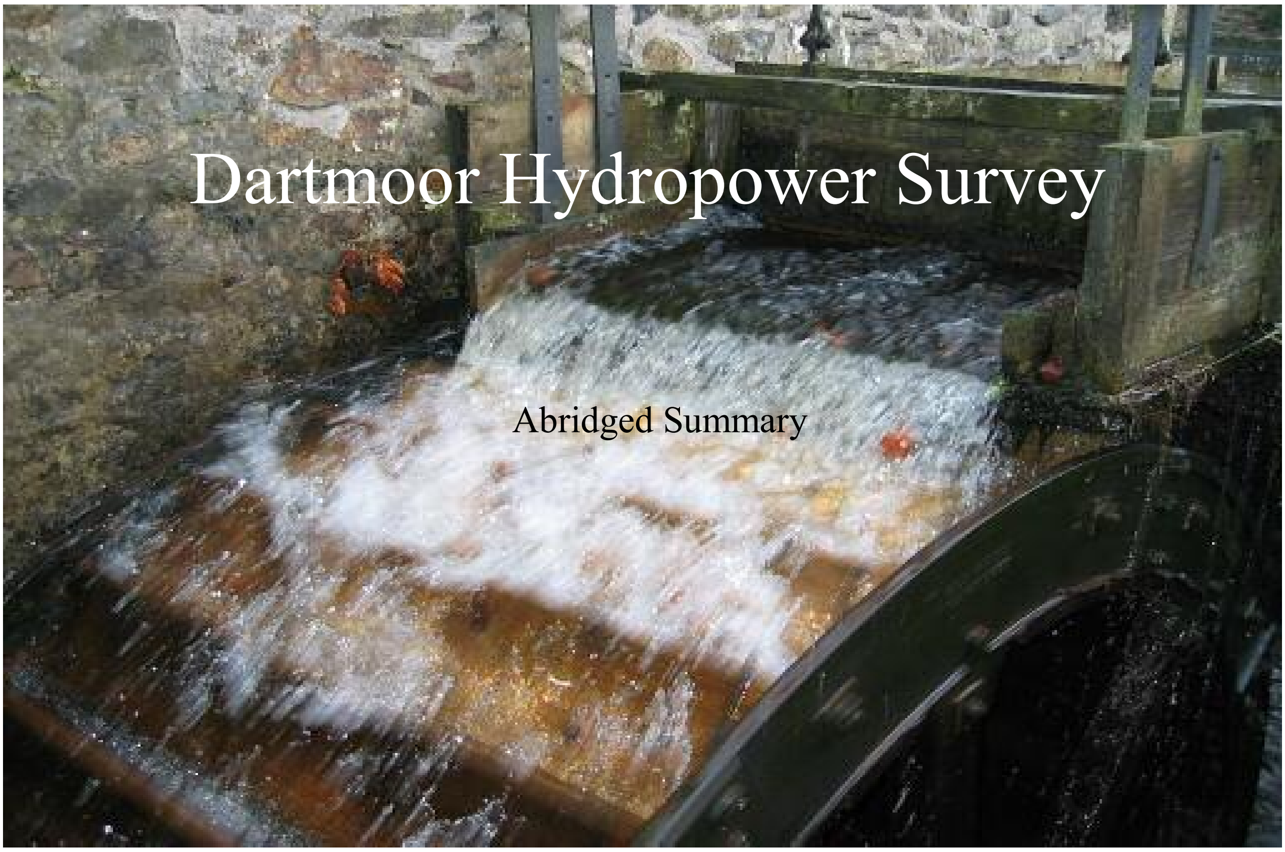
Dartmoor Hydropower Survey

Abridged Summary



The Dartmoor Hydropower Survey reviews

- The hydropower potential of Dartmoor waterways
- Hydro-generation equipment and costs
- Environmental issues
- Legislative issues

Background

Historically Dartmoor had a large number of water mills operating both within the mining and agricultural industries. Most of the old mill sites have long since fallen into disrepair many having disappeared altogether. A few sites still exist some with their original equipment insitu, one is currently being restored and a small number have been adapted to generate electricity.

The large number of abandoned sites is a good indicator of where hydropower may be found and may offer opportunities to re-use existing civil infrastructure for modern turbines.

In the 1980's the then Department of Energy, commissioned Salford University to conduct a UK wide survey of hydropower potential. Their results were published in 1987 by ETSU.

The Centre for Environment and Hydrology has developed a computer-modelling programme called 'HydrA' which combines rainfall data from the Meteorological Office and soil type information on a 1-kilometre grid system matching the Ordnance Survey grid.

The Mills Archive Trust maintains a database of all historic mill sites.

Drivers

There is not room here to rehearse in full, the case for renewable energy – it is assumed the reader acknowledges the need to mitigate environmental pollution due to burning fossil fuels and to develop alternative energy sources to reduce our dependency on foreign sourced energy.

The Government has set targets for renewable energy generation (electricity) and indicated the regions are expected to contribute, where appropriate. Dartmoor, by virtue of its elevation, receives above average wind and rainfall making ideal for both wind turbines and hydropower. Wind turbines are not considered appropriate for the open area of Dartmoor because of their visual impact on the landscape – hydropower is regarded as one of the most environmentally benign of all renewable energy systems and therefore the preferred option for Dartmoor. The question then became;

- How much hydropower is there on Dartmoor
- Where is it
- How best to exploit it having regard to its environmental impact and cost effectiveness.

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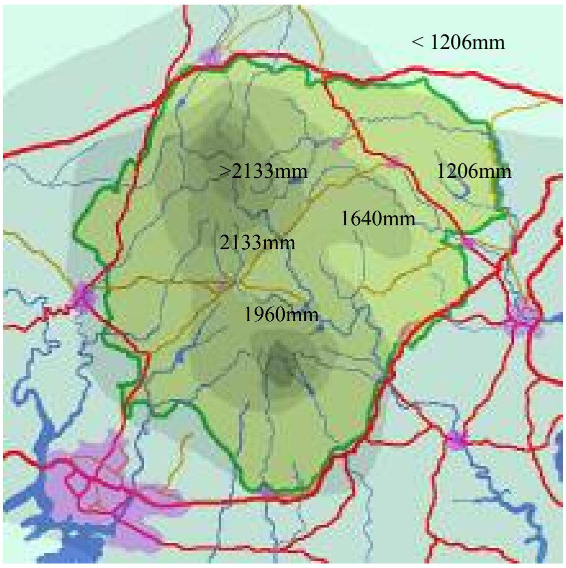
Methodology

An advisory panel was set up and included representatives from; Dartmoor National Park, The British Hydropower Association, the Environment Agency, the University of Plymouth and the Dartmoor Society. Using information from all sources, many of the historic and existing sites were visited. Contact was made with mill owners and a large number of site surveys were carried out and reports prepared.

The blue dots represent the old mill sites; the green dots - the existing abstraction licences (mainly for agricultural purposes).



The average annual rainfall on Dartmoor varies between 1206mm to over 2133mm on the highest parts of the moor (over 500m) and most of the main river systems on Dartmoor rise in the areas of highest rainfall.

Hydropower

Hydropower exploits the completely natural process of the ‘hydrological cycle’. Energy from the sun warms the oceans where water evaporates to form clouds which the wind then blows over land. The water vapour falls as rain on high ground, some of the rain is absorbed by plants to either become plant material or be transpired as water vapour again. Some rain soaks into the ground to issue as ‘springs’ elsewhere and some runs off to form streams and rivers which flow back to the sea. The whole process is powered by the sun and is infinitely repeated.

Flowing water has energy in it by virtue of its mass and the fact that gravity accelerates the water as it flows downhill. The power contained in flowing water can be expressed by;

Power = Mass x Height through which it falls x Gravity x the efficiency of the equipment.

To get the power output in kilowatts (kW), mass is measured in (Q)cubic meters per second (m^3/s), height (H) is measured in meters (m), gravity is a numerical constant (9.8 m/s^2), efficiency is a numerical constant for a particular turbine and generator set. The power equation can be simplified to;

$$P = 5 \times H \times Q$$

This is a slightly conservative value. In a well designed system, where the most efficient equipment is used, it should be possible to achieve;

$$P = 6.9 \times H \times Q$$

This is the level of output that should be aimed for but the slightly lower figure has been used to base the cost effectiveness of hydro-generation.

The power output is the product of both the rate of flow and height through which that flow falls. To achieve a good output either the head or the flow or both needs to be a reasonable figure. In reality the head will be fixed by the topography of the land and the flow by the size of the catchment area, the rainfall within the catchment and the losses due to evaporation.

A good hydro site may have a high head and low flow or a low head and high flow or any combination between. The most economic sites to develop will have both good head and a good flow. However recent developments in turbine design are improving the prospects for sites that were formerly considered un-economic to develop. The most ecologically sound sites tend towards the high head - low flow end of the spectrum as a good output may be achieved without depleting the mainstream of too much water. Low head sites need to use a significant flow to achieve a good output, however various methods can be used to mitigate any potential environmental damage.

How much Hydropower is there on Dartmoor?
If you; assume a figure for the average rainfall across the area, assume an average height above sea level, deduct the flow abstracted for drinking water purposes, consider soil and vegetation types to determine other water losses, it is possible to calculate a technical gross output. But such a figure will bear little relevance to an output that is both practical and economic. Looking at each river in turn and calculating the catchment area at periodic points along its length will offer a better estimate of how much power is available at that point. But knowing what power is available at a given point along the river does not necessarily imply that power can be used productively there or be economically exported to the gird. Consideration must be given to how the power is to be used; ie

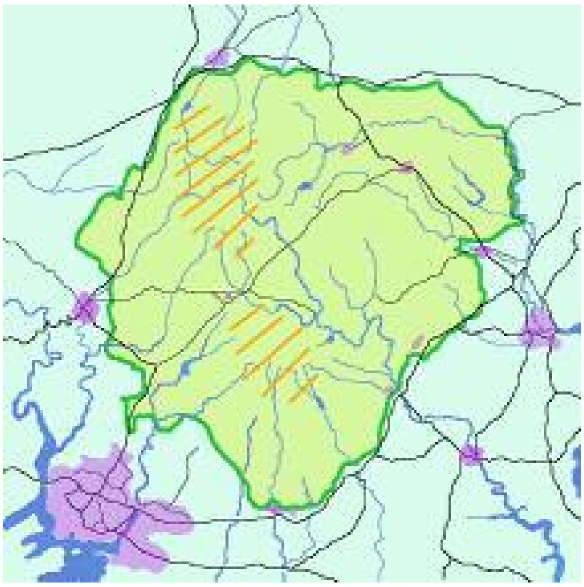
- Exported to grid to provide an income
- Used on site to offset mains power
- Used on site to replace a diesel generator
- Used on site where no power formerly existed

The economics of each scenario will be different so the viability will vary. Ultimately the amount of hydropower available on Dartmoor will be determined by the economics of its use. It seems reasonable to assume large commercial companies may develop the larger sites and export the power to grid. The smaller sites may be developed by individual landowners either for their own use or to offset mains power. The intermediate sized sites may fall into either category.

Site Description	Installed capacity (kW)			
Number of sites	14	14	22	26
Capacity (kW)	>100	25-99	5-24	<5
Existing capacity.	2835	293	34	2
Salford undeveloped	166	253	119	4
Dartmoor Hydropower	1210	112	133	37
Total 6700 kW	**5711**	**658**	**286**	**43**

These figures are not prescriptive. It is reasonable to assume that most of the large (>100kW) sites have been identified, however it is highly probable there will be many more small (<5kW) sites yet to be identified. The limiting factor for the small sites will be the continuing development of low-cost solutions to enable small sites to be economically viable.

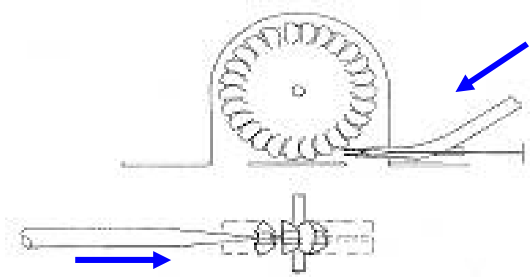
Where is it?
Essentially hydropower is available anywhere water flows but both economic and environmental factors will influence where it is practical to harness the power. Hydropower depends upon the head and the flow; we know the very highest ground receives the most rain but at the very highest reaches of a river the catchment area is at its smallest so the volume of water that has accumulated remains low. It is therefore impracticable to harness hydropower on high Dartmoor indicated by orange hatching on the map below.



This happily coincides with the more remote and wild areas of Dartmoor, which should be left untouched. Other areas where hydropower is not appropriate is on stretches of rivers that include spawning grounds for migratory fish.

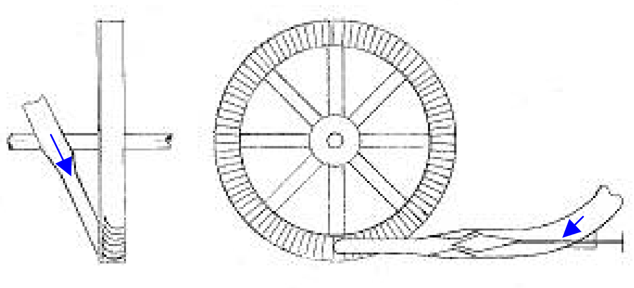
How best to exploit hydropower
There are a number of different turbine types, each having power output characteristics that make a particular turbine more appropriate in a given situation. Some turbine types are more complex than others and therefore more expensive to manufacture. Choosing the correct turbine is a process of balancing the best technical solution against the cost.

<u>The Pelton Wheel</u>



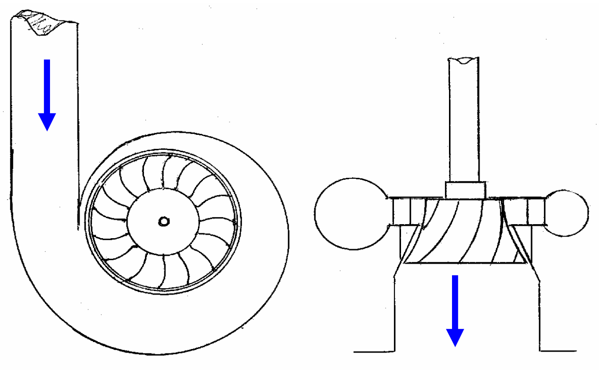
Water flows down a pipe and through a jet which is directed at cup shaped blades around the circumference of a wheel. The force of the jet causes the wheel to rotate which in turn drives a generator. Pelton wheels are suitable for high head sites.

The Turgo



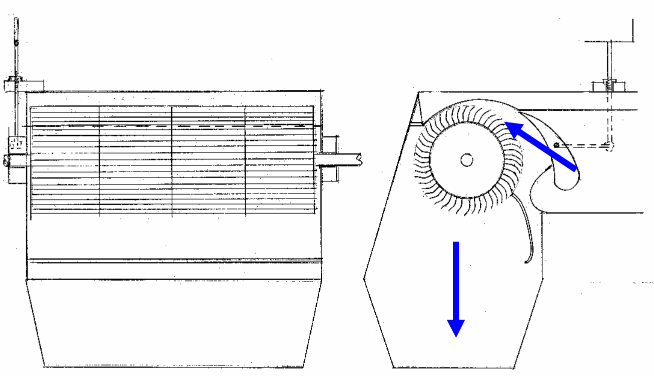
Water flows down a pipe and through a jet that is directed at curved shaped blades around the circumference of a wheel. The jet is deflected by the shape of the blades causing the wheel to rotate and driving a generator. Turgo's are suitable for high and medium head sites.

The Francis Turbine



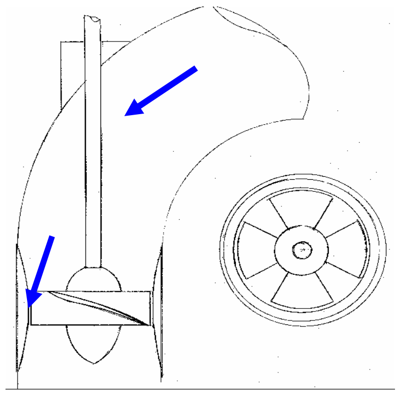
Water flows into a circular casing (a bit like a snail shell) and is directed onto a runner with curved blades. The spent water flows out the bottom. The Francis turbine is suitable for medium to low head sites.

The Crossflow Turbine



Water flows down a pipe into a runner with a large number of curved blades placed around a hollow cylinder. The water flows through the first set of blades where some of the energy is given up to the wheel, the water flows through the centre of the hollow cylinder and through the blades on the other side where the remaining energy in the water is given up to the wheel. Crossflow turbines operate across a range of heads and are relatively easy to fabricate so offer a very cost effective solution.

The Kaplan Turbine



Water flows through a pipe with what is effectively a propeller housed within it. The flow causes the propeller to turn. The pitch of the blades is adjustable to accommodate changes in flow. Kaplan's and the simpler (Propeller) version with fixed pitch blades operate best at low head sites. The mechanism to control the pitch of the blades adds to the complication and hence cost of Kaplan turbines.

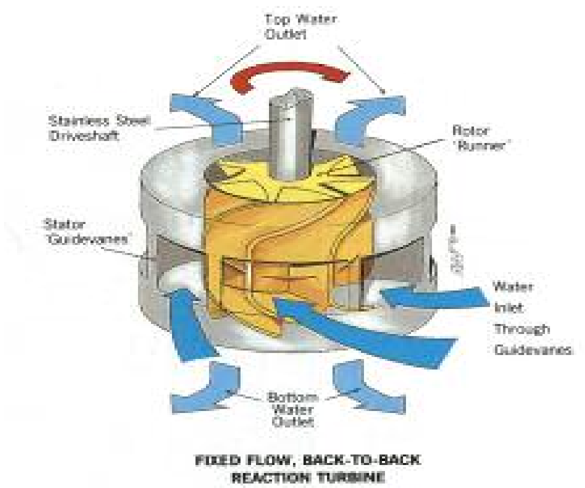
Historic water wheels still have a place in power generation. Where mechanical power is needed the traditional water wheel can function very effectively. Water wheels are less efficient than turbines and the power equation needs to be revised (P = 2 x H x Q) is more appropriate. For electricity generation, water wheels rotate too slowly so need to be geared up to increase the speed of rotation. The main issue with water wheels is regulating the speed within the fine limits necessary to maintain the frequency of the current. However water wheels are aesthetically pleasing and may, in some circumstances, get planning permission where a modern turbine may not. The slower speed of water wheels may allow the passage of some migratory fish species without harm, whereas modern turbines are not fish friendly at all.

Equipment review
In addition to the traditional turbines described above a number of modern innovations are now available.

Derwent Hydro has developed a siphonic turbine designed for installation on existing weirs. The turbine fits on the face of the weir with a suction tube in the water at the upper level and a long draft tube leading down to the lower water level. Suction is applied to lift the water over the lip into the draft tube that has a propeller turbine fitted inside. The generator is mounted above the casing

To stop the turbine the vacuum is broken by opening a valve. The siphonic turbine can be fitted to any existing weir with between 1 and 3 m head and can supply between 5 to 100 kW.
Contact; jon.needle@btinternet.com

Hydro Generation Ltd has developed an injection moulded plastic Francis turbine for use in low head sites.



The plastic turbine is made in three sizes to accommodate a range of flows and offers a cost effective solution for low head sites.
Contact; www.hydrogeneration.co.uk
Powerpal is a Canadian company with a UK representative. They manufacture a range of low power - low head turbines primarily for use in the developing world but eminently suitable for low head sites in the UK.

The range includes 200w, 500w and 1000w models and operate on a 1.5 m head.
Intended for installation in remote locations, the sections are easy to carry and require minimal civil infrastructure.
Contact; www.powerpal.co.uk

Stream Engine is also a Canadian low power device but capable of using a higher head with very low flows.

A small pelton wheel is mounted on a vertical shaft under the white cover. Water is piped to the inlets shown (either one or both if enough flow). The generator is seen on top and the control box in the front.
Contact e mail; sales@gotsolar.com

Valley Hydro is a Cornish company that manufactures a range of crossflow turbines. The smallest being the Pico 100 (below) ranging up to

machines capable of accommodating 1000ltr/sec (below) operating from 5 to 50 m head.

Contact; valleyhydro@lineone.net

Case Study

The case study shows a modern installation on Dartmoor where environmental mitigation was high on the priorities and the site is a finalist in the Ashden Awards for environmental excellence. The intake weir controls the flow of water to comply with the abstraction licence and to allow water borne grit to settle.

The flow continues along a 500m leat measuring

2m wide by 1m deep to provide a slow flowing water course that is ideal for fish breeding. 5 mature trees in the way of the leat had to be felled but 800 hardwood saplings have been planted to offset this. An area of low-lying grassland has been allowed to revert to nature to improve diversity.
The leat terminates at a penstock where an automatic screen removes any floating debris such as leaves. The screen, shown below, comprises a stainless steel wire link mesh with a 8mm gap to prevent fish being sucked into the turbine intake.

The penstock is a 700mm diameter buried steel pipe that takes the water down to the turbine house.

Two crossflow turbines allow the option to use one or the other or both depending upon the available flow in the river. At maximum flow 90kW of electricity is generated and exported to the grid via a control panel and metering panel.

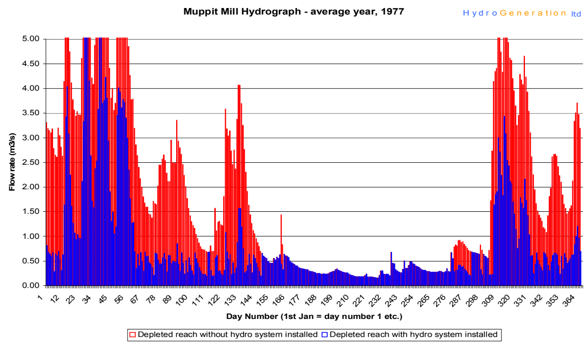
The output is monitored remotely by microwave link. The scheme was built as part of a farm diversification programme; it paid for itself in 5 years and now generates more income than the traditional farming practices.
Contact: mr.and.gr.fursdon@farming.co.uk

Environmental issues

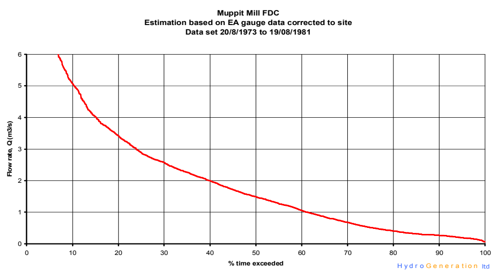
Although hydropower is considered the most benign of all renewable energy technologies, it still has an environmental impact.

- Water is abstracted from the main stream and diverted through a turbine. For the duration of the abstraction the main stream is depleted.
- The water quality can be altered as some turbine types aerate the water and some remove air.
- Weirs can alter the height of the flow changing water levels and changes to plant growth beside the river with consequent implications for flora and fauna.
- Both migratory and indigenous fish species may get drawn into turbine intakes or swim up the tailrace.

All the environmental issues can be mitigated against by a well-designed system. In almost every case an 'Abstraction Licence' will be required. The Environment Agency has a duty to maintain the health of rivers and will determine whether an application for abstraction will be permitted or not. If a licence is issued the EA will dictate the level of abstraction and have the power to shut a scheme down if water levels fall too low. Preparatory to applying for an abstraction licence it is usual to collect twelve months flow data at the proposed site.



The graph shows the daily flow rate over 365 days and shows how flows vary in response to rain storms over the seasons. From this information a Flow Distribution Curve is produced. The FDC is



plotted as a percentage of time over which a certain flow rate is exceeded. i.e. for 95% of the year, the flow will exceed a certain volume. This figure is important, and is known as Q^{95}, it is used by the EA to work out the safe minimum flow rates to be left in the river. [During 2004 the implementation of the Water Framework Directive is likely to revise this figure and it is believed that permissible abstraction flows will be reduced]

Apart from the environmental issues, the Q^{95} figure is important to work out the best size of turbine to install. Examination of the daily flow chart shows that on some days the river has a very heavy flow rate but for a period in the summer the flow is much reduced. If a developer were to install a large turbine suitable to accommodate the winter flow rates, that turbine may not function at all during the summer when flow rates are low – an expensive mistake. A turbine designed to function on lower summer flow rates will operate all year round but will not be able to capitalise on the heavier flows of winter. A compromise may be to optimise the size so it can operate for 80 – 90% of the time.

Care will be needed to ensure any alteration to the flow regime in the river does not cause flooding.

Planning

Large hydro schemes may require huge dams and flood large areas of land. Micro-hydro schemes do not present the same problems but still need to comply with planning. Developers will need to ensure any proposals are well designed and fit as unobtrusively into the landscape as possible. Noise minimisation and screening of the turbine house, power cables and pipelines all need to be considered.

Grid Connection

Grid connection is a very technical subject and is mentioned here simply to raise awareness of the issue. If electricity is to be exported to the grid the power distribution company responsible for the national grid will insist that all equipment connected complies with stringent standards to ensure public safety and protect the integrity of the supply network.

Power Purchasing Agreements

The legislation governing power purchasing has changed a number of times over recent years. As part of its policy to promote renewables the government introduced the Non Fossil Fuels Obligations (NFFO) which offered producers a higher rate for their energy. This has been replaced with Renewable Obligation Certificates (ROC's) which has extended the scheme. Energy Services Companies are obliged to source a % of the energy they supply to customers from renewable sources and will purchase from smaller energy generators.

Economics

Most of the costs associated with developing a hydropower site will be the capitol needed to design and construct the site; there will also be an ongoing maintenance cost. However a well-designed site should function for 30 – 40 years before needing major refurbishment. During this time the site will generate pollution free energy, which may be sold. Every development is site specific but development costs are likely to be in the range of £1,500 to £4,500 per kW of installed capacity. The purchasing price of electricity will vary over time but currently the government is making additional funds available through the ROC's scheme to offer developers a premium with a view to encouraging installations.
Over the lifetime of a hydro scheme it should be possible to earn many times the scheme's initial start up costs.

Developing a Hydro Scheme

Early contact with both your local Environment Agency and Planning Department is recommended. Government guidelines encourage both authorities to take a positive approach to renewable energy and this can identify insurmountable problems before the cost of a full feasibility study is incurred. Assuming there is no major problem the two most crucial points are head and flow – both of which need to be measured to get an idea of how much power may be available. Most land owners will have an idea of how much height fall they have access to across their land, most will have anecdotal evidence of winter and summer flow rates but it is rather more difficult to accurately assess what % of time a given flow rate is exceeded in order to work out an appropriate turbine size and estimate of annual power output. These figures are important to enable a potential developer to work out if a scheme is likely to be economically worthwhile and for this you are most likely going to need the services of a professional hydro-engineer or consultant. Most reputable hydro-engineering companies will offer a low cost initial assessment.

Useful contacts

Environment Agency
Tel: 08708 506506 (ask for Regulatory & Technical - Water Resources)
Web: www.environment-agency.gov.uk
British Hydropower Association
Tel: 01202 886622
Web; http://www.british-hydro.org

The Mills Archive Trust
Ron Cookson Chairman
The Mills Archive Trust, Watlington House, 44 Watlington St, Reading RG1 4RJ

Devon Association for Renewable Energy
12a, The Square, North Tawton. Devon
EX20 2EP Tel: 01837 89200
Web: www.devondare.org

The full report includes sections on the theory of hydropower, six case studies - covering a range of scenario's, an extensive review of the abstraction process and legislation, a review of hydropower equipment and a directory of designers, installers and suppliers. A full copy of the Dartmoor Hydropower Survey may be down loaded free of charge as a PDF from D.A.R.E.'s website. The full document is 118 pages and the file size is 16.4 MB. Alternately a hard copy of the full report can be purchased from D.A.R.E. for £10.00 incl. Postage. D.A.R.E. has developed a low cost initial hydropower assessment package to assist potential site owners.

About D.A.R.E.

D.A.R.E. is a company limited by guarantee promoting greater production and use of Renewable Energy and delivers the Community Renewables Initiative (CRI) for Devon and Cornwall. It is able to offer advice on all aspects of renewable energy technologies.

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