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I. PURPOSE OF THIS COURSE
   1. To help in making yes/no decision: small hydro project
      a) can I or can't I (technical feasibility, cost)
      b) should I or shouldn't I (personal priority decision: knowledge of small hydro's limitations, problems & pitfalls VS. foreseen benefits)
   2. To foster basic understanding of small hydro, so that one can begin to research a project without a lot of running around in circles - in other words, to define the questions one must ask, technological and otherwise, and where to get answers.
   3. For general interest - alternative energy

II. OUTLINE
   1. Overview
      a) what is it
         i. Definition

-System to convert the force of falling water into electrical or mechanical energy
-Small scale, but NOT simply a scaled-down version of the W.A.C. Bennett Dam, for instance.
-In use for mechanical power for thousands of years
-Small-scale use out of fashion in recent years due to capital cost, availability of cheap fossil fuel
-Rising fuel costs are creating renewed interest
-Resourcefulness of builder can reduce capital cost dramatically

ii. Terms
-Micro: Up to 25 kW: supplies a house, farm, fishing lodge etc.
-Mini: 25 to 250 kW: supplies a small community, logging camp, mill etc.
-Small: broad term, any hydro plant less than 10000 kW.

b) how does it work

i. Kinetic (acting) energy vs. Potential (stored) energy
-Any object sitting in a gravitational field has a type of energy stored in it called "energy of position"
-If the object falls to a lower place, some of this is converted into kinetic energy.
-examples: *dish falls on floor & breaks
*car rolls down hill & can be jump-started
*rock falls off mountain & breaks tree
*ore carried down mountain on conveyor belt runs generators at mine site
*water runs down stream, powers small hydro

ii. Source of energy
-Water cycle: sun shines on ocean, water evaporates,

vapor rises due to solar heating, blows inland, and falls as rain. Hence power in stream is derived from solar energy.

c) basic requirements

i. Pressure

-means the weight of water pressing on a given surface area. Since water is a fluid, this weight may be exerted in any direction.

ii. Head

-means the height of water above (not necessarily directly above) a given point where a measurement is taken from. In other words, the depth of the water.

-in a small hydro situation, head refers specifically to the distance the water drops vertically while going through the system, or rather the amount we can actually utilize of that distance.

-since water always weighs about the same, pressure and head are proportional and one can be converted to the other.

-natural head: the fall of a stream in its original bed. Utilized by placing a pipe in the stream at a high point and drawing water from the pipe at a lower elevation, where the water in the pipe is very "deep" and hence at high pressure. Note that "depth" is what creates this pressure; it has nothing to do with pipe size, except that forcing too much water through the pipe will create friction which reduces the effective depth of water at the bottom of the pipe.

-artificial head: mostly seen in large installations - a large dam is used to raise the water level significantly. This not only increases head, but allows the water to be stored up and then drawn down to maintain high flow in times of water shortage.

iii. Flow

-for our purposes, refers to the amount of water flowing past a given point in a given period of time.

iv. Energy

-the energy content (we're talking about energy of position only) of a stream depends upon only two things: head and flow. Both of these can vary greatly from season to season and year to year. In a big reservoir like Kinbasket lake, head is allowed to vary to provide a constant flow. However, in natural streams and in most small hydro systems, head is a feature of the landscape and it is flow that varies.

d) cost considerations

i. Small hydro vs. utility connection as power source

-depends on proximity to utility grid and other factors

-may take decades to show cost effectiveness compared to a grid connection, due to capital cost

-again, builder's resourcefulness may pay off

-there may be non-financial considerations such as personal independence, control over power source etc.

ii. Capital cost vs. operating cost
   - small hydro tends to have high capital cost (installation) but low operating cost (maintenance).

iii. Cost of different parts of system
   - pipe is often the most expensive component, and most difficult one to get a bargain on
   - for B.C. interior conditions, PVC plastic pipe is often the cheapest and most reliable type.
   - dam of some sort usually required to keep intake under water
   - don't forget powerhouse building (for very small systems, some sort of box may suffice)
   - most other components may be picked up secondhand at considerable savings.

iv. Site dependence
   - cost of installation is usually given in terms of dollars per kilowatt of power produced.

   - cost per kilowatt will depend on many site factors such as:
      * size of stream (flow available)
      * slope of land (how much pipe will be required to create a depth of water (head)

sufficient for the desired power output, and how large must the pipe be to carry the water that distance without too much friction loss

- reliability of stream (does it get too low at some times of the year to provide full output as designed into the plant?)
- is plant designed to utilize the stream's highest flow rates, or is it down-sized to allow full output on even the lowest expected flows?

2. Basic Hydrology
   a) Measuring flow of a stream
      i. Float method
         - least accurate
         - find a fairly uniform stretch of the stream channel
         - find the cross sectional area of the water in the channel by measuring with a tape at several points
         - time the travel of a small floating object along a measured path down the channel.
         - multiply the cross sectional area you found earlier by the distance over which you timed the float, to get volume of water passing in the time measured.
         - divide volume by the time in seconds to get flow.
      ii. Weir method
         - more accurate but much more work & disturbance of the stream required - see chapter 2 of the Small Hydropower Handbook
      iii. Container method

- for very small streams only, but very accurate.
- divert stream into a wooden flume leading to a container of known volume like a large barrel. find out how long it takes the stream to fill the container, observe and estimate how much water leaked away down the stream in that time, and divide the time taken by the total in the container and lost down the stream. As you can see, the more leakproof your temporary diversion is, the more accurate will be the results.

b) Predicting flow of a stream

i. Stream flow records - see Handbook for addresses
ii. Weather records - ditto
iii. Your own observations if you have lived near the stream
iv. Experience of long-time residents nearby
v. Experience with other streams with similar watersheds
vi. Computer modelling - Federal Government busy de-bugging a program for this right now.

3. Basic Hydraulics

a) Head, flow and energy

i. If you know head, flow, and the efficiency of your system including pipe friction losses (assume 60% overall efficiency if you're not sure) you can calculate the amount of electric power you will get by the following formula:

$$P = Q \times H \times E \times 9.81$$

where

P = power in kilowatts at the generator
Q = flow in the pipeline, cubic metres per second
H = head in metres, from intake to turbine
E = efficiency of plant including pipe friction expressed as a decimal, i.e. 60% = .6

The SMHYCALC.EXE program uses a similar formula, but rather than simply assuming an overall efficiency of 60% including friction loss, it calculates friction loss based on a form of the Hazen and Williams friction loss formula. This formula is shown below. If you have a scientific calculator or are willing to tackle raising numbers to decimal powers, you may then achieve a figure to more decimal places than the program displays - but please note that you must initially provide the same H&W friction coefficient for your type of pipe, which is a rough figure and should not be trusted to give extremely accurate results.

The program documentation file on the SMHYCALC.EXE disk contains a list of various types of pipe with their approximate H&W friction values.

b) Friction loss

-has the effect of reducing the effective head of the penstock
-increases as flow gets larger
-increases as pipe size gets smaller

-increases as more fittings and bends are added to pipe

-calculated for pressure pipelines using various forms of the Hazen Williams formula - an empirical formula useful for pipes from a few inches diameter up to a meter or two. This form solves for head loss:

Head loss hS1lT = -16.81 VS01.85T L -0
CS1HWTS01.85T DS01.17T

where
V = Velocity of water in pipe in meters per second.
L = Length of pipe in meters
D = Diameter of pipe in meters
CHW = Hazen Williams Coefficient of friction for pipe.

This course should be printed on a machine capable of printing sub & superscripts, such as most Epson and Roland machines. For screen viewing, printer control codes in the equation must be ignored and the equation read like this:

Head loss = 6.81 times V to the 1.85 power times L
all over
CHW to the 1.85 power times D to the 1.17 power

c) The hydraulic gradient

-an imaginary line, unique to each individual pipeline and specific amount of water flowing in it, which indicates the height, at all points on the pipeline route, at which friction loss would reduce pressure to zero.

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- -gets steeper as friction loss increases. It is a horizontal line if friction is zero (no flow).
- -If the pipe happens to be above this imaginary line at any point, a partial vacuum will occur in it. This is to be avoided as it can cause gas bubbles to form in the pipe which reduces the effective head. It can even cause the pipe to collapse, especially larger sizes of pipe.

4. Dams, Intakes and Penstocks
   a) Types of dams
      i. Earth fill - various types of impervious core used.
      ii. Concrete - Expensive but permanent. May be used in combination with earth fill in some configurations
      iii. Timber frame - best designed by an engineer
      iv. Gabion - made of wire baskets filled with rocks
      v. Any dam needs a spillway which will safely pass extra water including unusually heavy flows after rainstorms or during extreme spring runoff. The exception is a flow-through type of dam covered in coarse rock on top.

   b) Intakes
      i. Trash racks and filtering
         -objects which could damage turbine must be kept out.

- large object suddenly lodging in turbine could cause a violent water hammer and result in explosion of the penstock.
- a separate intake or filter for domestic water is suggested because the high flow to the turbine will quickly clog a screen fine enough for domestic water filtering.
- The dam should have a gate to facilitate draining the intake pond for cleaning.

ii. Intake losses and vortex formation

- if the intake is too close to the surface a vortex will form that sucks large quantities of air into the pipe.
- floating a large piece of plywood over the intake helps, but it is better to provide sufficient depth - at least 2X the pipe diameter.
- a bell-shaped end on the pipe, made of sheet metal, will reduce head loss where the water enters the pipe.

iii.Venting

- if the intake of the pipe were ever to be suddenly plugged, the result would be a powerful vacuum in the pipe which could collapse it. (in effect, the friction loss has become infinite, and the hydraulic gradient has dropped straight down underneath the intake. So all of the pipe is above it). An air vent below intake, but raised above pond level, stops this.

iv. cold weather

- intake must be deep enough to be below the ice
- trash rack or screen should not hold the water back noticeably, or turbulence may cause suspended

"frazil ice" to collect on it and stop the flow.
- in large streams, consideration should be given to what the effects of spring break-up of ice might do to the intake works.

c) Penstocks

  i. Typical sizes one might expect to require:
    - 1" to 12" for high head sites
    - 4" to 48" for low head sites
  ii. Types of pipe
    - PVC, polyethylene, fiberglass, aluminum, steel or wood stave pipe are all suitable for high heads.
    - working pressure rating must not be exceeded.
    - If the water is slowed down suddenly, such as by turning off the valve too quickly at the bottom of the pipeline, it is something like stopping a long freight train - all that momentum has to be absorbed somehow. The result is a rise in pressure called WATER HAMMER. Some allowance should be made for this extra pressure, and a pressure gauge should be watched closely when shutting off the water at the plant, to avoid exceeding the working pressure of the pipe.

-to save money, the pipeline may start with low pressure, less expensive grades with thinner walls at the top, and progress to higher and higher pressure ratings as pressure increases further down the line.

-if no used pipe is available, PVC is usually the least expensive type in this area. It must be buried as it can be damaged by sunlight eventually.

-for low head installations, various other types of pipe may be used such as concrete sewer line.

iii.Finding required size

-determine flow required & length of pipe required

-refer to a table of friction losses for the particular type of pipe you plan to use (see Handbook)

-add losses for fittings, etc. (simply considered equal to a certain amount of extra pipe).

-select pipe size which will carry the required flow for the required distance with no more than about a 15% loss of your total head due to friction. Do not oversize the pipe, or you may very seriously jeopardize the financial viability of your project.

iv. Cold weather protection

-pipe should be buried below the frost line if possible

-in high latitudes this may not be feasible. However, a penstock is extremely resistant to freezing when the water is flowing in it. As soon as any ice begins to form on its walls, increased flow rate at that point causes a friction buildup which erodes most of the ice away.

-water should not be stopped for any length of time in sub freezing weather. Some sort of bypass should be provided in the powerhouse to maintain flow if the turbine has to be shut down.

-pipeline should NEVER be drained in very cold weather. The last trickles dribbling down it, along with some cold air, may well build up into an ice plug near the bottom which will have you reading by kerosene lamplight until next spring - and may also burst the pipe.

5. Turbines
   a) impulse turbines
      i. Consist of a nozzle which shoots a jet of water at a wheel equipped with "buckets" around its circumference.
      ii. No pressure inside the turbine's case. The head in the penstock is converted into momentum by the nozzle.

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-pelton turbine: *water jet is directed at 90 degrees
                  to the axis of the wheel.
                 *good for high head - over 200 feet
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        -turgo turbine:  *water jet hits wheel at an angle and
                          passes through slots to the other
                          side.
                         *handles more water than same size
                          pelton turbine.
                         *medium to high heads

b) reaction turbines

    i.  Do not have a nozzle. water is forced to flow in a
        curved path and the resulting forces cause the turbine
        to rotate.
    ii. Turbine case is pressurized by the penstock.

        -Francis turbine:    *water passes through a ring of
                              curved stationary blades, then into
                              a ring of curved moving blades
                              mounted on the turbine wheel or
                              "runner".
                             *low to medium heads

        -Cross-flow turbine: *water flows into one side of a
                              squirrel-cage shaped runner and
                              then exits on the other side.
                             *low to fairly high heads
                             *a relatively easy type to home-
                              build

        -Propeller turbine:  *water is forced through a pipe
                              somewhat smaller than the
```

penstock in order to speed it up.
*in this pipe is a propeller something like a boat propeller.
*for low head.
*compact size.
*can develop quite high speeds in slow moving water.
*variable pitch type called "Kaplan turbine" (very expensive)

-Pump turbine: *an ordinary centrifugal water pump may be used as a turbine by connecting it to the penstock in reverse (water flows into the pump's outlet and out the inlet).
*fairly efficient if running at the correct speed

*efficiency falls off quickly outside a narrow range of speed
*low to high heads
*some pump manufacturers make special impellers for some of

their pumps which give somewhat better efficiency when used as turbines.

c) very low head turbines

-Traditional overshot wheel

*large diameter runner has buckets which are filled with water at the top and spill the water at the bottom. Therefore the downgoing side of the wheel is always heavier than the upgoing side, and a rotating force is developed.

*head is equal to diameter of runner

*very large size for a given power output

*extremely vulnerable to ice buildup & not for winter use because it has no case.

-Undershot wheel

*runner consists of large blades which dip into a moving stream and are pushed on by the force of the current.

*can utilize "invisible head" which has already been converted into momentum in the natural stream course. unfortunately, stream beds are not very efficient at this conversion - most of the head is converted into tiny temperature rises due to turbulence in the water. Since the stream isn't pressurized, (!) it must follow the hydraulic gradient, and so flows at speeds that cause enough friction loss to keep that imaginary line following right along on its surface. All the same, if the stream is really large, the small amount of energy stolen from it by the undershot wheel may be useful to somebody.

*this "invisible head" may be supplemented by restricting the stream flow using a low dam with a gap, in which is placed the undershot wheel. Efficiency a bit better but still poor.

*has no case and so is vulnerable to ice damage and freezeup.

-Darreius turbine

*an underwater version of the Darreius-rotor wind turbine

*also utilizes "invisible head" by intercepting existing momentum in a stream.

*efficient only in converting the momentum it intercepts into electricity. The momentum itself is derived inefficiently as described above.

*can be totally submerged below ice levels and hence useable in winter, but may have to be pulled out during spring breakup on a large stream.

*in tests, a small Darreius turbine has generated 5 kW of electrical power from the Gulf Stream in the Atlantic.

*in the experimental phase. None currently in practical use.

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6. Mechanical Power Transmission
    a) belts and pulleys
        -easiest way to arrive at proper speed for turbine and
         generator.
    b) direct couplings
        -turbine drives generator directly and so both must turn at
         the same speed, which isn't always convenient.
        -diameter of wheel may be selected to obtain the proper
         rotating speed for a given rim speed.
    c) gears
        -not often used on small plants
        -expensive to purchase and maintain

7. Basic Electricity
   If you're serious about this, obtain a textbook on basic
   electricity and pay particular attention to the following:
    a) simple theory
        -voltage
        -current
        -resistance
        -ohm's law
    b) batteries
        -chemical source of electricity
    c) generators
        -induction
        -DC
        -AC
        -rectification (allowing current to pass one way only)
        -excitation: (Power source for magnetizing generator) such as:
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            *small generator in or on big one
            *rectifiers for excitation
     d) voltage regulators
         -purpose
         -how to connect
     e) distribution
         -transformers
         -line loss vs. voltage (less at high voltages)
         -measuring or calculating line resistance
     f) safety
         -voltages above 60 volts can be dangerous
         -many generators produce 440 volts
         -do-it-yourself wiring vs. hiring a contractor
     g) regulations
         -technically apply to "home-made" electricity as well as
          the bought stuff
         -good idea to follow the electrical code

 8. Speed Control
     a) By constant load and constant power output
         -useful speed control method for small plants, but in its
          "technological infancy" and hence expensive.
         -all-electronic with few mechanical parts to wear out.
         -may be located anywhere - powerhouse, user's house, etc.
         -synchronous AC generators must run at an accurate speed
          since their output frequency is proportional to speed.
         -simplest but least desirable method is to have a frequency
          meter in the house and turn things off and on as needed
          to keep the speed and frequency within acceptable limits.
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- constant-load governor keeps load constant by adding on extra load as the user turns things off, and vice versa.
- plant runs at full output at all times.
- load management unit allows connection of more loads than the plant can handle all at once. It allows the user to classify loads according to their importance, and it shuts off low priority loads as the user turns on higher priority ones.
  Usually includes constant-load control as well.

b) By variable load and variable power output

- preferred speed control method for large plants.
- must be located at turbine.
- controls speed by reducing the force of water on the turbine as load is reduced, and vice versa.
- plant does not have to run at full output all the time.
- may help conserve water if turbine equipped for this.
- has more mechanical parts. Large units may require more upkeep than constant-load controls.
- this category includes the Carson Electronics Q/M 1000 UHTG governor which is inexpensive enough for very small plants.

9. Pre-feasibility studies - get a copy of the Small Hydropower Handbook for British Columbia. It's available from:

CANMET
Energy, Mines and Resources Canada
580 Booth Street, 7th floor
Ottawa, Ontario K1A 0E4
Canada

Refer to chapter 1. Most of the data applies to sites anywhere.

a) Estimate the power you need
    i. Inventory the -1loads-0
    ii. Estimate the -1time-0 they are connected and when
    iii.Consider -1load management-0
    iv. Consider energy -1conservation-0
    v. Estimate power -1need-0
b) Estimate the streamflow available
    i. Know your stream
        -How does it react after a storm?
        -How does it change in flow season to season?
        -How does it react to sub freezing weather?
        -History in government streamflow data if available
        -Estimate from data on nearest streamflow records
        -Ask old timers in the area what they can recall of your stream's past performance.
    ii. Estimate streamflow by one of above methods. Don't forget that these are estimates only.
c) Measure the head
    i. Make a rough estimate first, from your knowledge of the stream or from topographical maps
    ii. Identify where you might want to put the intake

iii. Identify where you might want to build the powerhouse
iv. Measure the head between the two using:
    -an altimeter
    -a hand level and yardstick etc.
    -a clinometer

d) Estimate the amount of electrical energy the stream could provide
  i. Assume an overall efficiency of 60%
  ii. Run SMHYCALC.EXE for a quick estimate of power output, or use the above flow/head efficiency/power formula.
  iii. Does the stream have enough power to meet your needs or satisfy your expectations? If not, think again about:
    -Load management
    -Putting intake site further upstream
    -Using a supplementary power source such as a diesel plant
    -Rationing power during low-water seasons in dry years
    -Connecting to the utility company instead

e) Make a preliminary layout of the project
  i. Site clearance
  ii. Where is intake to be? (consider natural objects like rock cliffs for possible use in the intake works.)

- iii. Where will the pipe run - how long? What size? what kind?
- iv. How many changes of direction? Thrust blocks needed?
- v. What climate - pipe above ground or buried?
- vi. Turbine and generator size required
- vii. Size and type of powerhouse building
- viii. Tail race - should return water to its original course
- ix. What size and type of load management system?
- x. Distance and voltages for transmission of electricity
- xi. Wiring house or upgrading house wiring if any
- xii. Estimate how much of the above you can do yourself

f) Make a preliminary cost estimate of the project

- i. Beside each item on the above layout place the following:
  - -How much confidence have I in this estimate? (%)
  - -Total cost
  - -cost per kilowatt
- ii. Then find the overall costs by adding it all up.

g) Compare costs with benefits as follows:

- i. Total annual costs
  - -loan repayment - amortization if any
  - -maintenance and repair
  - -wages if any
- ii. Project worth
  - -sale of electricity if applicable
  - -displaced diesel fuel
  - -replacement of diesel plant
  - -avoided cost of utility company power line & hookup costs
  - -eliminated utility bills
  - -other benefits: reliability, quiet operation, etc.
- iii. If you decide to go ahead, now is the time to apply for

a water license. It may take months to process. Meanwhile, the introduction to the Small Hydro Power Handbook for B.C. should be read carefully and then the rest of the book can be gone through as suggested - it will lead you by the hand through the entire detailed process of developing your stream's potential for energy production - be it a kilowatt or ten megawatts.