GUIDE LINES for Small Scale Hydropower (SSHP) Schemes
– A simplified understanding of what is involved.

SOME OBSERVATIONS to start with:

The Theory of Applied Hydraulics is well documented in modern textbooks unfortunately few of these relate the theory to water turbines and their installation. For this you will need to look at books from the early part of the 20th century when the practice was more widely appreciated.

There have been several modern books written about small-scale hydropower and may appear to be comprehensive to the newcomer, but do not be deceived. Over the past 40 years or more there have been very few quality engineered small hydropower installations in the British Isles but plenty of cut-price projects both in the UK and overseas. The question you should ask yourself is 'where did the author(s) of these books gain their experience and how comprehensive and reliable is the advice they are giving?'

Neither should you look at the Department of Trade and Industry (DTI) for, by their own admission, they have no expertise. They may publish information but to quote the DTI:

(The literature from DTI & former ETSU) "is not intended to provide detailed guidance on how to implement a hydropower project or to recommend any particular technology. The chosen schemes present a realistic view of the current state of the market (in the UK). Unfortunately there are very few schemes which with hindsight could not have been better implemented. Their failings could have been highlighted but clearly there is a balance to be struck between encouraging interest and exposing problems." (end of quote).

The DTI used to rely upon the ENERGY TECHNOLOGY SUPPORT UNIT (ETSU) at Harwell for 'practical' guidance. They in turn employed graduates who, from my past experience, have actually never installed hydropower. The last one I spoke to, his previous experience was with fire fighting and fire extinguishers.

HYDROPOWER

The economic viability of any potential hydropower site depends upon the number of kilowatt hours – the number of hours operation – that it can produce annually and the number of years it can be designed to last with low maintenance. This in turn depends upon the site conditions – HEAD and FLOW.

The first things we need to know about a site are the upstream and downstream geographical and hydrological constraints. For example, on the River Severn at Tewkesbury the water divides upstream at Stanchard Pits with some going over the weir and the rest flowing down to Abbey Mill weir. Who can have what in the way of water quantity, and when? (Down stream of Abbey Mill it is sometimes tidal, causing a loss of head.)

The Electricity Supply Industry has traditionally written off their power station investments over 25-30 years. SSHP needs at least a similar timescale to operate, if not longer. SSHP has a minimum life expectancy of 30 years for machinery – possibly 50 years or more and the civil engineering is designed to last indefinitely. Viz – we have mill sites hundreds or even thousands of years old. In North America, hydropower was installed at Niagara Falls at the turn of the last century and was refurbished after 80 years.

River authorities usually design for a minimum of one in one hundred year event and present day civil engineering is likely to last indefinitely. There is no reason to believe that SSHP should be any different.

CHECK LIST

1. Look at upstream – downstream, up to half a mile in either direction; identify possibilities for increasing head & flow. Can site potential be improved by regrading riverbed or raising head? Is water being taken off via another channel upstream?

2. Measure the available head and consider options to increase it without causing flood/land drainage problems etc.

3. Measure flows – look at flow duration curve – how much of the flow can be used – how much must be left for river environment, fish etc.

4. Where to site SSHP in relation to other river requirements i.e. flood relief – locks – canoes and fishing – water abstraction, channel and bank erosion and any other environmental factors?

5. What are you trying to achieve? Cheap installation with small constant output? OR maximum output to sell to the grid?

6. Can power be made use of locally or must it be transported by overhead or underground cables, more expensively, to another site or fed into the mains via an expensive grid connection?

7. Type of generation? ‘A’ synchronous OR synchronous?

8. Choice of turbine?

9. Screen cleaners – washout sluices – disposal of rubbish?

10. How will it be operated and maintained (and by whom)?

11. Security of site and equipment?

12. Who owns the site? Who owns the mill rights? These are not necessarily one and the same person. Has the sale of the site been properly conveyed in the past:-

    a. according to normal convention?
    b. according to mill property rights?

13. Possible effects on upstream – downstream property owners.

14. Possible effects on flood relief – good – adverse?

Low head sites often 'drown out' under high flows/flood conditions. The design should be such that plant and equipment are not damaged and access can be achieved to the turbine house under these conditions – even by boat! Because a site is completely flooded for several days or weeks each year, or may have insufficient water to operate for several months of the year, this does not mean it is not a viable site. Many hydropower sites throughout Europe and especially France operate for five or seven months of the year.

Short term licences by the Environment Agency or property owners leasing a site to a SSHP investor will only put pressure on the developer to cut corners in order to achieve a satisfactory payback. Hence less satisfactory design and manufacture of some 'cheap' types of modern turbine (which may prove expensive in the long term). The emphasis should perhaps be on quality rather than short-term payback; this way there will be fewer problems and ultimately greater profit.

Increased site availability without too much 'red tape' would enable a modest market to develop in the UK, allowing a manufacturing base to develop. This would lead to British exports. At present nearly all low head turbines are imported from Europe, America or as far away as Tasmania.

Yet our cheapest electricity comes from Hydropower, installed pre-war and still operating.

Some types of turbine have very high efficiencies of 90% or more but are expensive to manufacture and maintain. Other types of turbine have slightly lower efficiencies of 82%-87% but require very little maintenance or annual shutdown.

Most types of turbine suffer cavitation if air is introduced into them. One make of cross flow actually benefits water quality through the introduction of air and needs this for its satisfactory operation.

SSHP power plant often fails towards the end of its life as a result of poor design, poor installation or poor maintenance. Problems arise for river authorities because mill owners (SSHP) have abandoned their sites. Paddle type sluice gates can exacerbate these problems for the river authorities. Tilt gates are better for everybody. They can be lowered to provide increased flood protection without the river running dry or the turbine ceasing to generate.

In today's throw-away society, engineers find it difficult to design and manufacture equipment that runs for 24 hours per day for the next 30-50 years. Typically gearbox manufacturers design with a service factor of 2 when perhaps it should be 4; the same applies to turbine shafts and bearings.

TYPES OF TURBINE

Turbines may be classified under three main headings:-

1. Impulse turbines

2. Reaction turbines:-

   Sub-divided into
   a. Francis turbines
   b. Propeller turbines or variations

3. Cross-flow turbines

Reaction turbines work by means of the potential and pressure energies of water.

Impulse turbines act solely by means of the kinetic energy of water and are for higher heads.

Francis turbines can be designed to operate on a wide range of heads from as little as 1.3 metre up to several hundred metres.

Propeller type turbines are usually for low heads of 1-15 metres.

Cross-flow turbines can operate on 1-200 metres with some examples on as much as 300 metres, although the impulse turbine comes into its own at these heads.

The 'specific speed' of a turbine usually determines its characteristics. High specific speeds for lower heads; low specific speed for higher heads. The exception is the cross-flow; this has a low specific speed but can run on low and high heads, the length of the runner determines how much water it passes.

WATER VELOCITIES

Designing hydropower schemes calls for the most suitable sizes for:-

Intake channels
Pipelines
Outlet channels

Velocities should be kept as low as possible throughout; high velocities mean the sacrificing of large percentages of the available head, and the possible erosion of intake and outlet channels.

River authorities and turbine installation design engineers have a common interest in low velocities.

On the other hand, too low velocities require larger areas in the channels and pipes, increasing the capital cost. Low velocities also lead to increased residence times and the deposition of suspended solids in the channels.

A balance has to be reached between loss of head due to increased velocities and friction and a loss of power.

As a guide to the magnitude of velocity in various situations, the following may apply:-

Head Race or Intake Channels – head loss due to friction and eddies to be kept as small as possible, maximum velocity no greater than 1 metre/second, preferably 0.3-0.7 metres/second and may further be determined by the nature of the channel material – mud – concrete etc. High velocities above 1 metre/second also cause problems for the efficient operation of screen cleaners.

Turbine Pit – open flume turbine plants, the inlet channel leads into the turbine pit where the water is changing direction. Here velocities should be no greater than 0.6 metre/second and preferably lower for smaller plants to avoid eddies. At least one metre is required above the turbine top cover plate in the case of a Francis turbine, or above the mouth of the intake pipe, more if it is a larger turbine. If this is not observed, air may be drawn in through eddies and vortices and this will destroy the suction effect of the draft tube.

Draft Tube – should extend 0.3-0.45 metres below the tail water surface, again to avoid air being drawn in and destroying the vacuum. The suction in the draft tube has the same effect as an equivalent head above the turbine. The draft tube enables as much as possible of the velocity head and suction head to be recovered as energy. Draft tubes are a complicated subject requiring design and experience; they usually have 4-6 degrees of taper.

The Tail Water – with the exception of impulse turbines, the velocity in the tail race should be kept low, 0.3-1 metre/second. Too high a velocity causes eddies and destroys the suction action.

With the impulse turbine it is important to have adequate clearance below the turbine runner so that the water can escape without drowning the runner, thereby causing loss of power.

Pipeline Valves will have a potential friction loss and create disturbance in the water flow which will normally recover its steady state after it has travelled five times the diameter of the valve. Needle valves will result in the highest friction losses.

Spiral casing of a turbine – here the velocity depends upon the size of the turbine and the head. Velocities greater than 10 metres/second are unusual.

Impulse turbines – may have velocities in the inlet bend up to 7 metre/second on 500m head, but this depends upon the form of the bend and the number of bends preceding it.

Velocities in Pipes – the design and size of the pipeline is a complicated subject. Too often with small hydropower it is incorrectly sized because of cost considerations only.

Pipe size should be determined taking into consideration the following:-

The friction loss due to the resistance to flow caused by the walls of the pipe.
The number of bends and their nature.
The load factor of the plant.
The governing effect of the turbine and pressure rise.
The mode of operation of the hydropower plant.

The study and design of the pipeline with its flare entry in the forebay is a complex subject, but the following basic comments may assist in understanding what is required:-

With small diameter pipes, less than 0.75metres diameter, we are looking for low velocities of less than 1.5 metres/second.

If they are long pipelines with a hydraulically governed turbine and flywheel on the generator, then the subject is further complicated by acceptable levels of speed variation and pressure rise in the pipeline.

Pipelines above 1 metre in diameter, with a larger wetted area, may have velocities in the region of 2-2.5 metres/second or a maximum of 3 metres/second. Larger pipelines above 1.5 metres diameter may have velocities up to 5 metres/second but are usually for constant flows not experiencing the constraints of a governed system and continually varying flows.

As a general rule, total pipeline losses should not exceed 10%.

Pressure rise in pipeline – with high head schemes it is the pressure rise that is of concern when variations in flow occur due to turbine governing or the closing of valves. With low head plants and large diameter pipes (up to 5m diameter) it is the pressure drop inside the pipe which causes the pipe to be crushed by the atmospheric pressure acting on the outside of the pipeline.

Flared entrance to pipeline. Insufficient consideration is often given to pipe entry losses which can be greater than pipeline friction losses. Common sense will tell you that if you have water in the forebay traveling at 0.6 metres/second and you ask it to enter the restricted mouth of a pipe where it is immediately being asked to travel at 2-3 metres/second, then there will be tremendous vortices, eddies and friction losses. A flared bell mouth will enable the water to gradually increase speed.

Turbine manufacturers should be consulted about the pipeline sizes etc because of the governing effect of the turbine, pressure rises and friction losses.

OTHER MATTERS TO BE CONSIDERED

Anchoring and supporting pipes

Governing - hydraulic regulators
electronic load controllers
'A' synchronous operation – flow control

Electrical systems – meeting the regulations, G59 etc

Water quality – ph – suspended solids, silt basins

Screens – screen cleaners – rubbish

Forebay – stone traps – washout sluice

System layout

Possibility of low head turbine houses flooding or becoming buoyant under flood conditions!

Land ownership and property rights – Mill rights.

NOT comprehensive BUT this may help the enthusiast or newcomer from making very regrettable mistakes.

Osman M Goring, WATER POWER ENGINEERING, October 1993
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