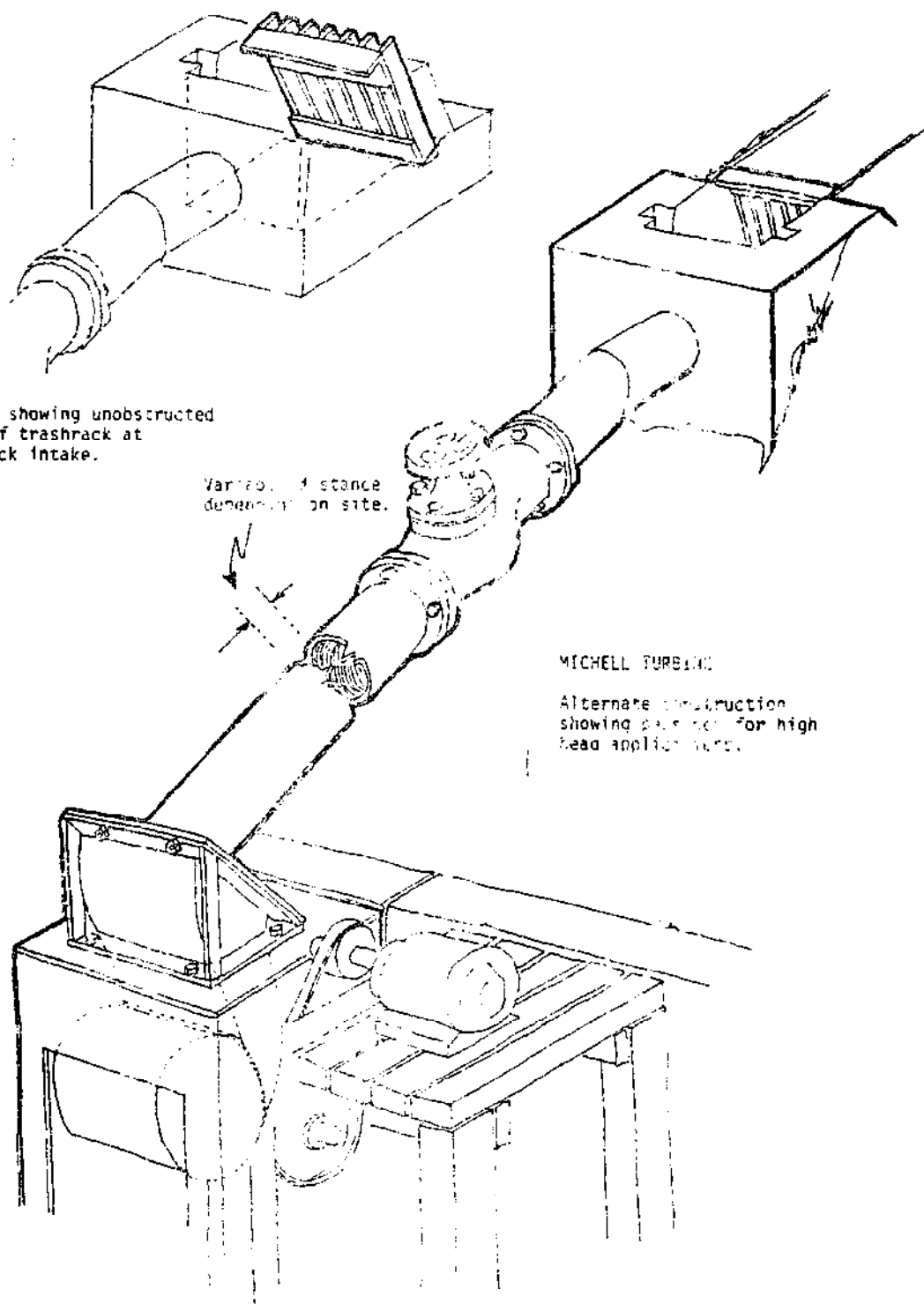
MICHELL TURBINE
UNOBSTRUCTED VIEW OF TURBINE,
SEAL AND BEARING. (DRIVE
PULLEY OMITTED FOR CLARITY)

-- Construct turbine housing so that there is easy access to the turbine for repair and maintenance.



MICHELL TURBINE
OVERALL VIEW

The illustrations below show a turbine installation for high head applications (4-100 meters). In this case the turbine housing is made from 6.5mm steel plate. A water shut-off valve allows control of water flow to these turbines. Never shut off the water flow suddenly as a rupture in the penstock is certain to occur. If maintenance on the turbine is necessary, gradually cut the water flow.



Detail showing unobstructed view of trashrack at penstock intake.

Variable stance depending on site.

MICHELL TURBINE

Alternate construction showing pressure chamber for high head applications.

IV. MAINTENANCE

The Michell (Banki) turbine is relatively maintenance-free. The only wearable parts are the bearings which may have to be replaced from time to time depending on the wood used. Lubrication in the case of non oil-impregnated bearings is a must in order to preserve the bearings for as long as possible. Bearings, which are not oil-impregnated and depending on wood chosen, should be lubricated once or twice a week. If oil-impregnated bearings are used, time between lubrication will be much longer. An unbalanced turbine or a turbine that is not mounted exactly will wear the bearings very quickly.

A chicken wire screen (1.5cm X 1.5cm weave) located behind the control gate will help to keep branches and rocks from entering the turbine housing. It may be necessary to clean the screen from time to time. Another alternative to chicken wire is the use of thin steel rods spaced so that a rake can be used to clean the leaves or sticks.

ELECTRICAL GENERATION

It is beyond the scope of this manual to go into electrical generation using the Michell (Banki) Turbine. Depending on the generator and accessories you choose the turbine can provide enough rpm for Direct Current (DC) or Alternating Current (AC).

Direct Current will be the less expensive of the two as the energy can be stored in batteries and then used. AC requires accessories to control the flow of water, since it cannot be stored. The cost of producing AC can be prohibitively expensive.

For information on the type of generator to purchase, contact manufacturers directly. A list of companies is provided here. The manufacturer often will be able to recommend an appropriate generator, if supplied with enough information upon which to make a recommendation. Be prepared to supply the following information:

- AC or DC operation (include voltage desired);
- Long range use of electrical energy (future consumption and addition of electric devices);
- Climatic condition under which generator will be used (i.e. tropical, temperate, arid, etc.);
- Power available at water site calculated at lowest flow and maximum flow rates;
- Power available to the generator in watts or horsepower (conservative figure would be half of power at water site);
- Revolutions per minute (rpm) of turbine without pulleys and belt;
- Intended or present consumption of electrical energy in watts if possible (include frequency of electrical use).

GENERATORS/ALTERNATORS

Lima Electric, Co., 200 E. Chapman Road, Lima, Ohio 45802 USA

Kato, 3201 3rd Avenue N., Menkato, Minnesota 56001 USA

Onan, 1400 73rd Avenue NE, Minneapolis, Minnesota 55432 USA

Winco of Dyna Tech., 2201 E. 7th Street, Sioux City, Iowa 51102 USA

Kohler, 421 High Street, Kohlen, Wisconsin 53044 USA

Howelite, Rendale and Nelson Streets, Port Chester, New York 10573 USA

McCulloch, 989 S. Brooklyn Avenue, Wellsville, New York 14895 USA

Sears and Roebuck

Winpower, 1225 1st Avenue East, Newton, Iowa 50208 USA

Ideal Electric, 615 1st Street, Mansfield, Ohio 44903 USA

Empire Electric Company, 5200-02 First Avenue, Brooklyn, New York 11232 USA

BATTERIES

Bright Star, 602 Getty Avenue, Clifton, New Jersey 07015 USA

Burgess Division of Clevite Corp., Gould P. O. Box 3140, St. Paul, Minnesota 55101 USA

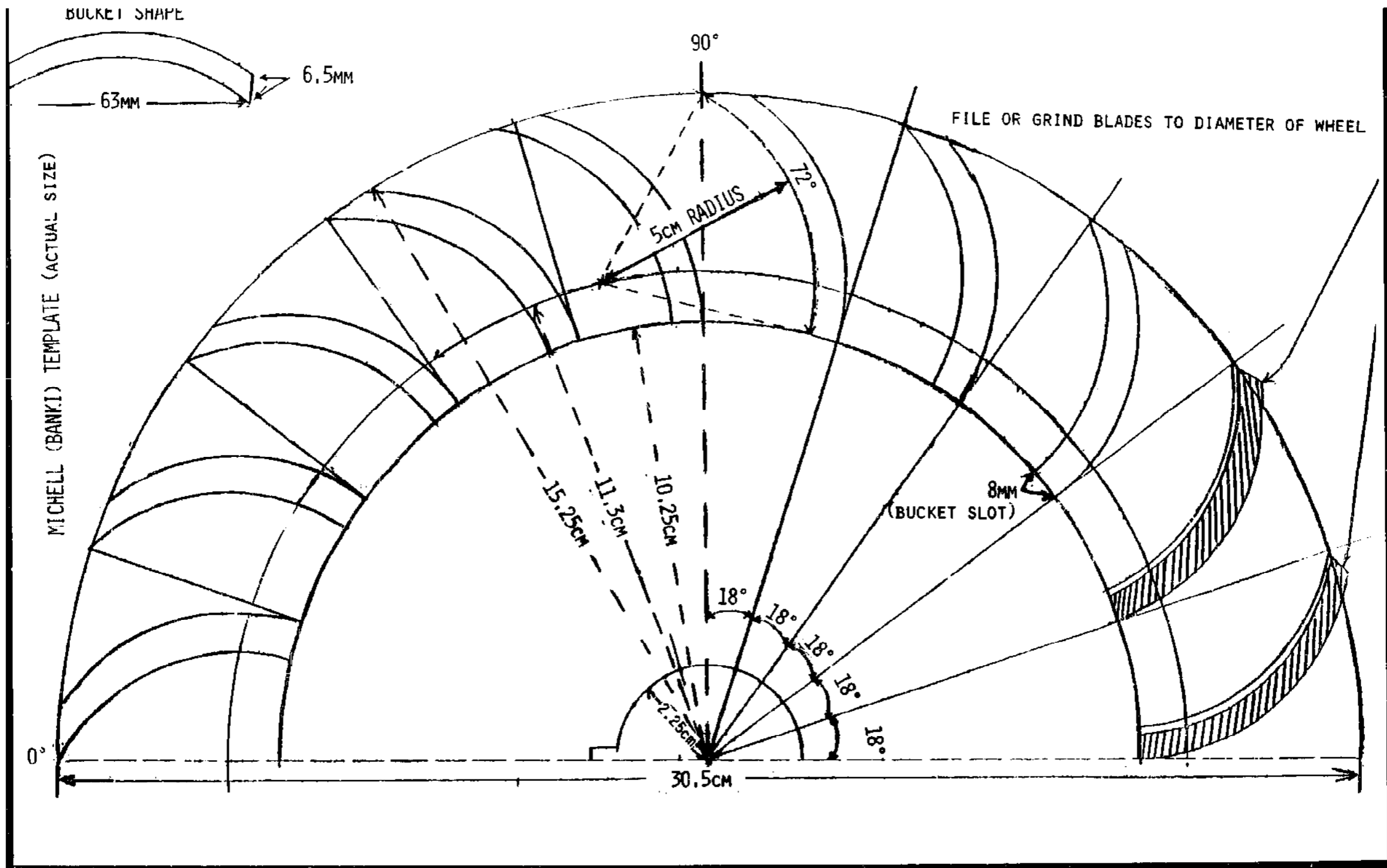
Delco-Remy, Division of GM, P. O. Box 2439, Anderson, Indiana 46011 USA

Eggle-Pichen Industries, Box 47, Joplin, Missouri 64801 USA

ESB Inc., Willard Box 6949, Cleveland, Ohio 44101 USA

Exide, 5 Penn Center, Plaza, Philadelphia, Pennsylvania 19103 USA

Ever Ready Union Carbide Corp., 270 Park Avenue, New York, New York 10017 USA



APPENDIX I. -- SITE ANALYSIS

DATA SHEET

MEASURING GROSS HEAD

MEASURING FLOW

MEASURING HEAD LOSSES

USING A NOMOGRAPH

DETERMINING CHANNEL WIDTH AND DEPTH

DETERMINING PENSTOCK LENGTH

THIS APPENDIX IS MEANT TO PROVIDE, IN ONE PLACE, A GUIDE TO MAKING THE NECESSARY CALCULATIONS FOR A DETAILED SITE ANALYSIS.

DATA SHEET

1. Minimum flow of water available in cubic feet per second (or cubic meters per second). _____
2. Maximum flow of water available in cubic feet per second (or cubic meters per second). _____
3. Head or fall of water in feet (or meters). _____
4. Length of pipe line in feet (or meters) needed to get the required head. _____
5. Describe water condition (clear, muddy, sandy, acid). _____
6. Describe soil condition (see Table II). _____
7. Minimum tailwater elevation in feet (or meters). _____
8. Approximate area of pond above dam in acres (or square kilometers). _____
9. Approximate depth of the pond in feet (or meters). _____
10. Distance from power plant to where electricity will be used in feet (or meters). _____
11. Approximate distance from dam to power plant. _____
12. Minimum air temperature. _____
13. Maximum air temperature. _____
14. Estimate power to be used. _____
15. ATTACH SITE SKETCH WITH ELEVATIONS, OR TOPOGRAPHICAL MAP WITH SITE SKETCHED IN.

The following questions cover information which, although not necessary in starting to plan a water power site, will usually be needed later. If it can possibly be given early in the project, this will save time later.

1. Give the type, power and speed of the machinery to be driven and indicate whether direct, belt or gear drive is desired or acceptable.

2. For electric current, indicate whether direct current is acceptable or alternating current is required. Give the desired voltage, number of phases and frequency.

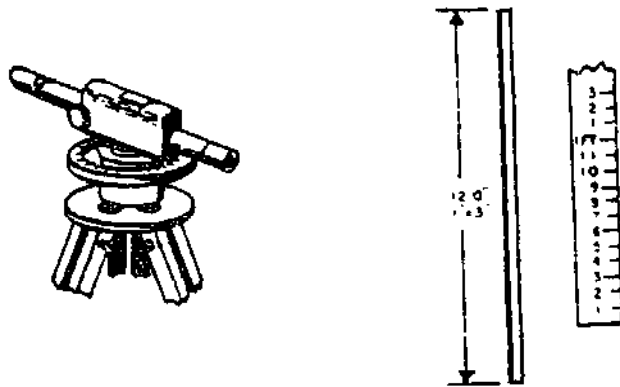
3. Say whether manual flow regulation can be used (with DC and very small AC plants) or if regulation by an automatic governor is needed.

MEASURING GROSS HEAD

METHOD NO. 1

1. Equipment

- a. Surveyor's leveling instrument - consists of a spirit level fastened parallel to a telescopic sight.
- b. Scale - use wooden board approximately 12 feet in length.

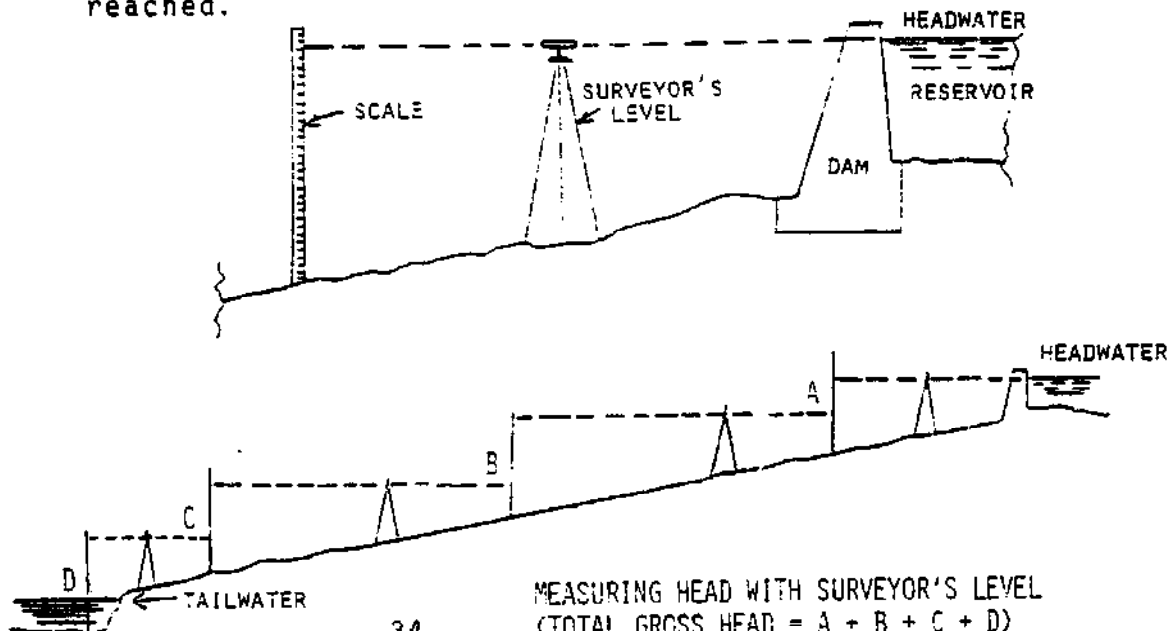


SURVEYOR'S LEVEL

SCALE AND DETAIL OF SCALE

2. Procedure

- a. Surveyor's level on a tripod is placed down stream from the power reservoir dam on which the headwater level is marked.
- b. After taking a reading, the level is turned 180° in a horizontal circle. The scale is placed downstream from it at a suitable distance and a second reading is taken. This process is repeated until the tailwater level is reached.

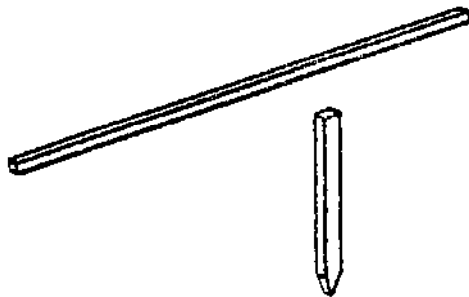


METHOD NO. 2

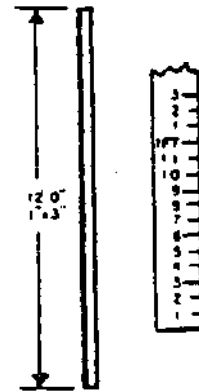
This method is fully reliable, but is more tedious than Method No. 1 and need only be used when a surveyor's level is not available.

1. Equipment

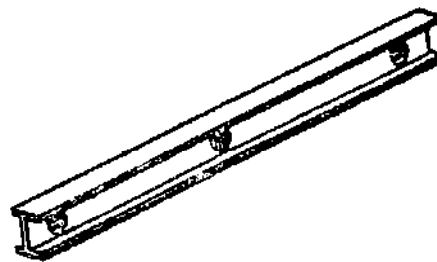
- a. Scale
- b. Board and wooden plug
- c. Ordinary carpenter's level



LEVELING BOARD AND PLUGS IN STOKES



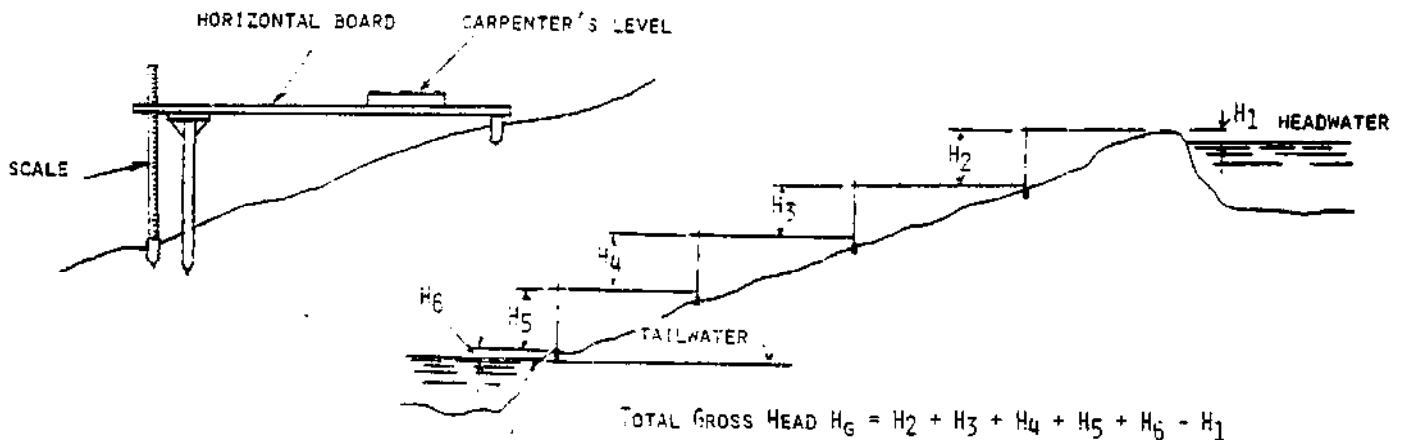
SCALE AND DETAIL OF SCALE



CARPENTER'S LEVEL

2. Procedure

- a. Place board horizontally at headwater level and place level on top of it for accurate leveling. At the downstream end of the horizontal board, the distance to a wooden peg set into the ground is measured with a scale.
- b. The process is repeated step wise until the tailwater level is reached.



$$\text{TOTAL GROSS HEAD } H_6 = H_2 + H_3 + H_4 + H_5 + H_6 - H_1$$

MEASURING HEAD WITH CARPENTER'S LEVEL

MEASURING FLOW

For power purposes, measurements should take place at the season of lowest flow in order to guarantee full power at all times. Investigate the stream's flow history to determine the level of flow at both maximum and minimum. Too often planners have overlooked the fact that if the flow in a stream is reduced below the minimum level required, other streams or sources of power may offer a better solution.

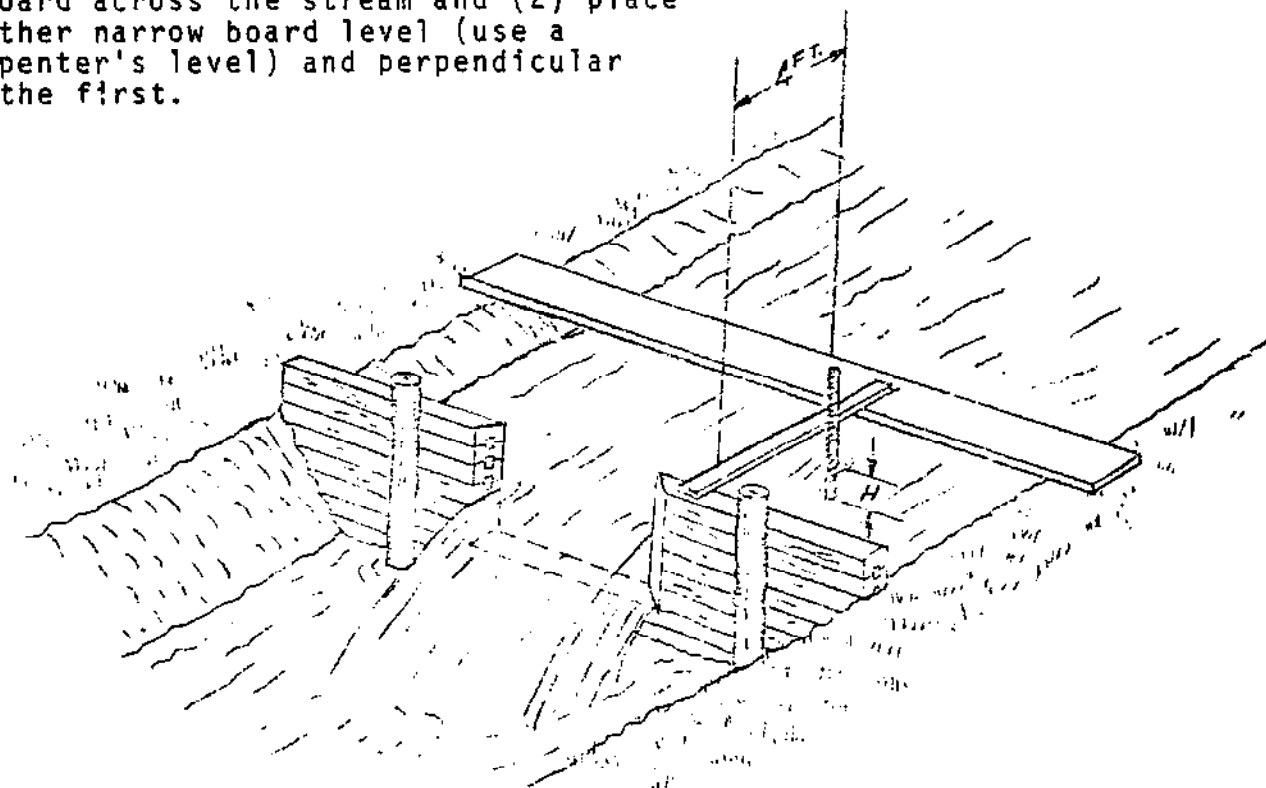
METHOD NO. 1

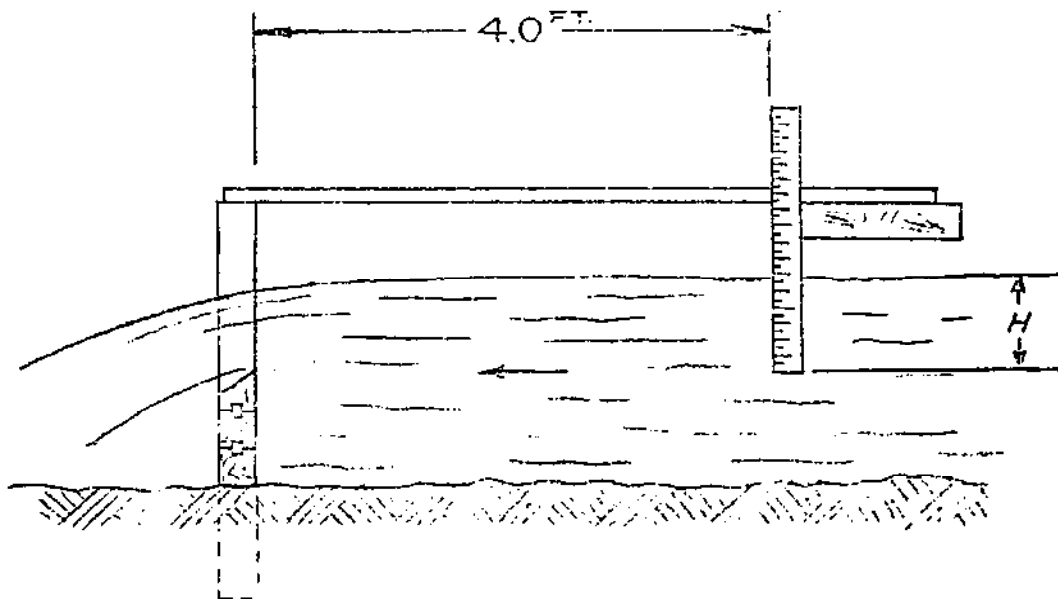
For small streams with a capacity of less than one cubic foot per second, build a temporary dam in the stream, or use a "swimming hole" created by a natural dam. Channel the water into a pipe and catch it in a bucket of known capacity. Determine the stream flow by measuring the time it takes to fill the bucket.

$$\text{Stream Flow (cubic feet/second)} = \frac{\text{Volume of Bucket (cubic feet)}}{\text{Filling Time (seconds)}}$$

METHOD NO. 2

For medium streams with a capacity of more than one cubic foot per second, the weir method can be used. The weir is made from boards, logs or scrap lumber. Cut a rectangular opening in the center. Seal the seams of the boards and the sides built into the banks with clay or sod to prevent leakage. Saw the edges of the opening on a slant to produce sharp edges on the upstream side. A small pond is formed upstream from the weir. When there is no leakage and all water is flowing through the weir opening, (1) place a board across the stream and (2) place another narrow board level (use a carpenter's level) and perpendicular to the first.





Measure the depth of the water above the bottom edge of the weir with the help of a stick on which a scale has been marked. Determine the flow from the table below.

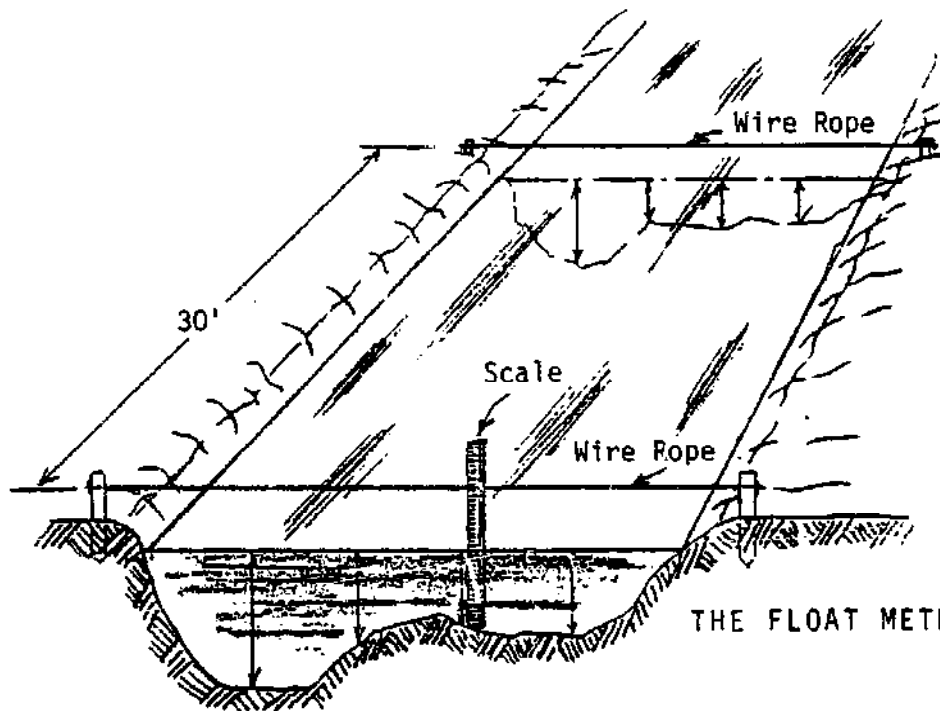
FLOW VALUE (Cubic Feet/Second)

Overflow Height	Weir Width						
	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	9 feet
1.0 inch	.24	.32	.40	.48	.56	.64	.72
2 inches	.67	.89	1.06	1.34	1.56	1.8	2.0
4 inches	1.9	2.5	3.2	3.8	4.5	5.0	5.7
6 inches	3.5	4.7	5.9	7.0	8.2	9.4	10.5
8 inches	5.4	7.3	9.0	10.8	12.4	14.6	16.2
10 inches	7.6	10.0	12.7	15.2	17.7	20.0	22.8
12 inches	10.0	13.3	16.7	20.0	23.3	26.6	30.0

METHOD NO. 3

The float method is used for larger streams. Although it is not as accurate as the previous two methods, it is adequate for practical purposes. Choose a point in the stream where the bed is smooth and the cross section is fairly uniform for a length of at least 30 feet. Measure water velocity by throwing pieces of wood into the water and measuring the time of travel between two fixed points, 30 feet or more apart. Erect posts on each bank at these points. Connect the 2 upstream posts by a level wire rope (use a carpenter's level). Follow the same procedure with the downstream posts. Divide the stream into equal sections along the wires and measure the water depth for each section. In this way, the cross-sectional area of the stream is determined. Use the following formula to calculate the flow:

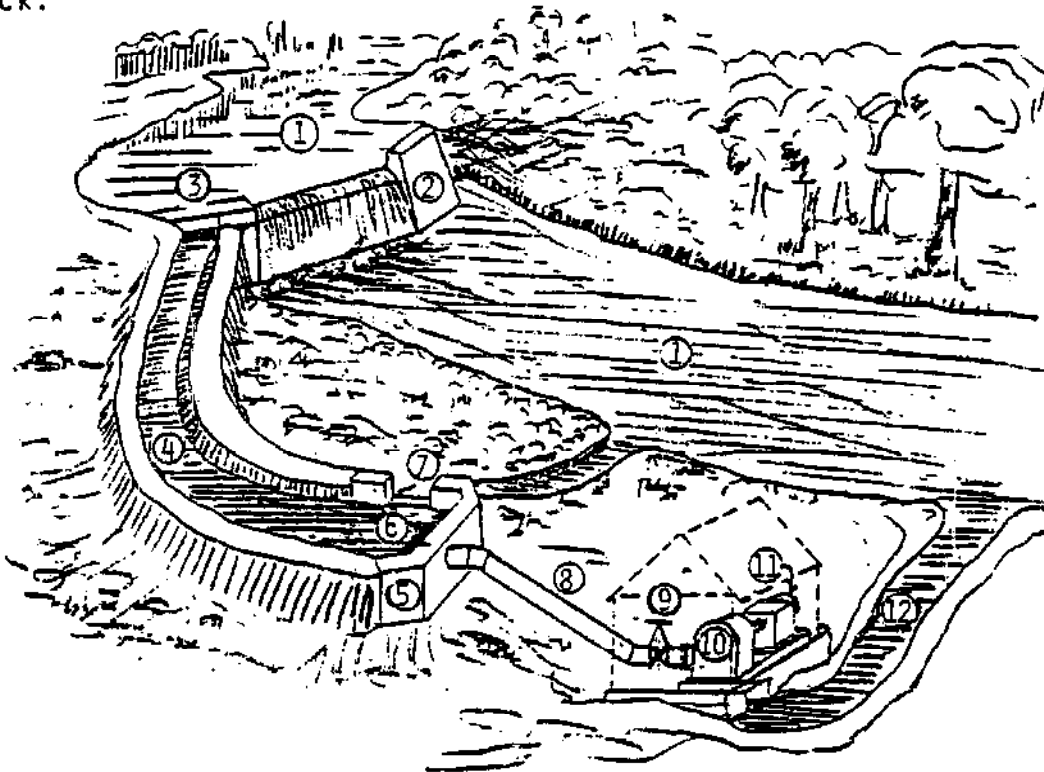
Stream Flow (cubic feet/second) = Average Cross-Sectional Flow Area (square feet)
X Velocity (feet/second)



THE FLOAT METHOD OF MEASURING FLOW

MEASURING HEAD LOSSES

"Net Power" is a function of the "Net Head." The "Net Head" is the "Gross Head" less the "Head Losses." The illustration shows a typical small water power installation. The head losses are the open-channel losses plus the friction loss from flow through the penstock.

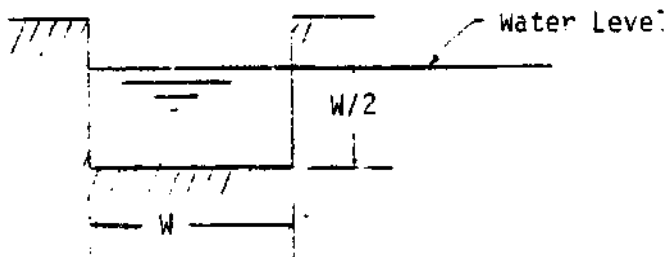


A TYPICAL INSTALLATION FOR A LOW-OUTPUT WATER POWER PLANT

- | | |
|-------------------------------|-------------------------|
| 1. River | 7. Overflow of Headrace |
| 2. Dam with Spillway | 8. Penstock |
| 3. Intake to Headrace | 9. Turbine Inlet Valve |
| 4. Headrace | 10. Water Turbine |
| 5. Intake to Turbine Penstock | 11. Electric Generator |
| 6. Trashrack | 12. Tailrace |

For Timber, Concrete, Masonry & Rock

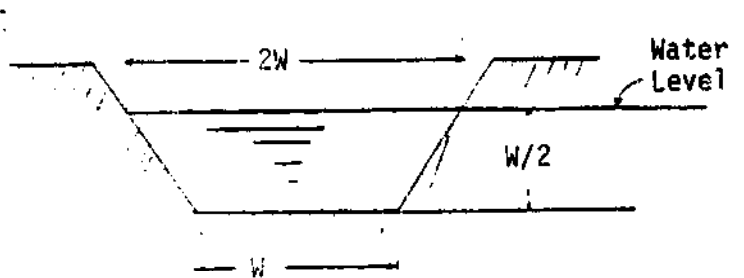
$$\text{Hydraulic Radius} = 0.25 W$$



W = Bottom Width

For Earth Channels

$$\text{Hydraulic Radius} = 0.31 W$$



BUILDING WATER CHANNELS

A. Open Channel Head Losses

The headrace and the tailrace in the illustration are open channels for transporting water at low velocities. The walls of channels made of timber, masonry, concrete, or rock, should be constructed perpendicularly. Design them so that the water level height is one half of the width. Earth walls should be built at a 45° angle. Design them so that the water level height is one half of the channel width at the bottom. At the water level the width is twice that of the bottom.

The head loss in open channels is given in the nomograph. The friction effect of the material of construction is called "n". Various values of "n" and the maximum water velocity, below which the walls of a channel will not erode are given.

TABLE II

Material of Channel Wall	Maximum Allowable Water Velocity (feet/second)	Value of "n"
Fine grained sand	0.6	0.030
Course sand	1.2	0.030
Small stones	2.4	0.030
Coarse stones	4.0	0.030
Rock	25.0	(Smooth) 0.033 (Jagged) 0.04
Concrete with sandy water	10.0	0.016
Concrete with clean water	20.0	0.016
Sandy loam, 40% clay	1.8	0.030
Loamy soil, 65% clay	3.0	0.030
Clay loam, 85% clay	4.8	0.030
Soil loam, 95% clay	6.2	0.030
100% clay	7.3	0.030
Wood		0.015
Earth bottom with rubble sides		0.033

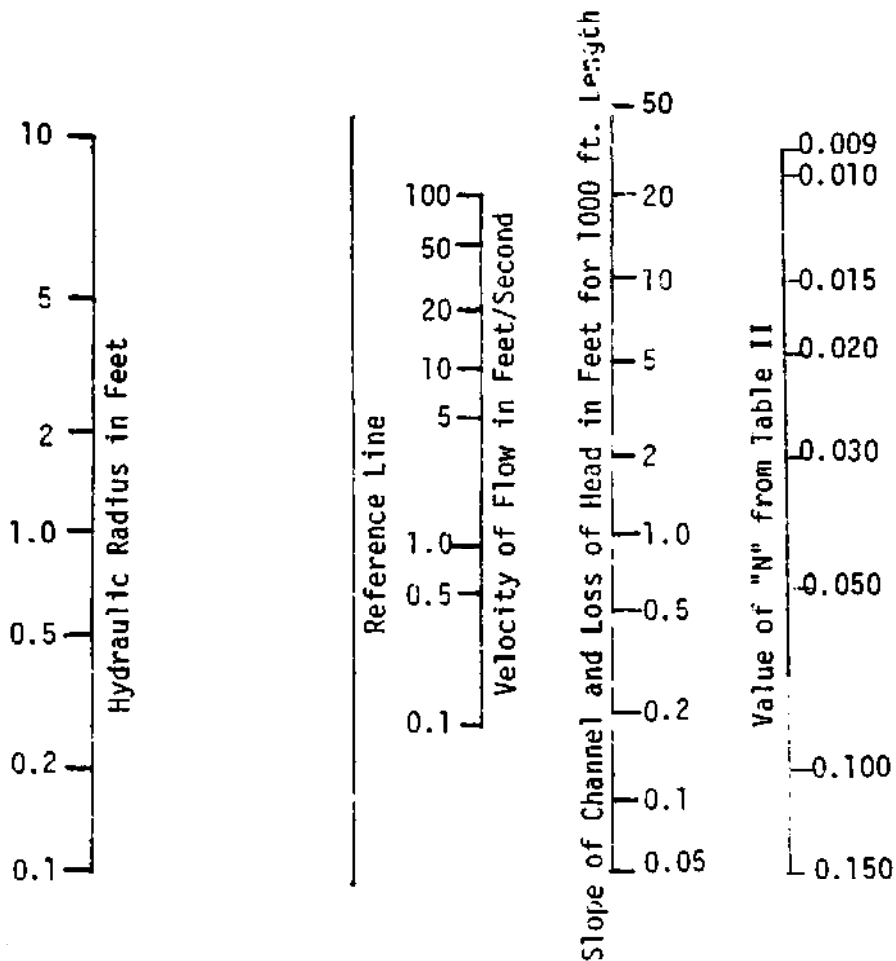
The hydraulic radius is equal to a quarter of the channel width, except for earth-walled channels where it is 0.31 times the width at the bottom.

To use the nomograph, a straight line is drawn from the value of "n" through the flow velocity to the reference line. The point on the reference line is connected to the hydraulic radius and this line is extended to the head-loss scale which also determines the required slope of the channel.

USING A NOMOGRAPH

After carefully determining the water power site capabilities in terms of water flow and head, the nomograph is used to determine:

- 1) the width/depth of the channel needed to bring the water to the spot/location of the water turbine, and/or
- 2) the amount of head lost in doing this.



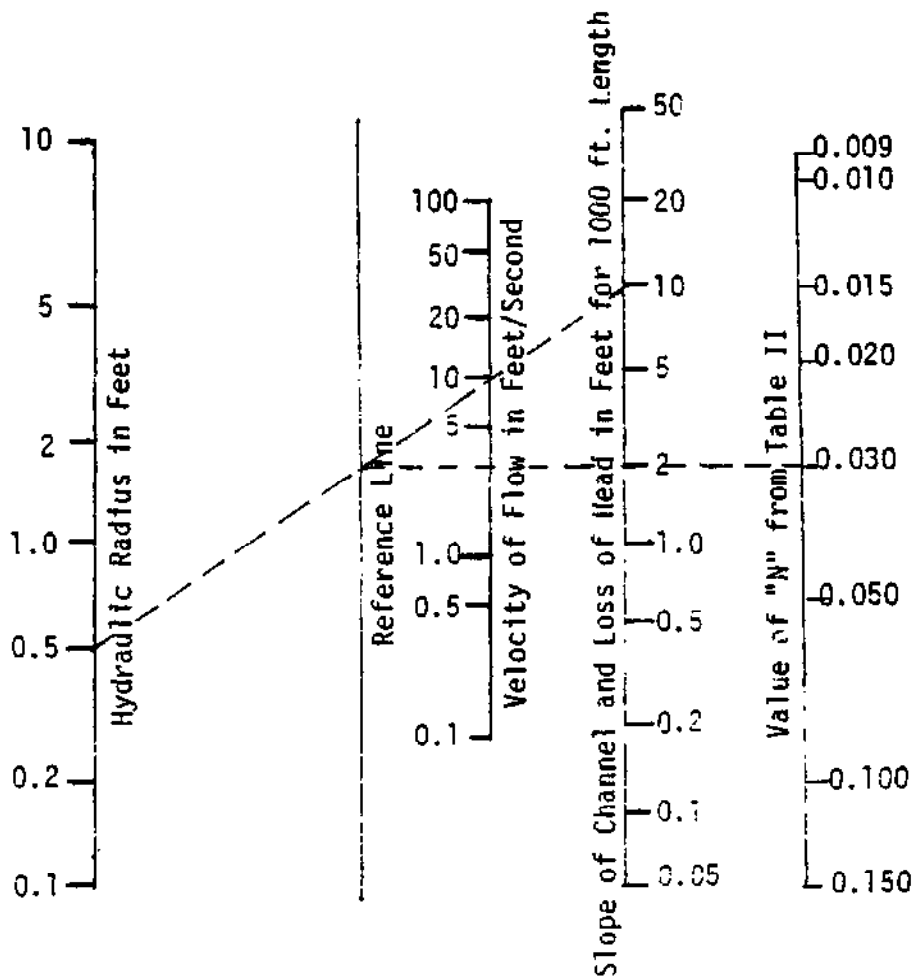
Fall of Channel (or Slope) in feet per 1000 feet of Channel Length (The total fall is equal to the Loss of Head in Feet through the Channel)

To use the graph, draw a straight line from the value of "N" through the flow velocity through the reference line tending to the hydraulic radius scale. The hydraulic radius is one quarter (.25) or (.31) the width of the channel that needs to be built. In the case where "N" is .030, for example, and water flow is 1.5 cubic feet/second, the hydraulic radius is .5 feet or 6 inches. If you are building a timber, concrete, masonry, or rock channel, the total width of the

channel would be 6 inches times .25 or 2 feet with a depth of at least 1 foot. If the channel is made of earth, the bottom width of the channel would be 6 times .31, or 19.5 inches, with depth of at least 9.75 inches and top width of 39 inches.

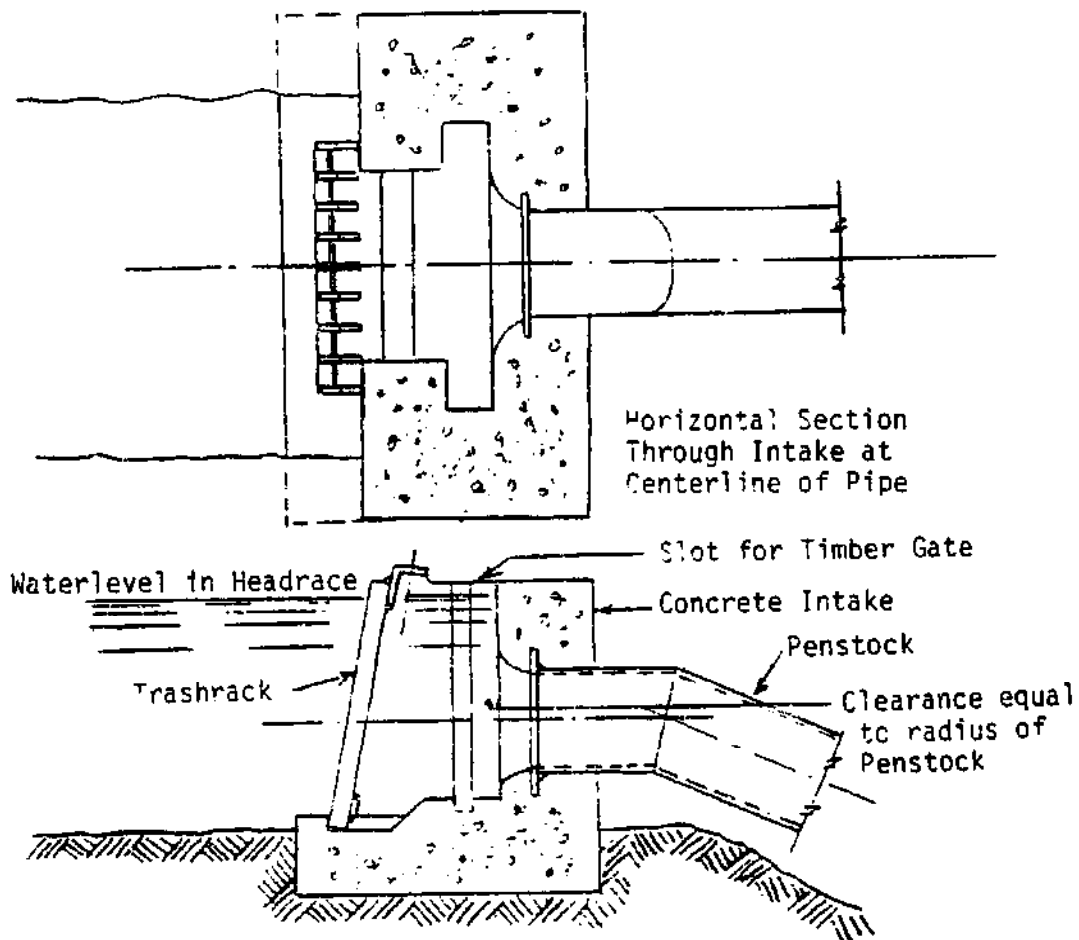
Suppose, however, that water flow is 4 cubic feet/second. Using the graph the optimum hydraulic radius would be approximately 2 feet--or for a wood channel, a width of 8 feet. Building a wood channel of this dimension would be prohibitively expensive.

However, a smaller channel can be built by sacrificing some water head. For example, you could build a channel with a hydraulic radius of .5 feet or 6 inches. To determine the amount of head that will be lost, draw a straight line from the value of "N" through the flow velocity of 4 feet³/second to the reference line. Now draw a straight line from the hydraulic radius scale of .5 feet through the point on the reference line extending this to the head-loss scale which will determine the slope of the channel. In this case about 10 feet of head will be lost per thousand feet of channel. If the channel is 100 feet long, the loss would only be 1.0 feet--if 50 feet long, .5 feet and so forth.



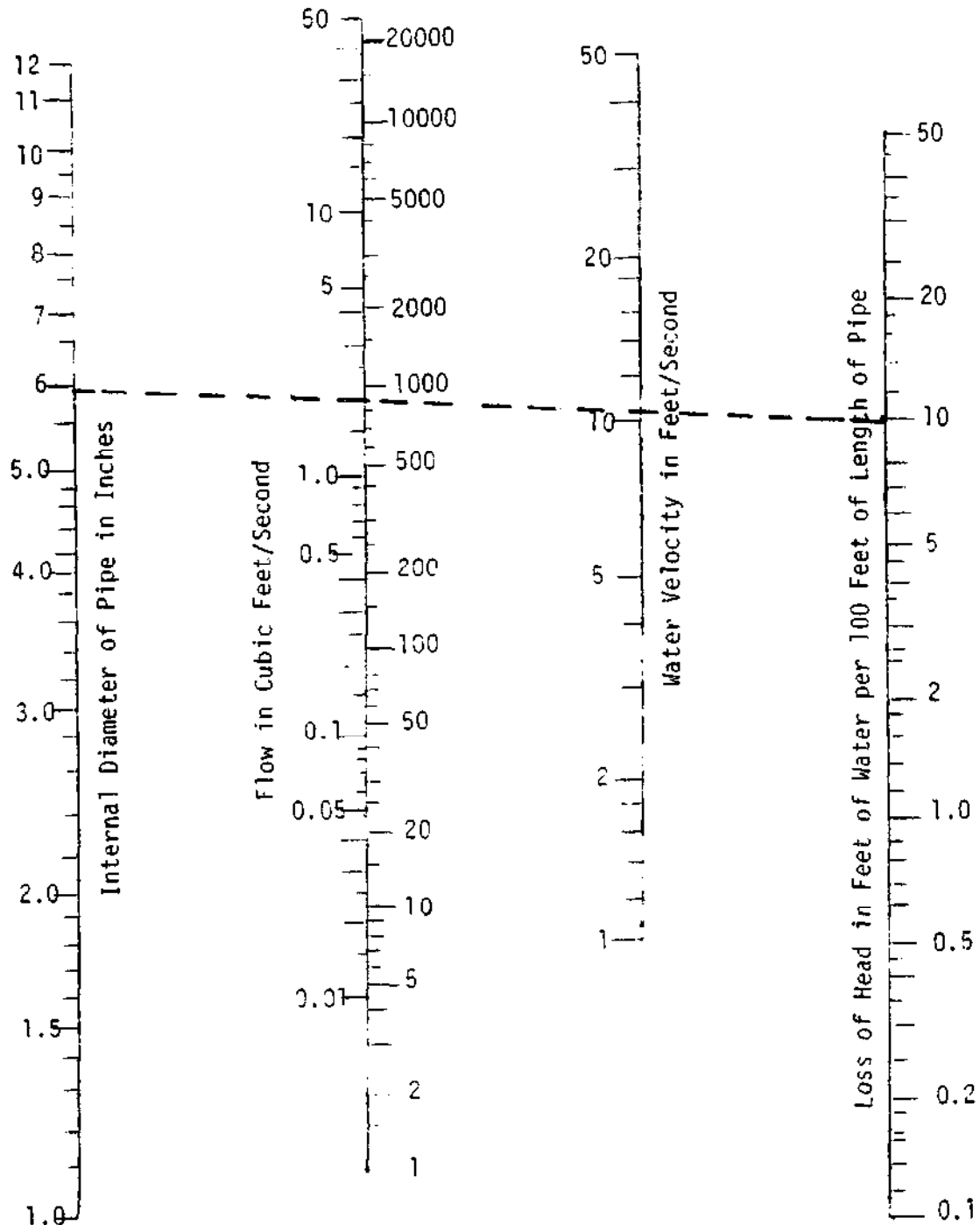
Pipe Head Loss and Penstock Intake

The trashrack is a weldment consisting of a number of vertical bars held together by an angle at the top and a bar at the bottom. The vertical bars must be spaced in such a way that the teeth of a rake can penetrate the rack for removing leaves, grass and trash which might clog up the intake. Such a trashrack can easily be manufactured in the field or in a small welding shop. Downstream from the trashrack, a slot is provided in the concrete into which a timber gate can be inserted for shutting off the flow of water to the turbine.



SECTIONAL ELEVATION: INTAKE TO PENSTOCK OF SMALL WATER TURBINE

The penstock can be constructed from commercial pipe. The pipe must be large enough to keep the head loss small. From the nomograph, the required pipe size is determined. A straight line drawn through the water velocity and flow rate scales gives the required pipe size and pipe head loss. Head loss is given for a 100-foot pipe length. For longer or shorter penstocks, the actual head loss is the head loss from the chart multiplied by the actual length divided by 100. If commercial pipe is too expensive, it is possible to make pipe from native material; for example, concrete and ceramic pipe or hollowed logs. The choice of pipe material and the method of making the pipe depend on the cost and availability of labor and the availability of material.



NOMOGRAPH FOR HEAD LOSS IN STEEL PIPES

APPENDIX II. -- SMALL DAM CONSTRUCTION

INTRODUCTION TO:

EARTH DAMS

CRIB DAMS

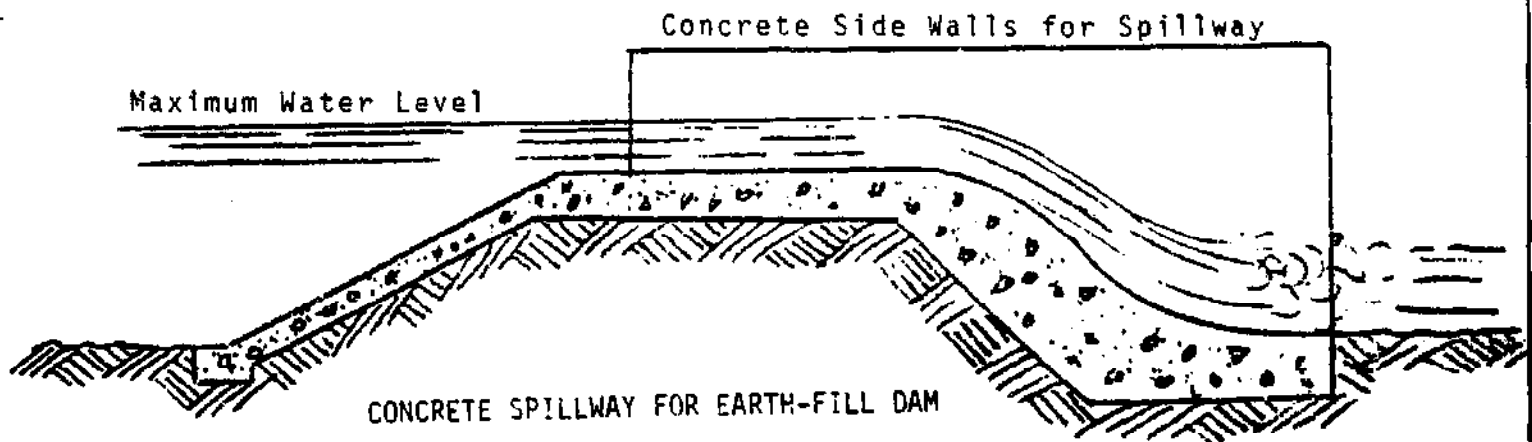
STONE DAMS

CONCRETE DAMS

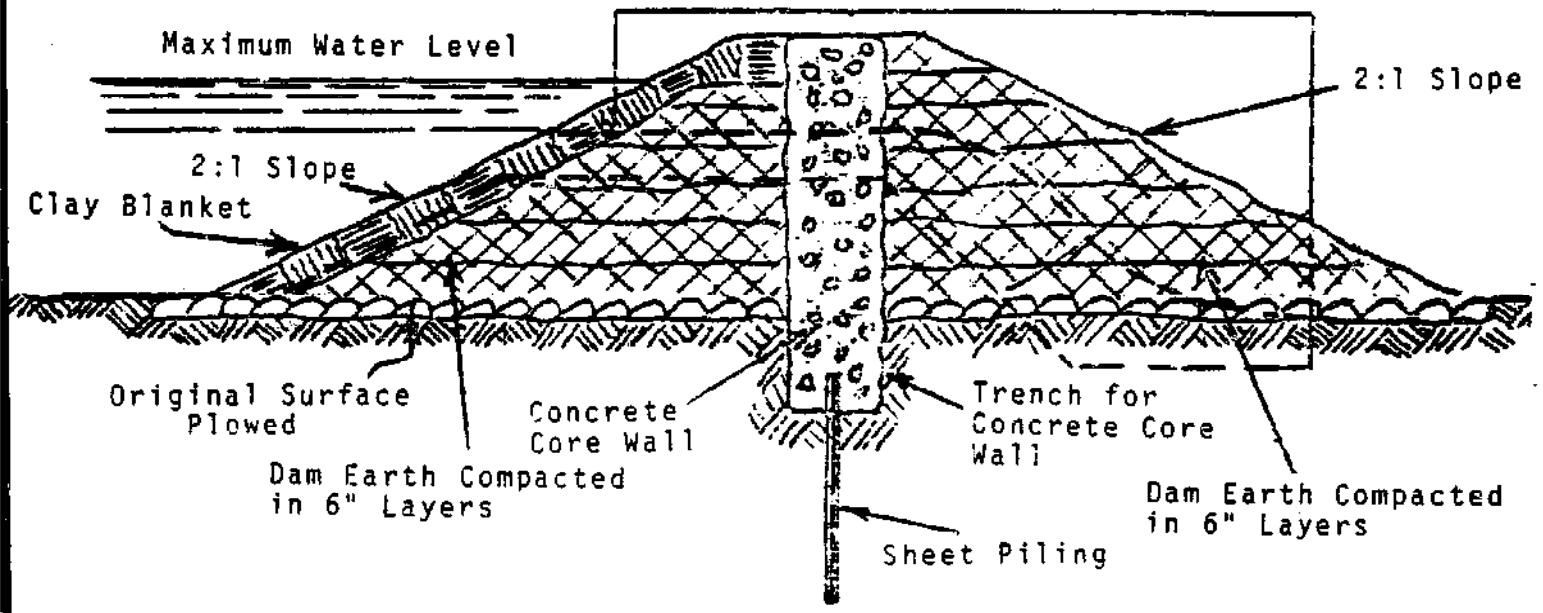
THIS APPENDIX IS NOT DESIGNED TO BE EXHAUSTIVE; IT IS MEANT TO PROVIDE BACKGROUND AND PERSPECTIVE FOR THINKING ABOUT AND PLANNING DAM EFFORTS. WHILE DAM CONSTRUCTION PROJECTS CAN RANGE FROM THE SIMPLE TO THE COMPLEX, IT IS ALWAYS BEST TO CONSULT AN EXPERT, OR EVEN SEVERAL; FOR EXAMPLE, ENGINEERS FOR THEIR CONSTRUCTION SAVVY AND AN ENVIRONMENTALIST OR CONCERNED AGRICULTURALIST FOR A VIEW OF THE IMPACT OF DAMMING.

EARTH DAMS

An earth dam may be desirable where concrete is expensive and timber scarce. It must be provided with a separate spillway of sufficient size to carry off excess water because water can never be allowed to flow over the crest of an earth dam. If it does, the dam will erode and be destroyed. A spillway must be lined with boards or with concrete to prevent seepage and erosion. Still water is held satisfactorily by earth but moving water is not. The earth will be worn away by it. The crest of the dam may be just wide enough for a footpath or may be wide enough for a roadway, with a bridge placed across the spillway.



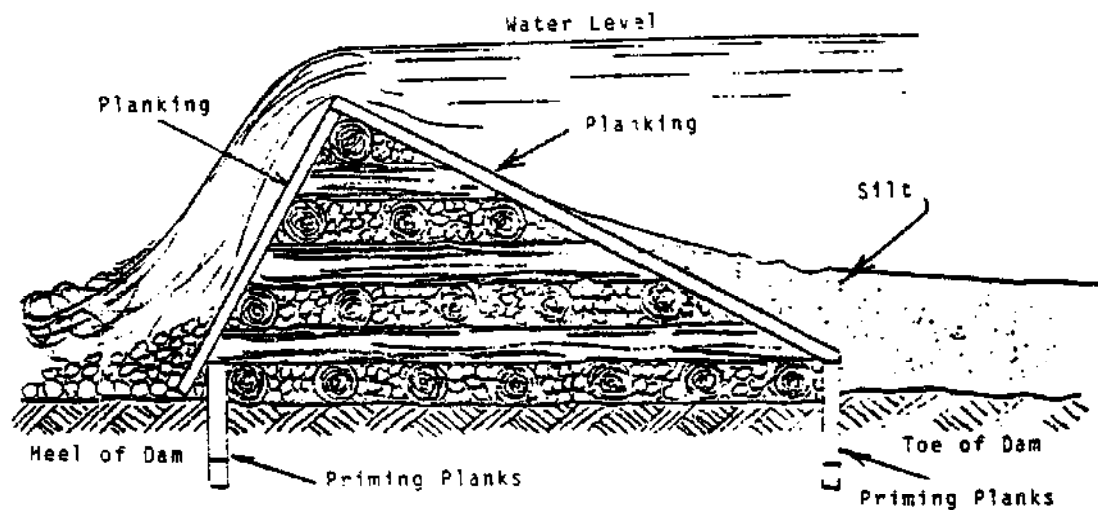
The greatest difficulty in earth-dam construction occurs in places where the dam rests on solid rock. It is hard to keep the water from seeping between the dam and the earth and finally undermining the dam. One way of preventing seepage is to blast and clean out a series of ditches, or keys, in the rock, with each ditch about a foot deep and two feet wide extending under the length of the dam. Each ditch should be filled with three or four inches of wet clay compacted by stamping it. More layers of wet clay can then be added and the compacting process repeated each time until the clay is several inches higher than bedrock. The upstream half of the dam should be of clay or heavy clay soil, which compacts well and is impervious to water. The downstream side should consist of lighter and more porous soil which drains quickly and thus makes the dam more stable than if it were made entirely of clay.



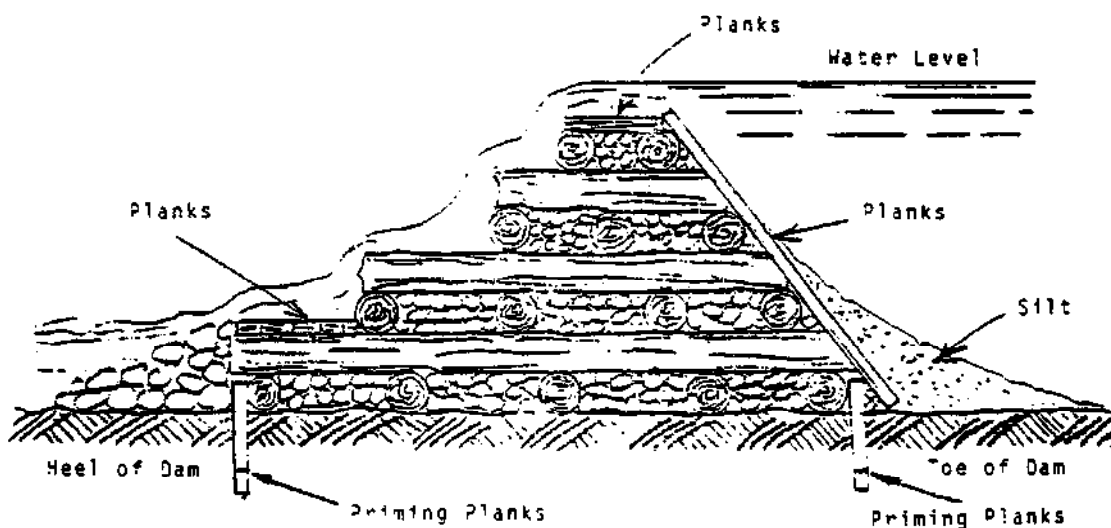
EARTH-FILL DAM

CRIB DAMS

The crib dam is very economical where lumber is easily available: it requires only rough tree trunks, cut planking, and stones. Four- to six-inch tree trunks are placed two to three feet apart and spiked to others placed across them at right angles. Stones fill the spaces between timbers. The upstream side (face) of the dam, and sometimes the downstream side, is covered with planks. The face is sealed with clay to prevent leakage. Downstream planks are used as an apron to guide the water which overflows the dam back into the stream bed. The dam itself serves as a spillway in this case. The water coming over the apron falls rapidly, and it is necessary to line the bed below with stones in order to prevent erosion. The apron consists of a series of steps for slowing the water gradually.

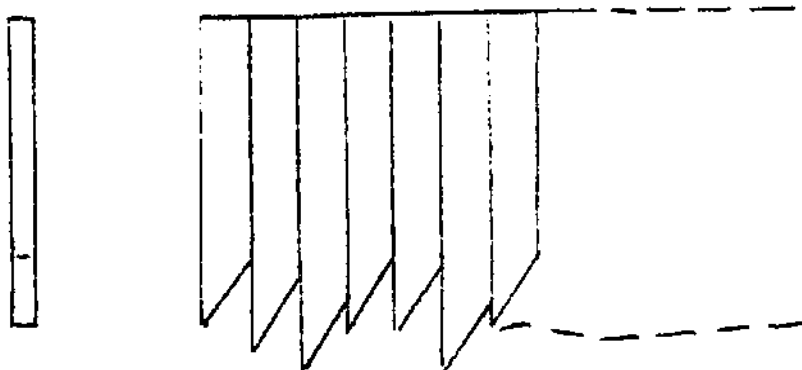


CRIB DAM WITH DOWNSTREAM PLANKING

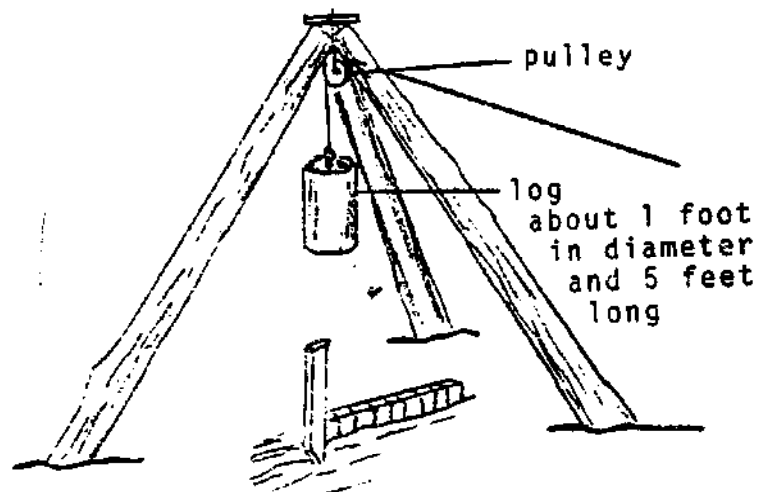


CRIB DAM WITHOUT DOWNSTREAM PLANKING

Crib dams, as well as other types, must be embedded well into the embankments and packed with impervious material such as clay or heavy earth and stones in order to anchor them and to prevent leakage. At the heel as well as at the toe of crib dams, longitudinal rows of planks are driven into the stream bed. These are priming planks which prevent water from seeping under the dam, and they also anchor it. If the dam rests on rock, priming planks cannot and need not be driven; but where the dam does not rest on rock they make it more stable and watertight. These priming planks should be driven as deep as possible and then spiked to the timber of the crib dam. The lower ends of the priming planks are pointed as shown in the illustration below, and they must be placed one after the other as shown. Thus each successive plank is forced, by the act of driving it, closer against the preceding plank resulting in a solid wall. Any rough lumber may be used. Chestnut and oak are considered to be the best material. The lumber must be free from sap, and its size should be approximately two inches by six inches. In order to drive the priming planks, considerable force may be required. A simple pile driver will serve the purpose.



PRIMING PLANKS

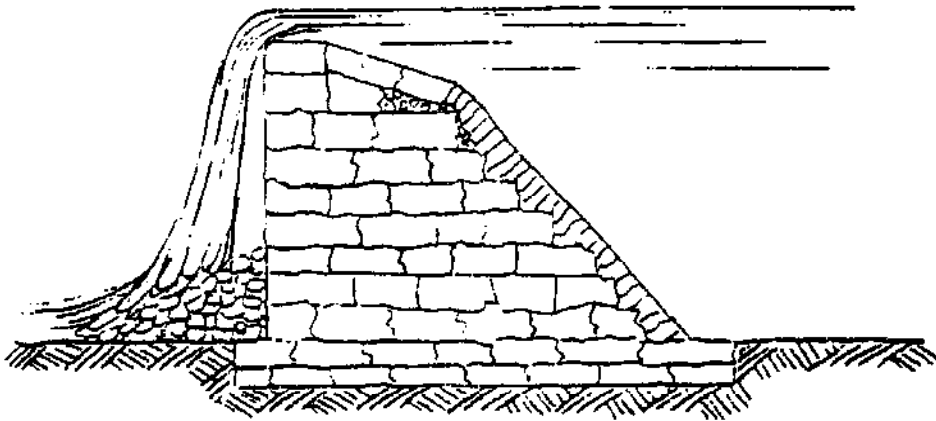


PILE DRIVER

CONCRETE AND MASONRY DAMS

Concrete and masonry dams more than 12 feet high should not be built without the advice of a competent engineer with experience in this special field. Dams of less height require knowledge of the soil condition and bearing capacity as well as of the structure itself. A stone dam can also serve as a spillway. It can be up to ten feet in height. It is made of rough stones. The layers should be bound by concrete. The dam must be built down to a solid and permanent footing to prevent leakage and shifting. The base of the dam should have the same dimension as its height to give it stability.

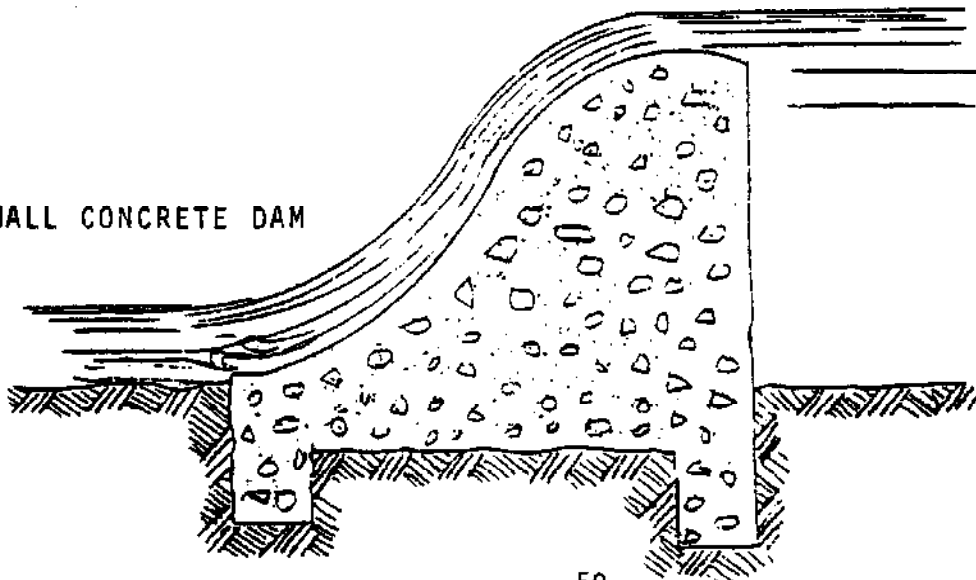
Water Level Upstream



STONE DAM

Small concrete dams should have a base with a thickness 50% greater than height. The apron is designed to turn the flow slightly upwards to dissipate the energy of the water and protect the downstream bed from eroding.

SMALL CONCRETE DAM



APPENDIX III.
CONVERSION TABLES
AND
BIBLIOGRAPHY

CONVERSION TABLES

Units of Length

1 Mile	= 1760 Yards	= 5280 Feet
1 Kilometer	= 1000 Meters	= 0.6214 Mile
1 Mile	= 1.607 Kilometers	
1 Foot	= 0.3048 Meter	
1 Meter	= 3.2808 Feet	= 39.37 Inches
1 Inch	= 2.54 Centimeters	
1 Centimeter	= 0.3937	

Units of Area

1 Square Mile	= 640 Acres	= 2.5899 Square Kilometers
1 Square Kilometer	= 1,000,000 Sq. Meters	= 0.3861 Square Mile
1 Acre	= 43,560 Square Feet	
1 Square Foot	= 144 Square Inches	= 0.0929 Square Meter
1 Square Inch	= 6.452 Square Centimeters	
1 Square Meter	= 10.764 Square Feet	
1 Square Centimeter	= 0.155 Square Inch	

Units of Volume

1.0 Cubic Foot	= 1728 Cubic Inches	= 7.48 U.S. Gallons
1.0 British Imperial Gallon	= 1.2 U.S. Gallons	
1.0 Cubic Meter	= 35.314 Cubic Feet	= 264.2 U.S. Gallons
1.0 Liter	= 1000 Cubic Centimeters	= 0.2642 U.S. Gallons

Units of Weight

1.0 Metric Ton	= 1000 Kilograms	= 2204.6 Pounds
1.0 Kilogram	= 1000 Grams	= 2.2046 Pounds
1.0 Short Ton	= 2000 Pounds	

CONVERSION TABLES

Units of Pressure

1.0 Pound per square inch	= 144 Pound per square foot
1.0 Pound per square inch	= 27.7 Inches of Water*
1.0 Pound per square inch	= 2.31 Feet of Water*
1.0 Pound per square inch	= 2.042 Inches of Mercury*
1.0 Atmosphere	= 14.7 Pounds per square inch (PSI)
1.0 Atmosphere	= 33.95 Feet of Water*
1.0 Foot of Water = 0.433 PSI	= 62.355 Pounds per square foot
1.0 Kilogram per square centimeter	= 14.223 Pounds per square inch
1.0 Pound per square inch	= 0.0703 kilogram per square centimeter

* at 62 degrees Fahrenheit (16.6 degrees Celsius)

Units of Power

1.0 Horsepower (English)	= 746 Watt	= 0.746 Kilowatt (KW)
1.0 Horsepower (English)	= 550 Foot pounds per second	
1.0 Horsepower (English)	= 33,000 Foot pounds per minute	
1.0 Kilowatt (KW) = 1000 Watt	= 1.34 Horsepower (HP) English	
1.0 Horsepower (English)	= 1.0139 Metric Horsepower (cheval-vapeur)	
1.0 Metric Horsepower	= 75 Meter X Kilogram/Second	
1.0 Metric Horsepower	= 0.736 Kilowatt	= 736 Watt

A LISTING OF RECOMMENDED RESOURCE MATERIALS

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- Durall, Mohammed, Design of Small Water Turbines for Farms and Small Communities, Tech. Adaptation Program, MIT, Cambridge, Massachusetts 02139 USA. A highly technical manual of the designs of a Banki turbine and of axial-flow turbines. Also contains technical drawings of their designs and tables of friction losses, efficiencies, etc. This manual is far too technical to be understood without an engineering background. Probably only useful for university projects and the like.
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TECHNOLOGIES FOR DEVELOPMENT

VITA is a private, non-profit development organization based in the United States. Since 1960 VITA has supplied information and assistance, primarily by mail, to people and organizations seeking help with technical problems in more than 100 developing countries.

VITA provides the services of a worldwide network of experts who have volunteered to respond to requests for assistance with improving homes, farms, communities, businesses, and lives.

VITA places priority on assisting low-income people in their own efforts, and on working in areas most important to achieving a better life -- agriculture and food, renewable energy sources, shelter, water supply, small industries.

VITA designs and adapts tools, methods, programs to respond to local needs, resources and conditions. VITA participates with local institutions in problem solving relationships in efforts to design and carry out local solutions.

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