A GUIDE TO UK MINI-HYDRO DEVELOPMENTS

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A GUIDE TO UK MINI-HYDRO DEVELOPMENTS

1. INTRODUCTION

1.1 Overview

This Guide is designed to assist anyone in the UK who is planning to develop a small-scale hydro-electric scheme. It has been prepared by the British Hydropower Association in order to support and encourage further developments in this sector.

The term used in this Guide will be "Mini-hydro", which can apply to sites ranging from a few kilowatts for electrifying a single property, to hundreds of kilowatts for selling into the National Grid.

The Guide will explain:

- The basic concept of generating power from water
- The purpose of different components of a scheme
- The principle steps in developing a project
- The technology involved
- Where to go for help

The Guide is available for download at: https://british-hydro.org/i-want-to-install-a-hydro/

1.2 Why mini-hydro ?

Small-scale hydropower is one of the most long term, cost-effective and reliable energy technologies to be considered for providing clean electricity generation.

In particular, the key advantages that small hydro has over wind and solar power are:

- A high conversion efficiency (70 - 90%), by far the best of all energy technologies, including thermal plant.
- A high capacity factor[1] (typically 40-50%), compared with <10% for solar and around 25-30% for onshore wind.
- A high level of predictability, varying with annual rainfall patterns.
- Slow rate of change; the output power varies only gradually from day to day (not from minute to minute).
- A good correlation with demand i.e. output is maximum in winter when energy is most needed.
- 24 hour generation i.e. it still works at night.
- It is a long-lasting and robust technology; systems can readily be engineered to last for 50 years or more.
- So every hydro scheme built today should still be generating in 2050 (and 2070), contributing to the Net Zero target.

Well-designed schemes have a negligible environmental impact. New small hydro are in most cases "run-of-river"; in other words any impoundment is quite small, often an existing weir, and little or no water is stored. Therefore run-of-river installations do not have the same kinds of adverse effect on the local environment as large-scale hydro, which involves a major dam and a more fundamental alteration to the

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[1] *Capacity Factor* is explained in Section 3.4.2

downstream flow pattern. However, modest storage schemes at the top end of a catchment can have a very low impact if they do not disrupt essential fish movements or hold back large volumes of sediment.

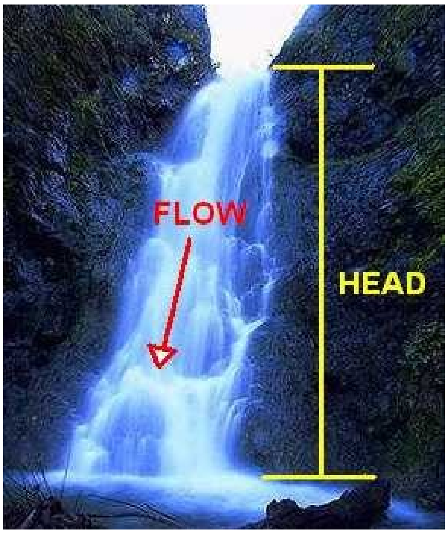
2. HYDROPOWER BASICS

2.1 Head and Flow

Hydraulic power can be captured wherever a flow of water falls from a higher level to a lower level. This may occur where a stream runs down a hillside, or a river passes over a waterfall or man-made weir, or where a reservoir discharges water back into the main river.

The vertical fall of the water, known as the "head", is essential for hydropower generation; fast-flowing water on its own does not contain sufficient energy for useful power production except on a very large scale, such as offshore marine currents. Hence two quantities are required: a Flow Rate of water **Q**, and a Head **H**. It is generally better to have more head than more flow, since this keeps the equipment smaller.

The Gross Head (H) is the maximum available vertical fall in the water, from the upstream level to the downstream level. The actual head seen by a turbine will be slightly less than the gross head due to losses incurred when transferring the water into, and away from, the machinery. This reduced head is known as the Net Head.



Sites where the majority of the head comes from a single impoundment and have a gross head generally less than 10 m would normally be classed as "low head". Sites from 10-50 m would typically be called "medium head". Above 50 m would be classed as "high head". Medium and high head sites derive nearly all their head from the natural gradient of the watercourse.

The **Flow Rate (Q)** in the river, is the volume of water passing per second, measured in m^3/second. For small schemes, the flow rate may also be expressed in litres/second where 1000 litres/sec is equal to 1 m^3/sec.

2.2 Power and Energy

Energy is an amount of work done, or a capacity to do work, measured in Joules. **Electricity** is a form of energy, but is generally expressed in its own units of kilowatt-hours (kWh) where 1 kWh = 3,600,000 Joules and is the electricity supplied by 1 kW working for 1 hour.

Power is the energy converted per second, i.e. the rate of work being done, measured in Watts (where 1 Watt = 1 Joule/sec and 1 kilowatt = 1000 Watts).

Most hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of *head* and *flow rate*. The general formula for any hydro system's power output is:

$$\mathbf{P = \eta \rho g Q H}$$

Where:

- **P** is the mechanical power produced at the turbine shaft (Watts),
- η is the hydraulic efficiency of the turbine,
- ρ is the density of water (1000 kg/m^3)
- **g** is the acceleration due to gravity (9.81 m/s^2),

- **Q** is the volume flow rate passing through the turbine (m^3/s),
- **H** is the effective pressure head of water across the turbine (m).

The best turbines can have hydraulic efficiencies in the range 80% to over 90% (higher than all other prime movers), although this will reduce with size. The smaller micro-hydro systems (<50kW) tend to be 75% to 80% efficient.

Beyond the turbine, there will be further losses in the speed-increaser (gearbox or belt-drive, if required) and the electrical generator, leading to an overall 'water-to-wire' system efficiency in the range 65% to 80%.

If we take 70% as a typical water-to-wire efficiency for the whole system, then the above equation simplifies to:

$$\mathbf{P}\ (\mathrm{kW}) = 7 \times \mathbf{Q}\ (\mathrm{m^3/s}) \times \mathbf{H}\ (\mathrm{m})$$

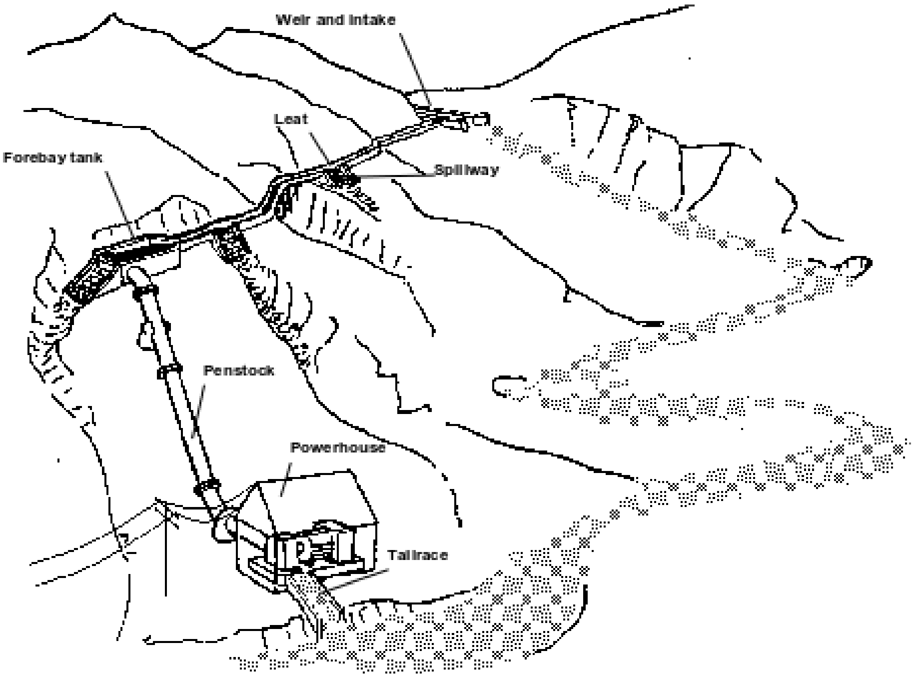
2.3 Main elements of a scheme

The figure below illustrates a typical small hydro scheme at a medium or high head site. Other possible layouts are discussed in Section 2.4.

The scheme can be summarised as follows:

- Water is taken from the river by diverting it through an intake structure at a weir.
- In medium or high-head installations water may first be carried horizontally to a 'forebay' tank by a small canal or 'leat'.
- Before descending to the turbine, the water passes through a settling tank or 'forebay' in which the water is slowed down sufficiently for suspended particles and/or air bubbles to settle out.
- The forebay is usually protected by a rack of metal bars (a trash rack) which filters out water-borne debris.
- A pressure pipe, or 'penstock', conveys the water from the forebay down to the turbine, which is enclosed in the powerhouse together with the generator and control equipment.
- After leaving the turbine, the water discharges down a 'tailrace' channel back into the river.

Hydro-scheme components



2.4 Different site layouts

In practice, sites that are suitable for small-scale hydro schemes vary greatly. They include mountainous locations where there are steep, fast-flowing mountain streams and lowland areas with wide rivers. In some cases development may involve the refurbishment of a historic water power site. In others it may require an entirely new construction. This section illustrates the four most common layouts for a mini-hydro scheme.

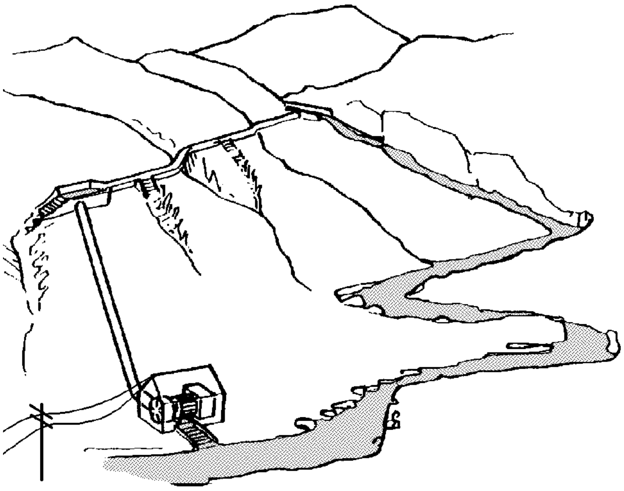
A variation on the canal-and-penstock layout for medium and high-head schemes (Section 2.3) is to use only a penstock, and omit the use of a canal. This would be applicable where the terrain would make canal construction difficult, or in an environmentally-sensitive location where the scheme needs to be hidden and a buried penstock is the only acceptable solution. Economics have also made this the default option in the modern era where pipeline materials are relatively cheap and labour for site construction more expensive.

For low head schemes, there are two typical layouts. Where the project is a redevelopment of an old scheme, there will often be a canal still in existence drawing water to an old powerhouse or watermill. It may make sense to re-use this canal, although in some cases this may have been sized for a lower flow than would be cost-effective for a new scheme. In this case, a barrage development may be possible on the same site.

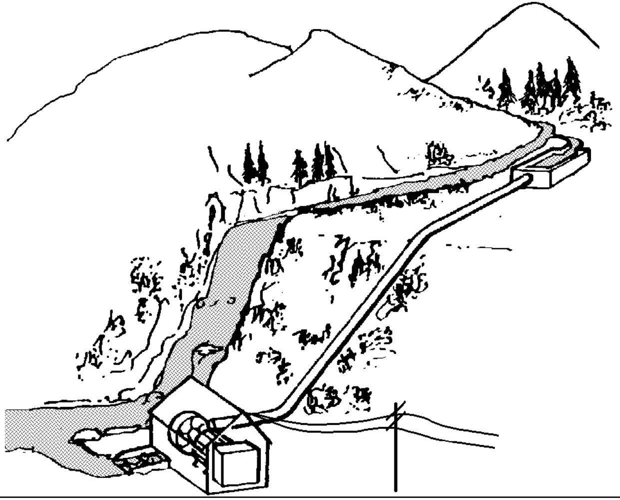
With a barrage development, the turbine(s) are constructed immediately adjacent to the weir, or incorporated into the weir itself, so that only a very short approach canal (or pipeline) is required.

A final option for the location of new mini-hydro turbines is on the exit flow from storage reservoirs, water-treatment plants or sewage works.

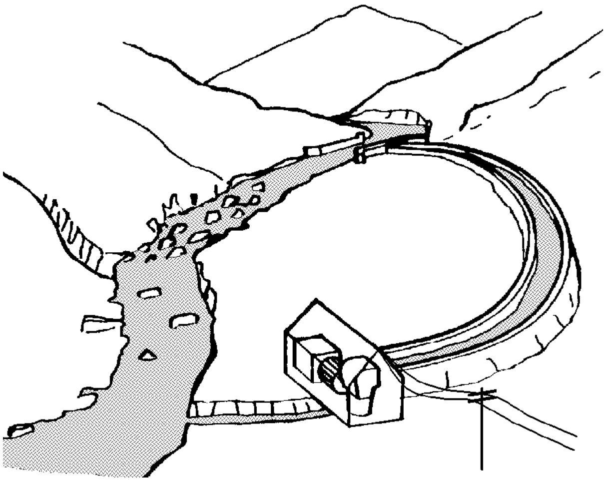
Canal and Penstock



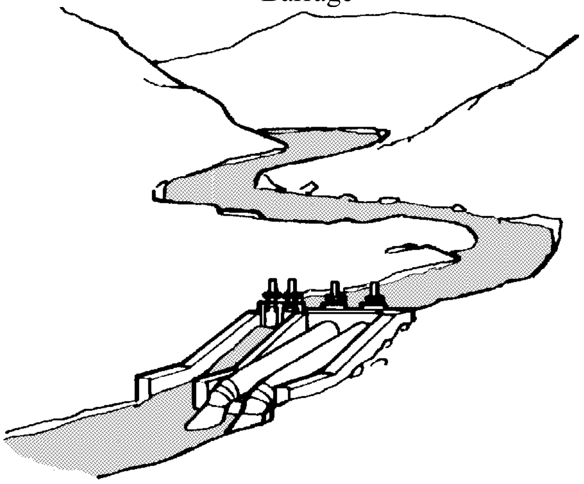
Penstock Only



Mill Leat



Barrage



3. ESSENTIAL INFORMATION ABOUT YOUR SITE

3.1 Summary

There are a few pieces of essential information that need to be obtained when a new site is being considered for hydro generation.

1. Firstly, one has to identify whether there is a worthwhile energy resource. This involves estimating or measuring the flow and available head, and calculating what annual energy capture would result.

2. If the potential output of a scheme is attractive, then one needs to be confident (i) that permission will be granted to use all of the land required both to develop the scheme and to have the necessary access to it, and (ii) that the necessary environmental licences will be granted to build the scheme and to divert the required flow from the watercourse.

3. Finally, there needs to be a clear destination for the power: is there a nearby load that needs to be supplied (factory, hotel, etc.) or is there a convenient point of connection into the local distribution network?

These issues are explored in more detail below.

3.2 Flow

3.2.1 Obtaining Flow Data

The flow in most of the significant rivers and streams in the UK is being measured on a continuous basis, and data from the network of 1300 gauging stations can be obtained from the National River Flow Archive. Data for hundreds of sites is available over the internet, at: https://nrfa.ceh.ac.uk/data/search These records can be used to assess stream flow at the proposed site, as long as due allowance is made for the actual site location in relation to the gauging station (upstream or downstream).

If no data is available for the stream in question, it is also possible to use hydrological methods that are based on long-term rainfall and evaporation records, plus the measured data from a nearby catchment areas. This allows initial conclusions to be drawn on the overall flow characteristic of site without taking any new flow measurements. The standard hydraulic model available to the UK public, and widely used to estimate annual river flows in the UK, is known as 'LowFlows 2' (available from Wallingford HydroSolutions).

However, for small catchment areas (e.g. less than $5km^2$), or ones that are strongly affected by the in-flow from springs, it is advisable to follow up with site measurements once the project looks likely to be feasible.

The mini-hydro reference books included in the bibliography (Section 9.2) offer a number of more or less sophisticated methods both for estimating the hydrology of a catchment area and for measuring the flow in streams.

For smaller streams, the most accurate and reliable method for measuring the flow rate is to install a flow-gauging weir, as summarised below.

3.2.2 Gauging Weirs

A flow-gauging weir has a rectangular (or triangular) notch which discharges all the water in the stream. It is useful typically for measuring flows in the region of 50-1000 l/s. The flow rate can be determined from a single reading of the difference in height between the upstream water level and the crest of the notch (see Figure). For reliable results, the crest of the weir must be kept 'sharp' and sediment must be prevented from accumulating behind the weir.

The formula for a rectangular notched weir is:

$$Q=\frac{2}{3}\,C_d\sqrt{2g}\,(L-0.2h)\,h^{1.5}$$

where:

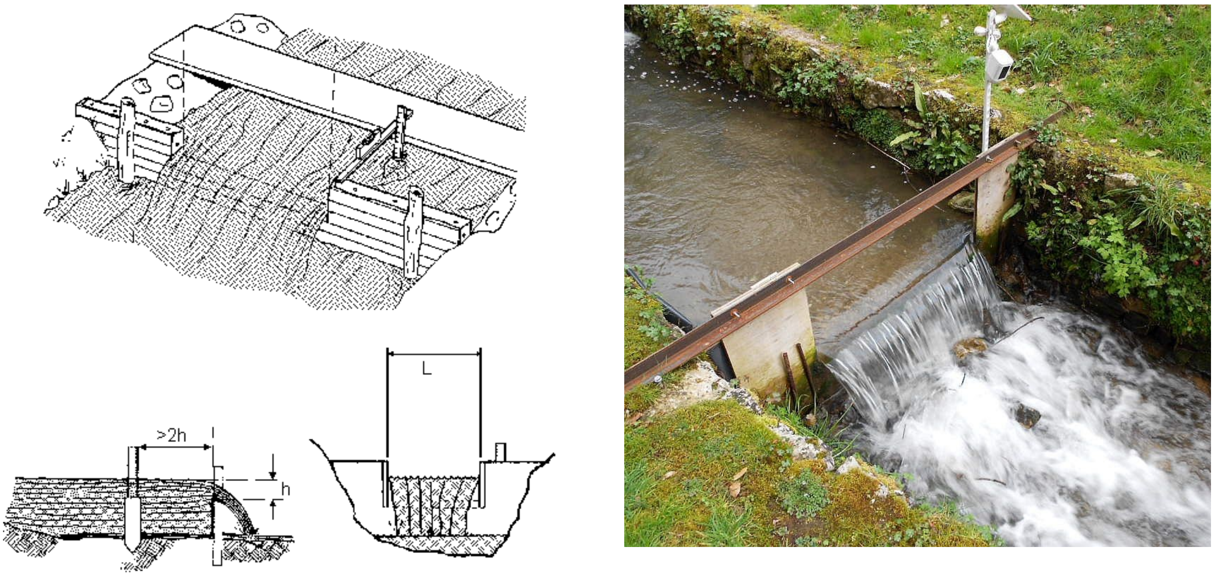
Q = flow rate (m^3/s)
C_d = the coefficient of discharge
L = the notch width (m)
h = the head difference (m)
g = acceleration due to gravity ($9.81m/s^2$)

If C_d is taken, typically, as 0.6, then the equation becomes:

$$Q = 1.8\,(L - 0.2h)\,h^{1.5}$$

Since stream flow varies both from day to day and with the season, measurements should ideally be taken over a long period of time, preferably at least a year, and correlated against the prevailing rainfall vs. long-term rainfall records to establish how the measured flows would relate to an ‘average’ year.

Flow-Gauging Weir



3.2.3 Flow Duration Curve

There are two ways of expressing the variation in river flow over the year: the annual hydrograph and the Flow Duration Curve or FDC, as illustrated below.

The annual hydrograph is the easiest to understand, since it simply shows the day-by-day variation in flow over a calendar year. However, the FDC is more useful when calculating the energy available for a hydro-power scheme.

The FDC shows how the availability of flow is distributed over a period (usually a year). The vertical axis gives the flow, the horizontal axis gives the percentage of the year that the flow exceeds the value given on the y-axis.

Hence, for example, the FDC can immediately indicate the level of flow that will be available for at least 50% of the year (known as Q_{50}). The flow exceeded for 95% of the year (Q_{95}) is often taken as the characteristic value for the minimum summer flow.

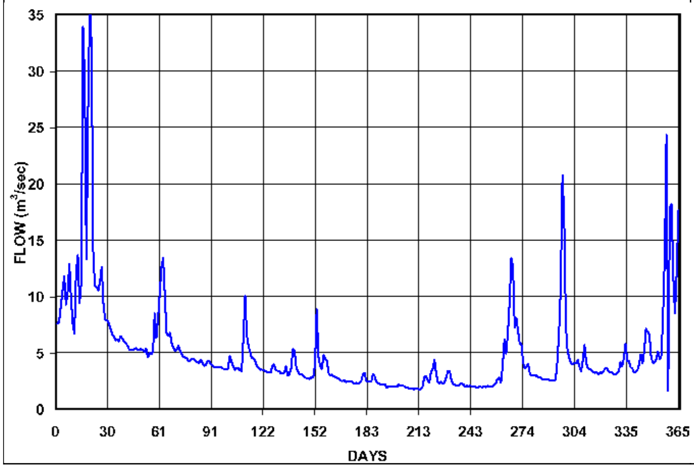
FDCs are often very similar for a region, but can be affected by soil conditions, vegetation cover, and to a lesser extent by catchment shape. They are also modified by man-made reservoirs, abstractions and discharges.

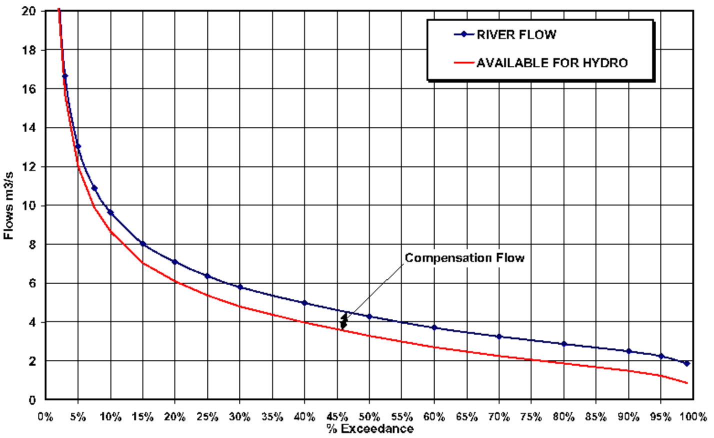
A flatter FDC (characterising a heavily spring-fed river) is preferable to a steeply sloping one, and means that the total annual flow will be spread more evenly over the year, giving useful flow for a longer period, with less severe floods.

Compensation Flow

A portion of the flow, historically called the **compensation flow** (but more recently referred to as the ‘residual’, ‘reserved’, ‘prescribed’ or ‘hands-off’ flow), will need to by-pass the scheme for environmental or aesthetic reasons. In schemes where water is diverted away from the main course of the river, this compensation flow is needed to maintain the ecology within the depleted stretch of the watercourse.

The amount of compensation flow will depend on site-specific factors, and is subject to detailed guidance by the environmental regulators, but a reasonable first estimate will lie between the Q_{80} and Q_{95} values of river flow. If there is no depleted reach (e.g. an ‘around-weir’ scheme), it may be possible to agree a value less than Q_{95} with the relevant regulator.


Annual Hydrograph


Flow Duration Curve

3.3 Head

3.3.1 Head measurements

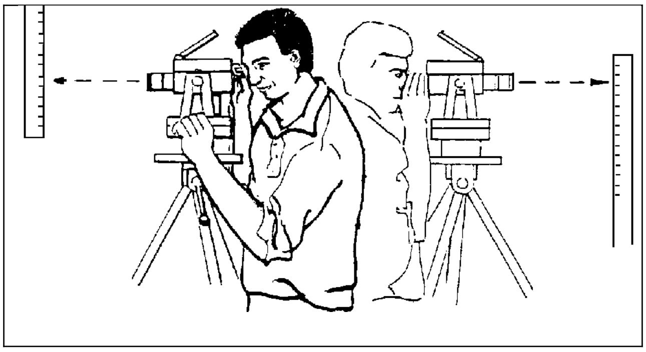
The head of water available at any one site can be determined by measuring the height difference between the water surface at the proposed intake and the water surface at the point where the water will be returned.

The mini-hydro reference books can provide details of basic survey techniques to measure or estimate the available head. The most common methods are summarised as follows:

1. An initial estimate for a high-head site (> 50m) can be taken from a large-scale map, simply by counting the contours between the inlet and discharge points: the distance between contours on standard Ordnance Survey maps is 10m on a 1:50,000 scale, but can often be 5m at 1:25,000.

2. Altimeters can be very useful for high-head feasibility surveys. Good quality altimeters in experienced hands will give errors of as little as 3% in 100m. Atmospheric pressure variations need to be corrected for, however, and several readings should be taken on different days to give confidence.

3. The use of a Dumpy level (Theodolite or builder's level) is the conventional method for measuring head accurately and should be used for low head sites (<10m). Such equipment should be used by experienced operators who are capable of checking the calibration of the device.



Low-head schemes and head variation
An important factor on low head schemes is that the gross head is not a constant but varies with the river flow. As the river fills up, the tailwater level usually rises faster than the headwater level, thus reducing the total head available. To assess the gross head accurately at a low head scheme, both headwater and tailwater levels need to be measured over the full range of river flows.

3.3.2 Flood Levels

When determining the gross head, it is also important to enquire about the severity of flood levels on the site, especially at the turbine location. It is essential to design every scheme to survive the worst conceivable flood (‘1 in 200 year’ is recommended), and to ensure that any new structures will not worsen flood-related problems in the locality.

The extent of the flood plain, as predicted by flood modelling, is now a standard service provided for planning applications, available online, and will give a first indication of the severity of flooding around the site.

3.4 Preliminary power and energy calculation

3.4.1 Design Flow

It is unlikely that low-head schemes abstracting significantly more than the mean river flow (Q_{mean}) will be economically attractive because the machinery and civil structures start to become excessively large and costly to handle this high flow volume. Therefore the turbine design flow for a low-head run-of-river scheme (a scheme operating with no appreciable water storage) will not normally be greater than Q_{mean}.

For medium and high head schemes on ‘flashy’ watercourses, higher design flows can be economically and environmentally justified, and design flows as high as $1.3 \times Q_{mean}$ can prove to be optimum.

The greater the chosen value of the design flow, the smaller the proportion of the year that the system will be operating on full power, i.e. it will have a lower ‘Capacity factor’.

3.4.2 Capacity Factor

Most turbines can operate over a range of flows (typically down to 10-30% of their rated flow – see Section 8.) in order to increase their energy capture and sustain a reduced output during the drier months.

The ‘Capacity factor’ is a ratio summarising how hard a turbine is working on average, expressed as:

$$\text{Capacity factor (\%)} = \frac{\text{Energy generated per year (kWh/year)}}{\text{Installed capacity (kW)} \times 8760 \text{ hours/year}}$$

A first estimate of how Capacity factor typically varies with design flow is given as follows:

Design Flow Q_D	Capacity Factor
1.30 x Q_{mean}	33%
Q_{mean}	40%
0.75 x Q_{mean}	50%
0.50 x Q_{mean}	60%
0.33 x Q_{mean}	70%

3.4.3 Rated Power

The peak power **P** can be estimated from the design flow $\mathbf{Q}_o$ and net head $\mathbf{H}_{net}$ as follows:

$$\mathbf{P}(\text{kW}) = 7 \times \mathbf{Q}_o\,(\text{m}^3/\text{s}) \times \mathbf{H}_{net}\,(\text{m})$$

3.4.4 Energy Output

The annual energy output can then be estimated using the Capacity Factor (CF) as follows:

$$\text{Energy (kWh/year)} = \mathbf{P}\,(\text{kW}) \times \mathbf{CF} \times 8760$$

There is clearly a balance to be struck between choosing a larger, more expensive turbine which takes a high flow but operates at a low Capacity factor, and selecting a smaller turbine which will generate less energy over the year, but will be generating full power for more of the time i.e. a higher Capacity Factor. As a result, the Capacity Factor for most mini-hydro schemes would normally fall within the range 40% to 60% in order to give a satisfactory return on the investment.

3.5 Rights over the relevant land

No project can proceed unless you have the right to access and utilise all the land needed to build it, and then operate and maintain it for the life of the scheme. It is also important to establish how contractors will access the different parts of the project with the necessary equipment, and to confirm that these temporary routes will be available for the construction phase.

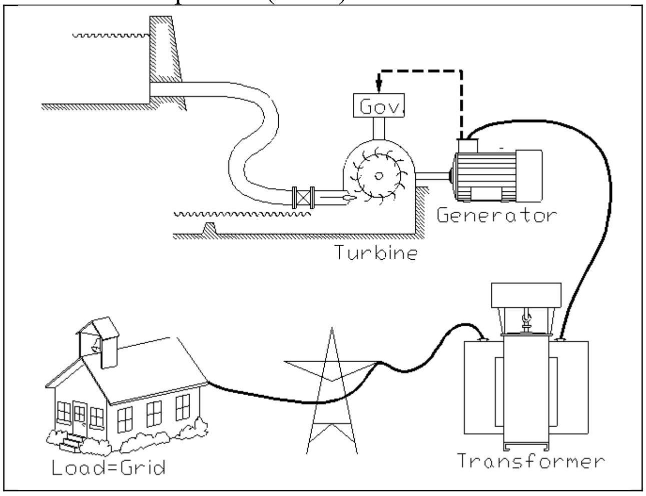
It is therefore wise to approach the relevant land-owners at an early stage to establish any objections to the proposed scheme and to negotiate access. Since watercourses often form property boundaries, the ownership of the banks and existing structures may be complex. Failure to settle this issue at an early stage may result in delays and cost penalties later in a project.

Legally binding leasing agreements will need to be drawn up which establish your right to use the necessary land areas and also to define your responsibilities, as a tenant, in maintaining it. For example, the operator of a scheme may be required to take on the maintenance liability of an existing weir and mill leat as part of an agreement allowing them to install a new turbine in the old mill workings.

3.6 Grid-connection

It is important to determine at the outset what the value of the electricity generated by the scheme will be i.e. to whom the power will be sold.

The electricity generated by a scheme may be used at the point of generation, in place of electricity supplied by the local electricity company. In addition, any excess power may be exported into the local distribution network by agreement with the Distribution Network Operator (DNO).



It is always financially advantageous to consume as much of the power as possible on site, and only export the surplus into the network.

If the scheme is to produce power for export to the local network, there should be early discussions with the DNO who will specify the system protection and metering equipment.

They will also provide an estimate of connection costs and the best location for feeding into their system.

4. COMMISSIONING A FEASIBILITY STUDY

4.1 Preliminaries

4.1.1 Getting Professional Help

Any developer should seek independent professional advice before committing significant finance to the design and construction of a small-scale hydro scheme.

The involvement of professionals in a small-scale hydro development can range from preliminary site assessment, through the conducting of a feasibility study with layout drawings, to a full ‘turnkey’ service, handling every aspect of a development. In addition, there are several companies that lease, develop and operate sites as a business activity, and can provide a full skills and finance package.

Some turbine suppliers will offer feasibility services as a loss-leader to procuring an equipment order. If you are seeking fully independent advice, it is important to check whether your adviser is linked to any specific suppliers.

4.1.2 Preliminary Site Assessment

An experienced hydro professional should be able to indicate whether a site is worth considering further, on the basis of an initial site visit and discussions with the developer and others. Preliminary investigations of this type will typically require no more than 2-3 days’ work and will cost in the region of £1000 - £1500. A relatively modest investment at this stage could save much greater expense and potential complications later in the development process.

The main issues that should be considered in a preliminary investigation are:

- The existence of a suitable river gradient, waterfall or weir to provide a worthwhile head.
- A sufficient flow of water at a usable head.
- The likely acceptability of diverting water to a turbine.
- A location of sufficient size for a turbine and powerhouse building.
- Suitable site access for construction equipment.
- A nearby demand for electricity, or the prospect of a grid connection at reasonable cost.
- The social and environmental impact on the local area.

- Land ownership and/or the prospect of securing or leasing land for the scheme at a reasonable cost.
- Outline scheme layout and equipment specifications.
- An initial indication of design power, annual energy output and revenue.
- Ball-park costs for developing the scheme.

The accuracy of the information may only be plus or minus 25%, however, this should be sufficient for deciding whether to proceed to a more detailed feasibility study.

4.2 Feasibility

A feasibility study uses accurate data, develops design drawings and looks closely at costs. It can take the project forward from the initial idea to a final design that will support applications for project finance and the necessary licenses. It is therefore always wise to employ a professional to conduct the feasibility study and the detailed design work.

The cost of a full feasibility study carried out by an independent consultant depends on its scope and on the specific characteristics of the site, but would typically be £7500 - £20,000 depending on the sale and complexity of the project.

For a domestic-scale scheme (i.e. less than 15 kW), a detailed feasibility may not be affordable, and a less detailed ‘Design Study’ may prove sufficient. This would cover the same basic ground but use approximate data analysed less extensively. It should be possible to commission a basic design study for around £5000.

The following essential tasks should form components of a feasibility, or design, study:

1. **Hydrological Survey.** Typically, a hydrological survey would produce a Flow Duration Curve. This would be based on long-term records of flow data and/or rainfall, or the output from a reputable hydraulic model. This information might be backed up by short-term flow measurements. The study should include a recommendation for the required compensation flow.

2. **System design.** This would include a description of the overall project layout, including a drawing showing the general arrangement of the site. The prominent aspects of the works should be described in detail, with appropriate drawings, covering:

   - Civil works (intake and weir, intake channel, penstock, turbine house, main inlet valve, tailrace channel, site access, construction details)
   - The generating equipment (turbine, gearbox, generator, control system) and machinery layout
   - Grid connection and cabling

3. **System costing.** A clear system costing would include a detailed estimate of the capital costs of the project, subdivided into:

   - Civil costs
   - Electro-mechanical equipment
   - Grid-connection
   - Installation and commissioning of all items
   - Engineering and project management fees

4. **Estimate of energy output and annual revenue.** This would summarise the source data (river flows, hydraulic losses, operating head, turbine efficiencies and methods of calculation) and calculate the output of the scheme in terms of the maximum potential output power (in kW) and the average annual energy yield (kWh/year) converted into annual revenue (£/year)

An additional task, which may form part of the main feasibility report but is often undertaken separately, is the **environmental assessment** of the scheme, discussed in Section 5..

5. PLANNING AND LICENSES

5.1 Whom to consult

Informal and formal consultation should underpin every stage of a development and may be handled either by the developer or by a hydro professional. Consultation will be tailored to each individual development. Some sites, for instance, may not be located on fishing rivers and therefore consultation with fisheries bodies or angling clubs would be limited. Similarly, where a site does not require planning permission (for example, it is re-using the infrastructure from an old mill), there is no need for detailed consultation with the planning authority.

The bodies listed in the table below should be approached, as appropriate, at the outset of a development, and contact should be maintained throughout. Full consultation will ensure that any problems are identified at an early stage, and this may prevent the incurring of unnecessary expenditure.

Body to be consulted	**Purpose of Consultation**
The Environment Agency (England) Scottish Environmental Protection Agency (SEPA) Natural Resources Wales (NRW) Northern Ireland Environment Agency (NIEA)	To ensure that the site is acceptable. To establish a design that is acceptable. To identify the permissions required. To specify any supporting environmental surveys. To agree an acceptable river operating regime (i.e. flow volumes to be abstracted and reserved).
Local planning authority	To ensure that the site plus access are acceptable. To identify heritage, noise or amenity concerns. To establish a design that is acceptable, especially where construction work is significant. To identify permissions required.
Statutory environmental bodies e.g. Natural England, Countryside Commission for Wales, Scottish Natural Heritage	To address potential impacts on protected habitats or species at the design stage.
Landowners	To address ownership, access and leasing issues, including way-leaves for pipes or cables. To address possible objections to development.
Fisheries bodies (e.g. river trusts, angling clubs). Scotland: the District Salmon Fisheries Board.	To address possible concerns at the design stage
Distribution Network Operator (DNO)	To establish any design constraints and costs for connecting to the local network.

5.2 Planning issues

Planning aspects of hydro developments are the responsibility of the local planning authority. Planning permission will be required for most hydro developments. A possible exception is the refurbishment of an existing or historic scheme, where there is no ‘change of use’.

The planning department will indicate whether planning permission is required and whether other related procedures will also be necessary, such as Listed Buildings Consent, Building Regulation Approval, or the submission of an Environmental Statement.

The planning department will also suggest who should be consulted, indicate sensitivities to development, and outline measures that might be taken to make developments more acceptable. An early approach to the planning department is recommended so that any uncertainties can be clarified and a good working relationship established.

The primary issues of concern to the planners are likely to be:

- The visual appearance of the scheme, particularly the powerhouse and penstock pipe.
- Potential noise impacts on nearby residents.
- Disturbance during the construction phase, both to local residents and disrupting traffic.
- Preservation of structures of historical importance.

On environmental issues, the planners will normally take advice from their statutory consultees, such as the Environment Agency/SEPA/NRW and Natural England/Scottish Natural Heritage. They will also be able to advise on whether the scheme warrants a public display for the purpose of presenting the project to local people and helping allay any concerns.

For larger schemes, it is sometimes advisable to apply for outline planning permission in the first instance, in which the main elements of the scheme can be agreed but without the completion of the final design. This means that the overall planning process will be longer, but allows feedback received during the outline planning process to be accommodated more easily into the final design and therefore reduces the risk of the full planning application being rejected.

5.3 Environmental Regulation

5.3.1 Environmental Licences

Jurisdiction over the abstraction and impoundment of watercourses in the UK has been devolved to four separate national bodies (which will be collectively referred to as the Environmental Regulators):

England	Environment Agency (EA)
Scotland	Scottish Environmental Protection Agency (SEPA)
Wales	Natural Resources Wales (NRW)
N.Ireland	Northern Ireland Environment Agency (NIEA)

Each of these devolved regulators have published separate guidance to advise hydro developers on how to address the wide range of issues that need to be considered before issuing the necessary licensing – links to these are provided in Section 9.3. Each regulator will ultimately require a report assessing the environmental effects of the proposed hydropower development on the aquatic environment.

To abstract water for a hydro project (even though it will be returned downstream) will almost always require regulatory permission in the form of a licence.

There are three licences that can apply to a hydropower schemes in England and Wales:

- **Abstraction Licence**, if water is being diverted ‘away from the main line of flow of the river’. In practice, this means that the only type of scheme which can avoid an abstraction licence would be a barrage-type project where turbines are installed as part of an existing weir and the water remains between the existing banks of the river. All new abstraction licences are time-limited to between 6 and 18 years, after which they must be renewed. The Regulators generally operate on the basis of a “presumption of renewal” unless there is firm evidence of environmental degradation.

- **Impoundment Licence**, if changes are being made to structures which impound water, such as weirs and sluices, or if new structures are to be built. An Impoundment Licence has no time limit.

- **Flood Risk Permit**, for any works being carried out in, or adjacent to, a 'Main River' – a link to the main rivers map is provided in Section 9.3.

In Scotland a single licence may be applied for under the Controlled Activities Regulations (CAR). This single licence will cover all aspects of the environmental licence required for a hydropower scheme of any size (i.e. abstraction, impoundment, construction methods).

In all cases, if you believe the terms of the License you are issued are unfair or unsatisfactory, then it is possible to appeal against the conditions of the licence issued within 28 days.

5.3.2 Fisheries

Hydro-installations on rivers populated by migratory fish, such as salmon and sea trout, are subject to special requirements as defined in the Salmon & Freshwater Fisheries Act.

Under the Act, migratory fish (salmon and sea trout) must be able to pass the scheme safely. Either the turbine must be fish-friendly, such as an Archimedes Screw, or the mesh of the trashrack must be fine enough to prevent juvenile fish entering the turbine. In addition, there must be a water passage by-passing the hydro-plant at all times so that fish can migrate up or downstream. To allow fish to pass upstream sometimes requires the construction of a fishpass, which may be a shallow ramp with baffles, or a series of pools such that fish can jump up from one pool to the next.

There are additional requirements where eels are present, as dictated by the Eel Order 2009, which may require an eel-pass and/or specific screening. The EA has provided specific guidance in their manual "Screening at intakes: measures to protect eel and elvers" issued in 2022.

5.3.3 Approaching the Environment Agency / SEPA / NRW / NIEA

Beyond the licensing procedures, the Environmental Regulators are also responsible for fish protection and other environmental aspects of any riverside development.

Whilst they have a duty to protect the environment from harmful development, each Regulator also has a statutory duty to promote sustainable development and to be proportionate and targeted in its requirements, bearing in mind the costs involved.

In general:

- approach the Regulator at an early stage and maintain a dialogue with them.
- respect the fact that the Regulator cannot compromise its statutory duties.
- maintain a flexible approach to the proposed scheme in respect of measures to mitigate its impact, even where this may be at the expense of some generating capacity.

The Regulator will advise on the scope of any environmental assessments that may be needed. Schemes less than 500kW are not required by law to produce a formal Environmental Impact Assessment. However, all license applications normally need to be supported by an Environmental Report which summarises the details and impacts of the scheme. The Regulator will provide the required scope of such a report.

If you believe the Regulator is not responding in a fair or efficient manner, then you should not hesitate to make a representation to the Area Manager or to the head of the National Permitting Department.

5.3.4 The Environmental Statement.

Some form of environmental assessment is essential when it comes to applying for planning permission and environmental licenses.

Under the Town & Country Planning (Assessment of Environmental Effects) Regulations 1988, the planning application for any development that is considered likely to have a significant impact on the environment must be accompanied by an Environmental Statement. This document provides an assessment of the project's likely environmental effects, together with any design, construction, operational and decommissioning measures that are to be taken to minimise them. It would typically cover such issues as flora, fauna, noise levels, traffic, land use, archaeology, recreation, landscape, and air and water quality.

If the Planning Authority has asked for an Environmental Statement, this may also meet the requirements of the Environmental Regulator. However, the Regulator may ask for environmental information even if the local Planning Authority does not. Such information might cover water use, water quality, fisheries, river ecology, flood defence, nature conservation, navigation and public recreation issues. The Regulator should therefore be consulted at an early stage in order to provide guidance on what is required.

Hydropower consultants with appropriate experience should be able to compile the Environmental Statement. However they will often need input from local specialists for assessing any potential impacts on the local ecology & protected species, and perhaps also experts on fisheries and river geomorphology.

6. COSTS AND ECONOMICS

6.1 Investment Costs

Small hydro costs can be split into four segments :

1. Machinery
This group includes the turbine, gearbox or belt-drives, generator, hydraulic or electrical actuators, and the water inlet control valve.

Generally speaking, machinery costs for high head schemes are lower than for low head schemes of similar power. High head machines have to pass less water than low head machines for the same power output and are therefore smaller. They also run faster and thus can often be connected directly to the generator without the complication of gearbox or belts & pulleys.

2. Civil Works
This includes the intake structure, forebay tank and screen, the pipeline or channel to carry the water to the turbine, the turbine house and machinery foundations, and the tailrace channel to return the water to the river.

The Civil Works are largely site-specific. On high head sites the major cost will be the pipeline; on low head sites probably the water intake, screens and channel.

3. Electrical Works
The electrical system will involve the control system, the wiring within the turbine house, and a transformer if required, plus the cost of connection to the electricity network. These costs are largely dependent on the maximum power output of the installation and the distance to the local network. The connection cost is set by the local electricity distribution company.

4. External Costs
This could encompass the engineering services of a professional to design and manage the installation, plus the costs of obtaining a the licences, planning permission, etc.

Indicative Total
For a 100kW small hydro installation, the costs could range as follows:-

	Low head	**High head**
	£1000s	*£1000s*
Machinery	200 – 250	60 – 150
Civil works	300 – 500	250 – 400
Electrical works (not grid connection)	40 – 50	40 – 50
External costs	50 – 100	50 – 100
Total:	**600 – 900**	**400 – 700**

Generally, the cost per kilowatt of new schemes increases as size reduces, due to economy of scale and the fact that any scheme has a certain fixed cost element which does not greatly change with size of scheme.

6.2 Running Costs

6.2.1 Leasing

If part of the land is leased, then there will be an annual rent to pay. It can be beneficial to tie this rent into the revenue from the scheme, so that the landlord also has an incentive for the turbines to be operating. Schemes which lease all the land should aim to pay no more than 5% of annual revenue as rent, although it is not unusual for land agents to start negotiations at a significantly higher figure.

6.2.2 Metering

Schemes over 30kW currently require half-hourly metering to be installed, which has to be monitored by an independent meter-reading company. There is an annual charge to pay for this service, typically in the range £300 - £600/ year.

6.2.3 Rates

Hydroelectric schemes which export the majority of their power into the network are subject to business rates, unless they are seen as being part of a domestic property. The rateable value is calculated by the Valuation Office according to various site parameters. For example: for the same rated power, a scheme will pay lower rates if its capital and operating costs are higher and its annual generation is lower.

Community-owned hydropower projects can benefit from partial or total relief from business rates, depending on their location.

6.2.4 Maintenance and Servicing

Modern, automated equipment requires very little maintenance. The cost of routine inspections and an annual service should come to no more than 0.5 to 1% of the capital cost of the scheme. As the machinery ages, there will eventually be extra costs associated with replacing seals and bearings, a new generator, refurbished sluice gates, etc., but these should not occur for at least 10 years.

6.2.5 Insurance

Although hydro plant is generally very reliable, the following insurances are recommended (and may be required by financiers):

- Material damage insurance against the cost of repairing damage to the works caused by fire and 'special perils' such as explosions, storms, flooding, impact and malicious damage.
- Business interruption insurance against loss of revenue caused by fire or special perils damage.
- Public and employer's liability insurances, which are required by law; a minimum indemnity of £5 million is recommended.

6.3 Maximising the revenue from your scheme

Operators of new renewable electricity-generating plant can generate revenue from:

- Displacing electricity from the on-site premises, otherwise bought-in from the grid.
- Selling the electricity to a major nearby consumer (factory, office, hotel, leisure complex).
- Exporting the electricity into the local network in order to sell to an electricity retailer.
- Selling REGO Certificates ('Renewable Energy Guarantees of Origin')

Pre-existing schemes have been able to benefit substantially from either ROCs (Renewables Obligation Certificates) or the Feed-in-Tariff, but both these schemes are closed to new entrants.

Selling Electricity - PPAs
If the electricity generated by a hydro-scheme is sold directly to an electricity company though a Power Purchase Agreement (PPA), then the price offered for the electricity can be relatively modest - in the range 6.0 to 9.0 p/kWh averaged over the year, although shocks in the global gas price have pushed tariffs much higher for short periods. PPAs are most commonly contracted for 6 months to 2 years.

It is also possible to have a PPA linked directly to the spot price of electricity calculated half-hourly through the day. The developer thereby takes the risk on how the market will behave, but this can be especially beneficial if the hydro scheme has a storage reservoir which allows it to dictate when to generate, and can therefore focus the output when market values are known to be higher (morning and evening).

Private Wire
Alternatively, if there is a substantial electrical load close to where the power is being generated (e.g. factory or office complex), it will be more beneficial to use the hydropower to feed that load, so displacing electricity that would otherwise be bought in from the grid at perhaps 20 – 25 p/kWh.

This essentially requires a private wire to run from the hydro project to the switchboard of the receiving premises, so this becomes less economically feasible if the cable-run is much more than 750m or so.

REGOs
Renewable Energy Guarantees of Origin, or REGOs, are certificates administered by Ofgem which state how many MWh of electricity have been generated from a renewable source. These have a value to companies seeking to off-set their carbon emissions. Electricity trading companies offering PPAs will make an offer for the REGOs as part of the overall contract. This also allows them to prove what percentage of their overall supply is from renewable sources.

6.4 Financial Assistance

Grants
There have been various local and regional funding mechanisms offering grants towards small-scale renewable energy projects, often to cover feasibility costs for community groups. District and County Councils should be able to advise on the availability of such funds.

7. CONTRACTING A SCHEME

7.1 Development Options

7.1.1 Turnkey Contracts

Since any hydro scheme requires a substantial up-front investment, it is clearly essential that the project is implemented correctly and with robust engineering and equipment.

For the larger schemes, requiring a hundreds of thousands of pounds investment, it will be important for the project to be managed by a professional hydro-engineering firm, and installed by an experienced contractor.

A common approach for implementing larger projects is the “turnkey contract” in which a single contractor takes on the entire scheme from start to finish. The contractor, who might be a civil engineering company or the turbine installer, brings together a team of sub-contractors and suppliers under a single contract, typically following a competitive tendering process.

From the owner’s point of view, this greatly simplifies the management of the job. However, since the main contractor is taking on most of the risks and unknowns, this will inevitably be reflected in the cost of the tender.

7.1.2 DIY

For the smaller schemes (generally less than 50 kW), it may be possible for the owner and his local team of contractors to share the tasks of implementing the scheme with the equipment supplier.

This approach can lead to significant savings on the project cost, but requires the responsibilities of the different parties to be very clearly defined.

Even if the owner is keen to adopt a DIY approach, there are certain activities where professional inputs will be essential to ensure the technical viability of the scheme. These areas can be summarised as follows:

1. The detailed site survey
2. The general layout of the scheme
3. The design of the intake
4. The layout of the powerhouse
5. The specification of the turbine and penstock
6. The installation and commissioning of the electro-mechanical equipment (which would often be undertaken by the turbine supplier)

Therefore the main tasks which the scheme-owners may feel they can implement using local labour would be:

1. Construction of the intake works
2. Installation of the penstock pipe
3. Construction of the powerhouse and tailrace
4. Laying of electrical cabling

All of the above would be completed to a specification provided by the equipment supplier or hydro-power consultant.

7.1.3 Hybrid

Combining the above 2 approaches, it has also proved cost-effective to split the work into 3 contracts:

Hydro installer	Electro-mechanical equipment supply and installation - generally covering everything made of metal and all electrical items
Local contractor	Civil construction works (and the 'Principal Contractor' under CDM) - everything made of concrete, all pipework, heavy lifting
Hydropower designer	Project management and supervision (the 'Principal Designer' under CDM) - specifying the equipment, issuing the construction drawings, supervising the key elements of the build and contractor liaison, plus final commissioning.

This allows each party to focus on what they understand and do best, so keeping their costs competitive, and minimising the risk of the project being compromised by inexperience or misunderstanding.

7.2 Suppliers

Small-scale hydro power is a proven and mature technology. Reliable and efficient equipment and sound advice is available from a range of experienced suppliers and manufacturers in the UK and worldwide.

The term 'supplier' covers any company which will sell you equipment for your scheme. They may also be the manufacturer, or they may be the agent for imported equipment. The BHA maintains a database of equipment suppliers that are active in the UK.

Many turbine suppliers will also offer to provide the full equipment package including the gearbox, generator, control panel, trashrack, sluice gate, etc. which they will assemble from their preferred sub-contractors.

Suppliers are usually willing to provide a 'budget quote' for the equipment for your scheme, based on limited information, in order to help you identify whether their equipment is appropriate and affordable without investing significant resources.

The minimum information they would need to respond to an enquiry would be the design head and flow. Additional useful information to include in such a request would be:

- Scheme location
- Length and diameter of penstock pipe
- Flow Duration Curve and compensation flow
- Type of turbine required (if already known)
- Any unusual constraints of the site e.g. access difficulties, environmental sensitivities

The typical lead time for a turbine, from placing an order to delivery on site, is between 6 and 12 months. This is an important consideration when planning the timescale of a development.

7.3 Installers

Installers are engineering companies who will manage the specification, procurement, installation and commissioning of all the components of a hydro-scheme. In essence, they will offer a turnkey project for the electro-mechanical aspects of the scheme. Some installers are fully independent, whilst others are linked to a specific turbine manufacturer (or have agency agreements with more than one manufacturer).

Installers may also offer to undertake the site survey and initial feasibility work, but their recommendations may be geared towards specific turbine products.

Some installers may also take on the civil works, if relatively minor, otherwise a civil contractor will also be required to implement the construction works. The turbine installer should always provide a specification for the preparatory works required to mount their equipment correctly.

The most reliable method for checking an installer’s credentials is to obtain references from previous work. Installers should be able to supply a list of past projects and the contact details of at least one recent customer. The BHA will be able to confirm whether an installer is a member of the Association and has a known track record in the industry.

7.4 Commissioning and handover

The final stage in the installation of a micro-hydro plant involves performance tests. The purpose is to check the function of the different components of the scheme and to measure the overall system performance against the figures arrived at during the design of the scheme.

Depending on the complexity of the system, it may take several months before all working conditions are experienced (i.e. the full range of river flows). Hence, although formal commissioning and hand-over may be completed in a few days, the end-user should not consider the job fully completed until satisfied that all operating conditions have been met.

Important activities during commissioning will include:

- Ensuring sufficient flow is being drawn through the intake.
- Checking that surplus water passing through the intake will escape down the appropriate spillways and will never overflow the channel walls.
- Confirming that the channel can pass the design flow without undue head loss.
- Confirming that the design flow will pass down the pressure pipe without entraining air at the forebay.
- Measuring the head loss in the pressure pipe.
- Checking the pipe and valve joints for any leaks.
- Confirming the smooth running of the turbine and generator, including checking the bearings for noise and temperature.
- Checking that belts and pulleys are correctly aligned, or that the gearbox is operating effectively without overheating.
- Ensuring that the lubricating systems are working for the turbine bearings and the gearbox.
- Confirming that the turbine achieves its design power at rated head and flow.
- Checking all the functions of the control panel, in particular: start-up and shut-down sequences, feedback from all sensors, emergency trips, and all the switchgear which interfaces with the grid.

7.5 Operating the scheme

Both the lifetime of the equipment and the level of effort required for operation and maintenance will depend on the project design, although small-scale hydro schemes generally tend to have long lifetimes and low maintenance costs.

Modern schemes are usually automated, and regular maintenance is restricted to tasks such as the periodic clearing of the intake trash-rack and the lubrication of parts of the generating equipment. Older schemes may require more regular manual intervention, for instance daily raking of the trashrack and operating sluice gates or control valves.

For schemes without an on-site or local operator, a remote monitoring system is strongly recommended which will give a continuous update on system performance to a web-site, and provide an early indication of faults.

During system commissioning, the installer should run through all the routine inspection and maintenance tasks with the owner of the scheme. He will also provide the documentation from the various equipment suppliers which should detail the relevant maintenance tasks and timings for each part of the system.

If the electro-mechanical equipment is of modern design, only an annual service will be necessary. This can usually be carried out during the low-flow period when the plant is less likely to be generating. It will typically be undertaken by the equipment supplier or the installer and, except for larger or more complex schemes, should be completed in a day – unless significant problems are identified.

8. TECHNOLOGY

8.1 Overview

All hydro turbines convert the energy from falling water into rotating shaft power, but there can be some confusion as to which type of turbine should be used in different circumstances.

The selection of the turbine depends upon the site characteristics, principally the head and flow available, plus the desired running speed of the generator and whether the turbine will be expected to operate in reduced flow conditions. There can be other site-specific factors which also guide the choice of machinery, such as noise sensitivities, space limitations, or access constraints.

8.1.1 Classification

There are at least 6 different types of turbine in widespread use. These can be crudely classified as high-head, medium-head, or low-head machines, as shown in Table 1.

The head classification is based on the running speed of the different types of turbine. Standard 'off-the-shelf' electrical generators require to be driven at shaft speeds of 1500, 1000, 750 or 600rpm. Ideally the turbine would run at one of these speeds, allowing a direct drive to the generator.

If direct drive is not achievable, it is desirable for the turbine speed to be as fast as possible so as to minimize the speed change between the turbine and the generator. The bigger this speed change, the more expensive the gearbox or belt-drive required to match the speeds and the greater loss of efficiency. Since the speed of any given type of turbine reduces with head, low-head sites need turbines that are inherently faster under a given operating condition.

Turbines are also divided by their principle of operation and can be:

1. An *Impulse* turbine, which is driven by a high-velocity water jet (or multiple jets).
2. A *Reaction* turbine. The rotor of a reaction turbine is fully immersed in water and is enclosed in a pressure casing. As with any propeller, the runner blades are profiled so that pressure differences across them impose lift forces, just as on aircraft wings, which cause the runner to rotate faster than is possible with a jet.
3. A *Gravity* turbine is driven simply by the weight of water entering the top of the turbine and falling to the bottom, where it is released – for example, an overshot waterwheel. These are inherently slow-running machines.

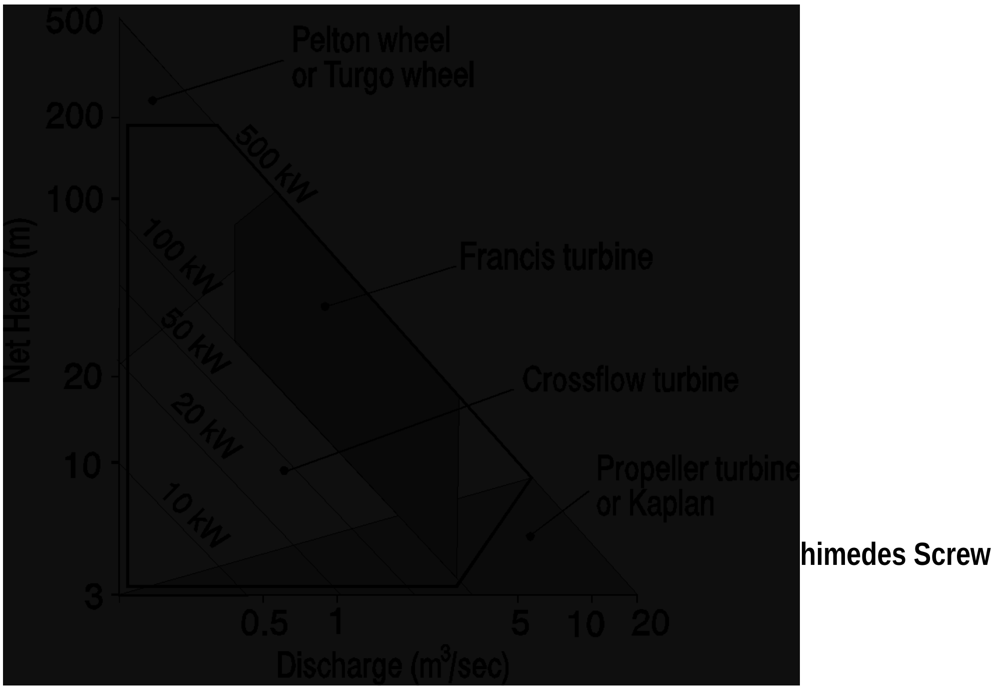
There are 3 main types of impulse turbine in use: the Pelton, the Turgo, and the Crossflow turbine. The two main types of reaction turbine are the propeller turbine (with Kaplan variant) and the Francis turbine. The reverse Archimedes Screw and the overshot waterwheel are both gravity turbines.

The approximate ranges of head, flow and power applicable to the different turbine types are summarised in the chart of Figure 1 (up to 500kW power). These are approximate and depend on the precise design.

Table 1 Turbine classifications

Head Classification	**Turbine Type**		
	Impulse	*Reaction*	*Gravity*
High *(>50m)*	• Pelton • Turgo		
Medium *(10-50m)*	• Crossflow • Turgo • Multi-jet Pelton	• Francis (spiral case)	
Low *(<10m)*	• Crossflow • Undershot waterwheel	• Propeller • Kaplan • Francis (open-flume)	• Overshot waterwheel • Archimedes Screw

Figure 1 Head-flow ranges of small hydro turbines



8.2 Modern Turbine-Types

The seven principal types of turbine in use today are depicted in Figure 3 and summarised below.

8.2.1 Impulse Turbines

The *Pelton Turbine* consists of a wheel with a series of split buckets set around its rim; a high velocity jet of water is directed tangentially at the wheel. The jet hits each bucket and is split in half, so that each half is turned and deflected back almost through 180º. Nearly all the energy of the water goes into propelling the bucket, and the deflected water falls into a discharge channel below.

The *Turgo* turbine is similar to the Pelton but the jet strikes the plane of the runner at an angle (typically 20° to 25°) so that the water enters the runner on one side and exits on the other. Therefore the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a Turgo turbine can have a smaller diameter runner and rotate faster than a Pelton for an equivalent flow rate.

The *Crossflow* turbine has a drum-like rotor with a solid disk at each end and gutter-shaped “slats” joining the two disks. A jet of water enters the top of the rotor through the curved blades, emerging on the far side of the rotor by passing through the blades a 2nd time. The shape of the blades is such that on each passage through the periphery of the rotor the water transfers some of its momentum, before falling away with little residual energy.

8.2.2 Reaction Turbines

Reaction turbines exploit the oncoming flow of water to generate hydrodynamic lift forces to propel the runner blades. They are distinguished from the impulse type by having a runner that always functions within a completely water-filled casing.

All reaction turbines have a diffuser known as a ‘draft tube’ below the runner through which the water discharges. The draft tube slows the discharged water and so creates suction below the runner which increases the effective head.

Propeller-type turbines are similar in principle to the propeller of a ship, but operating in reversed mode.

A set of inlet guide vanes admits the flow to the propeller and these are often adjustable so as to allow the flow passing through the machine to be varied. In some cases the blades of the runner can also be adjusted for maximum efficiency, in which case the turbine is called a *Kaplan*. The mechanics for adjusting turbine blades and guide vanes can be costly and tend to be more affordable for larger systems, but can greatly improve efficiency over a wide range of flows.

The *Francis* turbine is essentially a modified form of propeller turbine in which water flows radially inwards into the runner and is turned to emerge axially. For medium-head schemes, the runner is most commonly mounted in a spiral casing with internal adjustable guide vanes.

Since the cross-flow turbine is now a less costly (though slightly less efficient) alternative to the spiral-case Francis, it is rare for these turbines to be used on sites of less than 100 kW output.

Pit-Francis. The Francis turbine was originally designed as a low-head machine, installed in an open chamber (or ‘pit’) without a spiral casing. Thousands of such machines were installed in the UK and the rest of Europe from the 1920s to the 1960s. Although an efficient turbine, it was eventually superseded by the propeller turbine which is more compact and faster-running for the same head and flow conditions. However, many of these ‘open-flume’ or ‘wall plate’ Francis turbines are still in place, hence this technology is still relevant for refurbishment schemes.

8.2.3 Gravity Turbines

The Archimedes Screw has been used as a pump for centuries, but in recent decades has also been operated in reverse as a turbine. It’s principle of operation is the same as the overshot waterwheel, but the clever shape of the helix allows the turbine to rotate faster than the equivalent waterwheel and with a high efficiency of power conversion (over 80%). However they are still relatively slow-running machines, which require a multi-stage gearbox to drive a standard generator.

A key advantage of the Screw is that it is proven to be a ‘fish-friendly’ turbine, so avoids the need for a fine screen and automatic screen-cleaner because fish and smaller debris can pass safely through the turbine.

8.3 Turbine efficiency

8.3.1 Relative efficiencies

A water turbine running at a certain speed will draw a particular flow. If there is not sufficient flow in the river to meet this demand, the turbine could start to drain the river and its performance rapidly degrades. It therefore either has to shut down, or it has to change its internal geometry – a process known as regulation. Regulated turbines can either adjust an inlet valve or rotate their guide vanes and/or runner blades in order to increase or reduce the amount of flow they draw. However the efficiency of the different turbines will inevitably decrease as they consume less flow. The typical variation is shown in Figure 2.

Reducing the flow passing through an Archimedes Screw can be achieved in 2 ways: either the incoming flow is ‘throttled’ by closing the main inlet gate, or the rotation of the Screw can be slowed down. The latter solution is usually more efficient, as well as being quieter, but it requires a variable-speed control system which involves a significant additional cost. Hence variable-speed is normally applicable for larger projects (typically >30kW).

It is therefore apparent that a significant factor in the comparison of different turbine types is their relative efficiencies both at their design point and at reduced flows. For example, Pelton and Kaplan turbines retain very high efficiencies when running below design flow; whereas the efficiency of Crossflow and Francis turbines falls away more rapidly if run at below half their rated flow.

Figure 2 Part-flow efficiencies

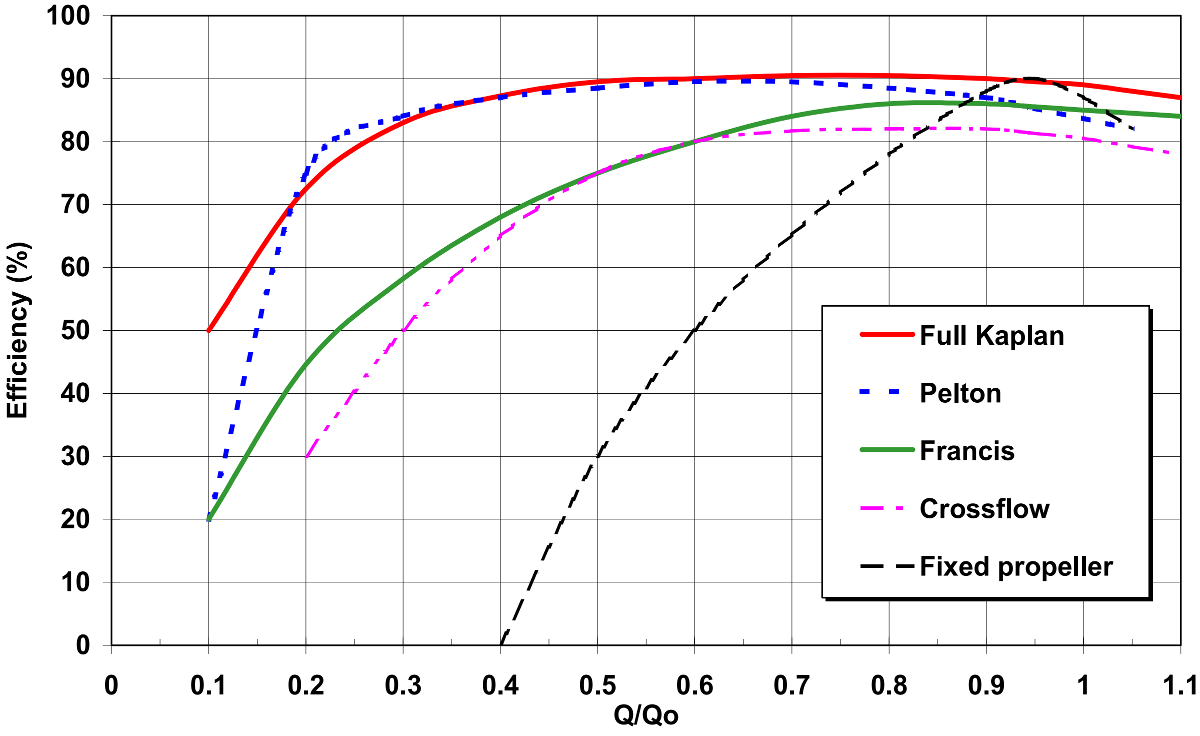
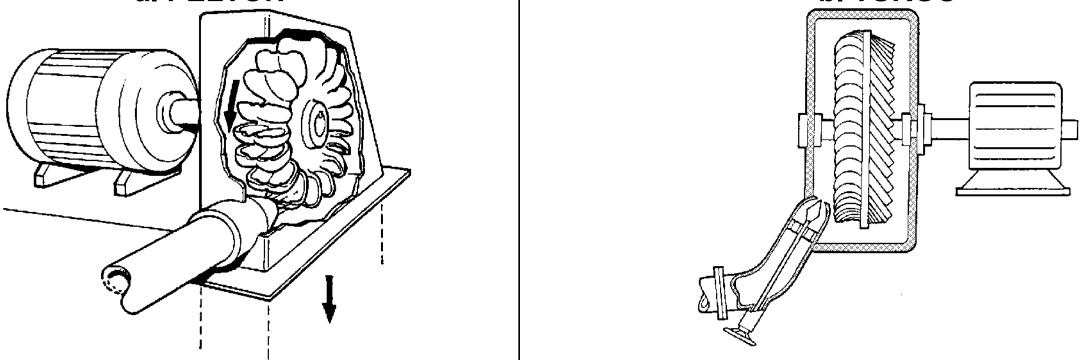
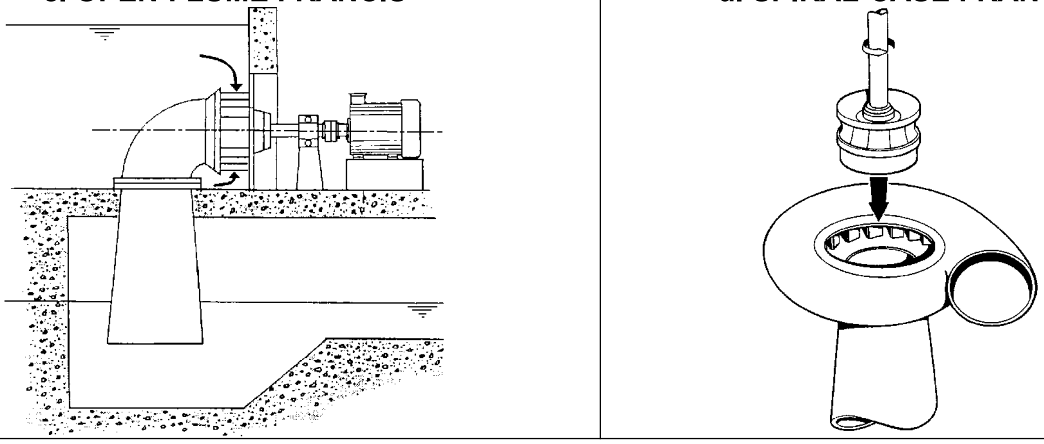


Figure 3 Principal turbine types



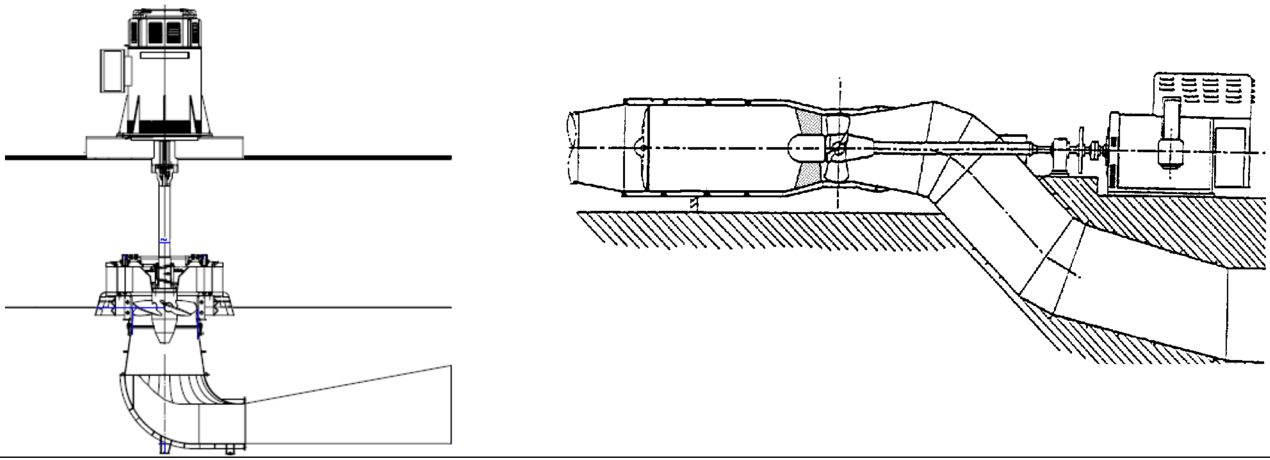
a. PELTON

b. TURGO

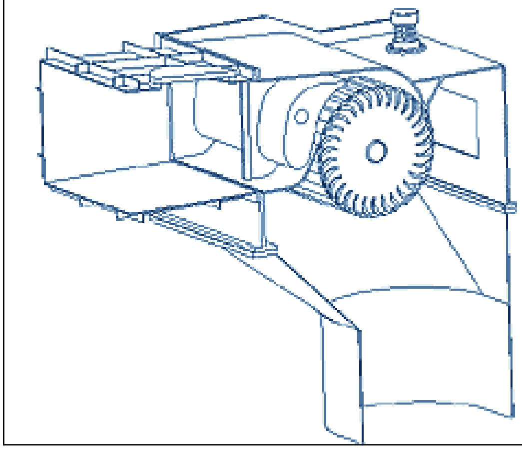
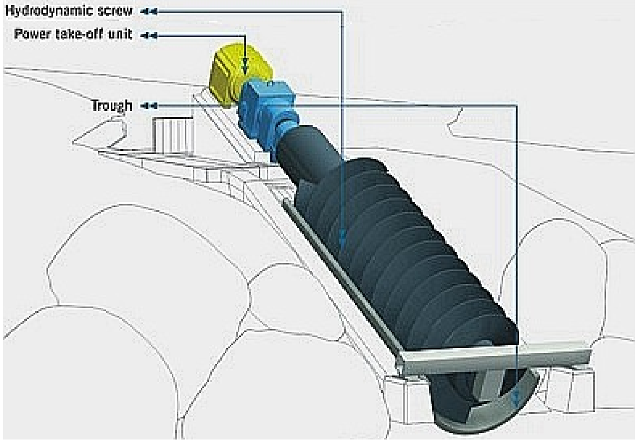


c. OPEN-FLUME FRANCIS

d. SPIRAL-CASE FRANCIS



e. PROPELLER / KAPLAN TURBINES

f. CROSSFLOW	**g. ARCHIMEDES SCREW**
	

8.4 Screening

8.4.1 Trash screens

The screen, or ‘trashrack’, filters out river-borne debris before it reaches the turbine. It is an extremely important component of the whole scheme, and can be one of the more expensive items. The large majority of operating problems and maintenance costs, especially on a low head / high flow scheme, can be traced back to the screening system. Therefore investment in a robust design will pay for itself in the long run.

The first line of protection can be a floating boom angled across the flow upstream of the intake. This will catch large items of floating debris before they reach the trashrack. However such debris will eventually make it under the boom unless cleared within a few days.

The standard screening solution, which has been used since the days of waterwheels, is to place a rack of bars in front of the intake, with the bars spaced so that a rake can be used to drag the accumulated debris up to the top of the screen.

The screen is a hindrance to the flow and introduces a slight head loss. Therefore the bar-spacing should ideally be the maximum that will still trap debris large enough to damage the turbine. The turbine supplier will advise on the correct dimensions. In addition, the flow velocity approaching the screen should be relatively slow, preferably less than 0.3 m/sec and certainly no greater than 0.5 m/sec.

8.4.2 Fish-screening

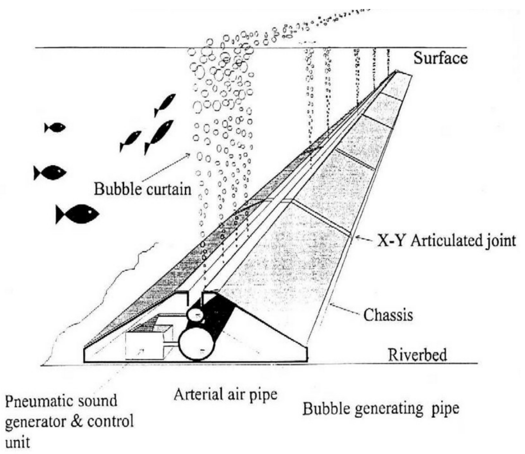
On rivers where there are important fisheries concerns, the Environmental Regulator will stipulate more stringent screening requirements to ensure that fish will be deterred from the turbine intake and will be diverted to a suitable by-wash. The precise fish-screening measures will be a matter for negotiation, depending on the sensitivities of the site and the most recent screening guidance.

The guidance issued by each national Regulator usually specifies the default bar-spacing they would expect to see in different circumstances. The Environment Agency have published a detailed guide to fish screening, referenced in Section 9.2.

Where there are salmon smolts migrating down-river, it is normal to require a fine mesh-spacing of 10 to 12 mm for at least 3 months in spring and early summer – unless the turbine is approved as 'fish-friendly'. A fine-meshed screen will accumulate large volumes of debris and an automatic cleaner then becomes essential to keep the turbine running.

A number of innovative methods for excluding fish from intakes have been trialled. These include the use of electric currents, bubble curtains and sound waves to guide the fish away from the intake. These methods offer significant advantages to the operator by avoiding any obstruction to the flow, but are less effective than a physical screen and are yet to find general acceptance with the Regulators.

The Bio-Acoustic Fish Fence (BAFF) uses a combination of air bubbles and sound waves to form a behavioural screen to guide fish away from hydro intakes.



8.4.3 Automatic cleaners

Manual raking is only viable for small schemes, or sites which are manned for other reasons. There are now a range of self-cleaning screens or automatic raking devices which clean the screen and dispose of the trapped debris. The most common types, illustrated in Figure 4, are as follows:

Robotic Rake
These come in a variety of designs, but usually involve one or more rakes, up to 3m wide, operated by a hydraulic ram. Some designs require only a single rake which can index along the screen; otherwise two or more rakes can operate side by side.

Grab-and-Lift Cleaner
This is a robust alternative to the robotic rake. A single set of heavy-duty 'jaws' indexes along the screen, pushing the debris down to the base of the screen when the jaws close. It then lifts the captured material vertically up, and along to a disposal area.

Rake-and-Chain Cleaner
A solid steel bar with low-friction pad is moved up the screen by a chain drive at each end. The bar deposits the collected debris in a channel running the length of the screen. The channel can be flushed clean by a water supply (pumped if necessary), washing the debris towards a side spillway.

Rotating Mesh Screen
This consists of a conveyer-belt system using a stainless-steel or plastic mesh with aperture from 10mm down to 3mm. The belt rotates as often as needed to keep the screen clean, dropping the debris into a trough along the top. The whole mechanism is compact and almost entirely below water.

Coanda screen
A Coanda screen is an 'overwash' screen whereby the flow runs down the face of the screen and drops through the finely spaced horizontal bars into a sump below which supplies the penstock pipe.

At least 0.5m of head is lost in this process, and the screen has a low flow capacity per metre of width, so it is only applicable for high and medium head schemes. However this screen requires no raking because the carefully profiled shape exploits the Coanda Effect to filter out and flush debris and silt particles downstream, allowing only clean water to pass through the bars, which have an aperture of between 1 and 2mm.

Tyrolean screen
A simpler type of overwash screen, this is suited to high and medium head sites which require a greater flow capacity, or cannot sacrifice as much as 0.5m of head.

The screen consists of a flat panel of bars, parallel to the flow direction and set at roughly 10º to the horizontal (a flat plate with 3mm circular perforations can also be used for very small abstractions). The aperture can be up to 10mm and the screen can extend downstream by over a metre if necessary, so a much greater flow can be abstracted for a given width. The screen is only partially self-cleaning so, depending on the site, does require some manual cleaning during the leaf season. Stopping the turbine will backwash up to half the screen, and is therefore the quickest means of clearing some of the debris.

The flow collected beneath an overwash screen is highly aerated, therefore a suitably-sized settling tank is usually required to allow the bubbles to disperse before the flow enters the penstock pipe.

Figure 4 : Screens and debris management

(a) Robotic Rake

(b) Grab-and-Lift

(c) Rake and chain

(d) Rotating mesh

(e) Coanda screen

(e) Tyrolean screen

8.5 Control Panel

The control panel is the black box which monitors the operation of the hydro scheme. The main functions of the control panel are to:

- Start up and shut down the turbine
- Synchronise the generator with the local network
- Correct the power factor of the generation to better than 95%
- Monitor the upstream water level and ensure it is maintained above its minimum value
- Operate the flow-control mechanism to match turbine abstraction to the availability of water
- Detect faults and activate warning or shut-down sequences

For grid-connected schemes, the control panel must conform to the G99 recommendations for the connection of embedded generators. In practice, this means incorporating an approved G99 relay which will respond correctly to different faults on the grid. (Very small plant, less than 3.7 kW per phase, only need to comply with a reduced set of standards defined under G98).

For the rare schemes which are not connected to the local network, but operate in isolation, the control system will also ensure that both the voltage and frequency of the generator remain within the allowable ranges regardless of the load being applied.

Remote monitoring and control

The widespread availability of low cost digital controls, combined with the mobile phone network, means that it is possible to set up even remote projects with real-time monitoring over the internet at reasonable cost. The status of the turbine and all sensors is then immediately available anywhere in the world that has an internet connection. Alerts or faults can be transmitted instantly by SMS or email for immediate attention.

It is also now common for all but the smallest projects to have some level of remote control, allowing the operator to stop or start the turbine, or make some limited adjustments, using only a smart-phone.

9. FURTHER INFORMATION AND ASSISTANCE

9.1 The BHA

The British Hydropower Association (BHA) represents the interests of all those involved in the UK hydropower industry. It promotes the use and awareness of small hydropower, organises training events and technical seminars, consults with the relevant government bodies, and lobbies to protect and promote its members' interests.

Membership of the Association is open to any company, organisation or individual with an interest in the use of waterpower. Members include manufacturers of all kinds of equipment used in the industry, civil, mechanical and electrical consulting engineers, utility companies, academic institutions, developers - large and small, individuals, charities and students - anyone who is interested in and keen to promote the use of hydropower.

9.2 Reference books

There are relatively few books that have focused on the issues relating specifically to small-scale hydropower; the most useful sources of information are listed below.

Readers looking for the hydraulic theory of turbines should examine traditional hydraulics engineering textbooks; although these are usually written with large-scale projects in mind, the basic theory for a small turbine is no different to that of a large turbine.

1. **Micro-Hydro Design Manual,** A.Harvey et al., IT Publications Ltd, London 1993.
   A comprehensive technical guide to small-scale hydropower, focusing mainly on projects <500kW. It covers the whole topic from initial site survey, through to equipment selection and installation.
2. **Micro-Hydro Power: a guide for development workers,** P.Fraenkel, O.Paish, V.Bokalders, A.Harvey, A.Brown, R.Edwards, IT Publications Ltd, London 1991 (reprinted 2001).
   A shorter manual covering all the important topics but without going into in-depth technicalities.
3. **Layman's guidebook on how to develop a small hydro site**. Published by the European Commission, 200 Rue de la Loi, B-1049 Brussels, Belgium, 1994 (out of print, but available as PDF).

   2-volume manual describing the steps to be taken in the development of a small hydro site in Europe.
4. **The Micro-hydro Pelton Turbine Manual**, Jeremy Thake, ITDG Publishing 2000.
5. **Going with the Flow: Small Scale Water Power**, Billy Langley, Dan Curtis, CAT Pubs. 2004
6. **Planning and Installing Micro Hydro Systems, a Guide for Designers, Installers and Engineers**, Chris Elliott, Earthscan 2014.
7. **Screening for Intake and Outfalls: a best practice guide**, The Environment Agency, 2005.
8. **A UK Guide to Intake Fish Screening Legislation, Policy and Best Practice,** Fawley Aquatic, Crown Copyright, Department of Trade and Industry, 1998.

9.3 Internet Links

Web-site for the **British Hydropower Association**:
http://www.british-hydro.org/

Environment Agency: Guidance for run-of-river hydropower development, Dec 2017
https://www.pla.co.uk/assets/lit13108-guidanceforrun-of-riverhydropowerdevelopment.pdf

SEPA: Guidance for developers of run-of-river hydropower schemes. Nov 2015
www.sepa.org.uk/media/383805/guidance-_for_developers_of_run_of_river_hydropower_schemes.pdf

NRW: Hydropower portal
https://naturalresources.wales/permits-and-permissions/water-abstraction-and-impoundment/hydropower/

NIEA: Guidance: Run of River Hydropower Schemes, April 2018.
https://www.daera-ni.gov.uk/publications/hydropower

The **National River Flow Archive**, containing river flow data from the UK network of over 1600 gauging stations:
www.ceh.ac.uk/data/nrfa/index.html

The Main River Map for England

https://environment.maps.arcgis.com/apps/webappviewer/index.html?id=17cd53dfc524433980cc333726a56386

The Main River Map for Wales
https://datamap.gov.wales/maps/new?layer=inspire-nrw:NRW_MAIN_RIVERS#/

9.4 Terminology

Abstraction Licence	Authorisation granted by the Environment Agency or NRW to allow the removal of water from a source (permanently or temporarily)
Bywash	A side-channel close to the inlet screen which provides safe downstream passage for fish
Capacity factor (also called ‘Load Factor’)	The ratio of energy output per year to the maximum output if the system runs at full rated capacity all year round.
Compensation Flow	The flow which must be left in the river at the point of abstraction, for ecological purposes. Also referred to as the ‘residual’, ‘reserved’, ‘prescribed’ or ‘hands-off’ flow
Fish Ladder (or Fish Pass)	A structure for allowing migrant fish to travel upstream past a dam or weir, consisting of a shallow ramp or a series of pools.
Flow Duration Curve	A graph showing the percentage of time that the flow at a particular river location exceeds a specific value.
Forebay	An open tank for slowing down the incoming flow and settling out silt and gravel before the flow passes into the penstock.
Gauging Station	A site where the flow of a river is measured.
Gross Head	The difference between the upstream and downstream water levels.
Headrace, Leat or Lade	An open channel that conveys water at a shallow gradient from a watercourse to the turbine forebay tank. (Also sometimes called Goit or Contour Canal).
Impoundment Licence	The authorisation granted by the Environment Agency to permit changes to structures which impound water, such as weirs and sluices, or if new structures are to be built.
Installed Capacity	The total maximum output (kW) of the generating units in a hydropower plant.
Kilowatt (kW)	Unit of power, equal to 1000 watts
Kilowatt hour (kWh)	Unit of electrical energy, equal to the electricity supplied by 1 kW working for 1 hour. 1 kWh = 3,600,000 Joules
Net Head	The pressure head available to the turbine after friction losses through the intake, pipeline and trash rack.
Output	The amount of power (or energy depending on definition) delivered from a piece of equipment, station or system.
Penstock	A pipe (usually steel, concrete or plastic) that conveys water under pressure from intake to turbine.
Sluice Gates	A vertical shaft slide gate, which can be operated either manually or by electric motors (there are other types).
Spillway	A controlled discharge of excess flow back into the river.
Tailrace	The channel that takes flow away from the turbine outlet
Trashrack	A protective screen that prevents large branches, tree trunks and other debris from entering and damaging the turbine. It usually consists of vertical bars spaced between 30-100 mm apart. The screen is typically cleaned by an automatic rake which removes the debris, either to a platform or to be flushed into the river.
Turbine	A machine converting the speed and/or pressure of flowing water into rotational energy.
Weir	A low dam which is designed to provide sufficient upstream depth for a water intake while allowing flow to pass over its crest.