FOREST OF BOWLAND
Area of Outstanding Natural Beauty

Micro Hydro Feasibility Study

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Inter Hydro Technology
October 2011

Introduction

Inter Hydro Technology (IHT) have been commissioned to undertake a feasibility study for small-scale hydropower generation at sites within the Forest of Bowland Area of Outstanding Natural Beauty (AONB), as well as areas of the Ribble Valley and Lancaster and Pendle boroughs, which lie outside the AONB boundary. The project steering group have specified 30 sites for the study and a further 5 sites have been identified by IHT.

The purpose of the study is to support local landowners, investors and community groups with a source of site-specific information on hydropower development. It is intended that this report shall also provide useful reference material for organisations required to assess new developments, such as Local Planning Authorities, the Environment Agency, Natural England and English Heritage, as well as other consultant bodies.

The study is separated into two stages, representing different levels of detail. Stage 1 includes pre-feasibility detail and covers all 37 identified sites. Stage 2 includes full feasibility detail and is conducted on 5 out of the 37 sites, which have been identified as most favourable in terms of economic viability and suitability for development within a protected environment.

This report is divided into the following sections:

- **Section A** presents general information relating to all hydropower developments
- **Section B** presents the results of the Stage 1 study for the total 37 sites
- **Section C** presents the results of the Stage 2 study

For Stage 1 sites, a site visit has been conducted to identify preliminary locations for the major scheme structures, as well as potential access and construction issues. A desktop study, incorporating gauged hydrology data, has been used to determine the catchment area, annual rainfall and the annual flow duration within the river. A suitable turbine has been identified, and estimates have been made for power capacity, the annual energy production and the annual CO_2 offset amount. A budget development cost has been calculated, based on current equipment costs and an assessment of the required civil works. Finally, the annual generated electricity and simple payback period have been estimated.

For Stage 2 sites, a comprehensive site assessment has been conducted, including a levelling survey and investigation of any existing hydraulic structures. The turbine type and performance have been verified. Details of the electricity export connections have been established. Estimates have been refined for budget costs, electricity output, revenue and simple payback. The Environment Agency has been approached to comment on outline agreement for development and an indication of environmental assessment requirements. Finally, recommendations for further work have been made, as well as contact details for companies providing suitable services to take each hydropower development forward.

Section A: General Information

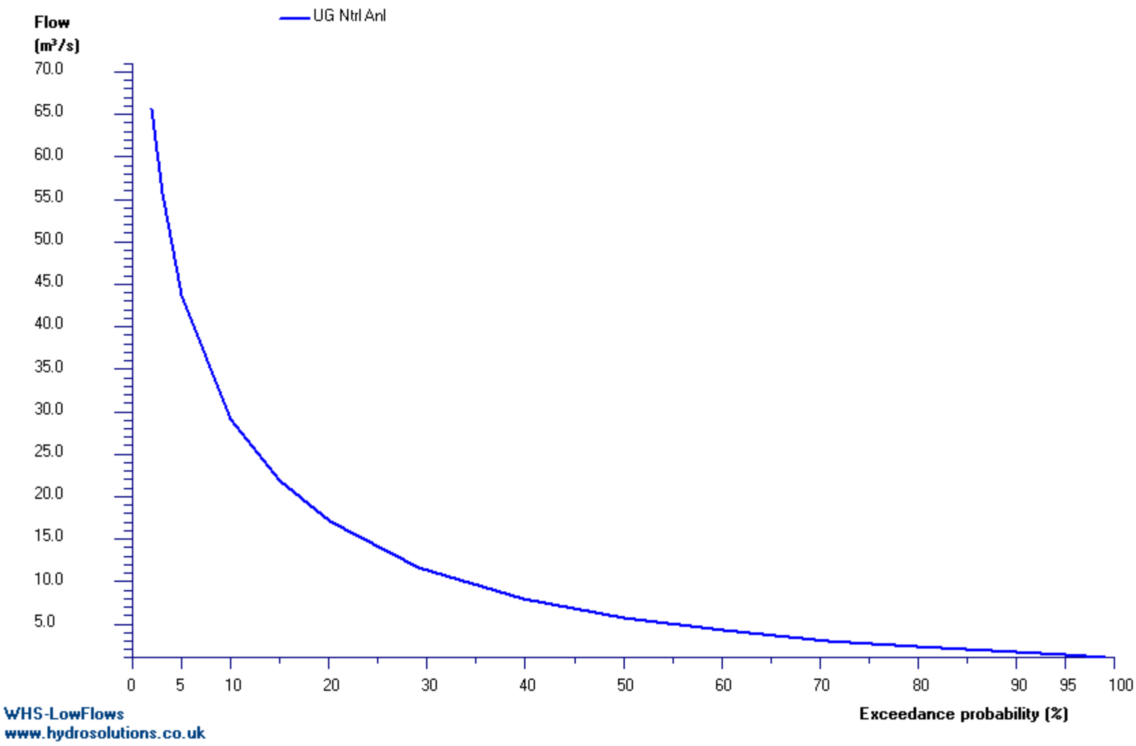
Hydropower

All hydropower schemes depend first and foremost on determining the viability of a particular site. Fundamentally, the two primary requirements are a readily available fluid flow, in combination with an adequate vertical change in elevation, referred to as 'gross head'. The hydraulic power available at a particular site is proportional to the product of flow and head. A waterfall or weir structure within a watercourse is a promising starting point for a hydropower feasibility study.

Flow

The flow rate within a watercourse can vary considerably depending on the frequency, intensity and volume of rainfall, as well as the catchment characteristics, such as size, topography and ground porosity. It is common to demonstrate the annual variance in flow at a particular point on a watercourse, using a flow duration curve (FDC), which plots flow against exceedance probability. Figure 1 shows a flow duration curve produced using LowFlows software. A particular notation is used to refer to FDC flow rates; e.g. 'Q95' refers to the flow rate which is exceeded 95% of the year. LowFlows is industry standard software used by the Environment Agency of England and Wales, as well as the Scottish Environment Protection Agency.

Figure 1 Flow duration curve produced using LowFlows



The variance in watercourse flow, in combination with the performance characteristic of the turbine, affects the annual energy production of a scheme. Further constraints can be applied by a variable abstraction regime specified by the relevant licensing authority, such as a 'hands-off flow' (minimum flow remaining in the depleted reach of the watercourse) serving to protect the ecology. The performance characteristic of the turbine is dependent on the type of turbine, as well as the 'start-up flow rate' and 'design flow rate'.

A steep flow duration curve indicates a 'flashy' watercourse, where there is wide and frequent variation in flow. Conversely, a shallow curve demonstrates that flow rate is relatively consistent. This condition is good for a hydropower scheme as it facilitates a high capacity factor – ratio of average annual electrical energy production and theoretical annual electricity production were the scheme to operate at full power capacity continuously.

The Environment Agency of England and Wales (EA) have published *Good Practice Guidelines for Hydropower*, which provides default acceptable values for turbine design flow and hands-off flow. These values are dependent on the length of the depleted reach of river and on the Base Flow Index (BFI). The BFI provides an indication of how widely flow in a watercourse varies and is estimated by the EA as the ratio of Q_{95} and Q_{mean}.

Head

Whereas 'gross head' refers to the difference in elevation (in metres) between the intake and outfall, the 'net head' refers to the head directly across the turbine. That is, the gross head minus any head losses.

The vertical head difference may be the operational head on some machines where there is little or no conveyance channel or pipe between the abstraction and return points for the water. More typically however there will be a channel or pipe between these two points. Friction between the flowing water and the walls of the channel or pipeline result in a loss of head. The design of the scheme should result in less than ten per cent of the vertical head difference being lost to friction.

Electricity Generation

Turbine Types

As water passes through a hydraulic turbine, hydraulic power is transferred to shaft power by a prime mover, commonly referred to as a 'runner'. The runner can incorporate blades, vanes or buckets, which are forced to rotate around a central axis. The runner shaft is coupled to a generator which converts shaft power into electrical power. There are a number of different designs of commercially available turbines, each with varying geometry and performance.

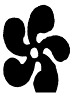
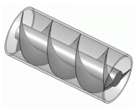
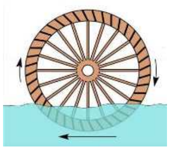
It is well established convention to group these turbines into two main categories: 'impulse turbines' and 'reaction turbines'. These names are not particularly descriptive and the defining difference is that with an impulse turbine there is no change in static pressure across the runner. It is also a common feature of reaction turbine runners to be wholly immersed in the fluid flow, as opposed to an impulse turbine where a jet of fluid strikes the runner. There are, however, some turbine designs that do not fit comfortably within these categories, notably the classic water wheel. A list of commercially available turbines is included in Table 1.

Turbine Selection

Each turbine has a unique performance characteristic, which equates to the variance in efficiency of the machine when operating under different head and flow conditions. Selecting the optimum turbine type and power capacity for a specific site is an extensive process requiring comparison of the maximum annual net benefit (annual benefit minus annual cost) associated with a number of design variants. A complete evaluation would require determination of the capital costs, operational costs and borrowing costs associated with each variant – where variation would cover many aspects including design flow, gross head and turbine type. At the feasibility stage, a simpler approach is taken to establish a good solution without incurring large design requirements. This approach is as follows:

1. Intake and outfall positions on the watercourse are selected using hydropower engineering experience to predict a suitable trade-off between maximising gross head across the scheme and avoiding undue capital costs. There are also additional costs from the potential project obstacles, including dealing with multiple landowners, working in sensitive habitats, and completing construction works within a short permitted in-river works period.
2. Plant power capacity is maximised by selecting the maximum design flow rate that can be expected to be licensed by the Environment Agency. This serves to exploit the well established rule that larger schemes benefit from scales of economy, thereby improving the cost per kilowatt installed capacity. Furthermore, within the range of the Environment Agency's good practice guidelines for design flow rate, maximising flow rate will invariably result in maximised annual average energy generation.
3. Once the head and design flow rate have been determined, the software HydrA, developed by the Institute of Hydrology, is used to identify turbine types with applicable efficiency characteristics under these site conditions. Figure 2 is produced using the HydrA software and shows the application range for several commercially available turbines. Using inputted catchment descriptors, HydrA produces a performance report showing the capacity and average annual energy production for each turbine type. The turbine type providing the most energy is selected as the basis for average annual revenue and capital cost estimates.

Table 1 Commercially available hydraulic turbines

Type	Description
Pelton Wheel 	Impulse turbine named after early developer, Lester Pelton. Utilises one or more high velocity jets directed tangentially onto runner buckets.
Turgo 	Impulse turbine that utilises a high velocity jet imparted at an angle to the face of the runner. In comparison to the Pelton Wheel, this orientation allows for a larger jet and higher rotary speed; however, efficiency is reduced.
Cross-flow 	Impulse turbine, also known as a Banki or Michell turbine, where the water jet crosses through the runner vanes twice. A draft tube creates sub-atmospheric pressure in the runner housing. The cross-flow can achieve higher running speeds than the other impulse type turbines.
Francis 	Mixed-flow reaction turbine with flow entering the runner in the radial direction and leaving in the axial direction.
Propeller 	Axial-flow reaction machine with fixed runner blades.
Kaplan 	Axial-flow reaction machine with adjustable runner blades and guide vanes allowing improvement of part-flow efficiency.
Semi-Kaplan 	Axial-flow reaction machine with adjustable runner blades and fixed guide vanes.
Archimedes Screw 	Fish friendly turbine which turns slowly and generally requires the addition of a gearbox to increase generator shaft speed.
Water Wheel 	Classical design developed from early industrial application and generally requires the addition of a gearbox to increase the generator shaft speed.

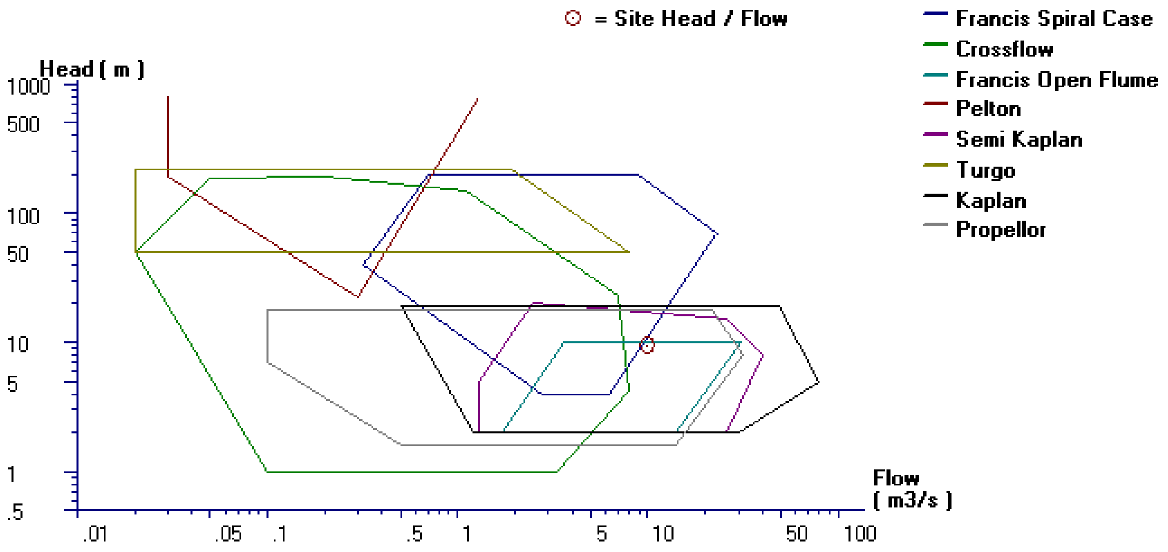


Figure 2 Application range for common turbine designs

(excluding Archimedes screw and waterwheels – not strictly turbines in this sense)

It is important to note that maximising annual net financial benefit, within the limits of appropriate environmental consideration, is not always the most suitable approach for turbine selection. If a project concerns the restoration of an existing water mill, then the aesthetics of the solution may dictate that a waterwheel is used rather than any other turbine type. Run-of-river schemes (i.e. negligible water storage capacity) may have to make use of turbines that pose less of a risk to fish populations. Often there will be more than one turbine type that could be used, quite justifiably, on a particular project.

Annual Carbon Dioxide Offset

To calculate the annual amount of carbon dioxide offset by the production of hydropower generated electricity, it has been assumed that the demand for grid electricity is reduced by the amount generated by the scheme. It is also assumed that hydropower generated electricity incurs no carbon dioxide cost. Consequently, the annual offset amount is equal to the annual energy output multiplied by the carbon dioxide emission from the UK national grid per kWh of electricity used at the point of final consumption (i.e. electricity grid transmission and distribution losses are included). Based on the most current greenhouse gas conversion factors published by the Department for Energy and Climate Change (DECC), this is equal to **0.54284kg CO_2eq per kWh**.

Revenue and Feed-In Tariffs

Revenue values are based on the annual energy output, in kWh, calculated using HydrA for each site under consideration.

For individuals, communities and businesses interested in generating their own electricity from small-scale hydropower, the government has increased potential revenue and improved the rate of return on investment through the Feed-in Tariffs scheme (FITs). The government believes the scheme, launched on 1 April 2010, will trigger a revolution of small-scale electricity by providing "clean energy cash back". This cash back will predominantly be in the form of two guaranteed tariffs, although additional value can be achieved:

- **Guaranteed Generation Tariff:** This tariff is received regardless of whether the electricity is used on site, or exported to the grid. The size of the generation tariff is dependent on the rated power capacity of the scheme, details of which are provided in Table 2
- **Guaranteed Export Tariff:** If the electricity is exported off site, then the generator can choose to receive an export tariff of 3p/kWh, or sell the electricity on the open market (typically 4.5p/kWh as of early 2011). Generators can choose annually whether to accept the 3p/kWh price floor, or negotiate an alternative tariff with energy suppliers
- **Additional Value (On site usage):** If the electricity is used on site, then import costs are offset, which can typically be much larger than the achievable export tariff
- **Additional Value (Levy Exemption Certificates):** The Climate Change Levy (CCL) is a charge on non-domestic supply of electricity, at a current rate of 0.47p/kWh. The Climate Change Levy (General) Regulations 2001 provide for an exemption from this levy for renewable electricity. Renewables Levy Exemption Certificates (Renewables LECs) are electronic certificates, issued monthly by OFGEM to accredited generating stations for each Megawatt/hour (MWh) of renewable source electricity generated. These certificates can be used by generators with non-domestic import requirements to offset their CCL bill; alternatively, they can be sold to an electricity supplier or established trading company

Table 2 Feed in Tariff Payment Rate Table (*Source: DECC, August 2011)*

Hydropower Rated Capacity [kW]	Generation Tariff [p/kWh]
0 to15	20.9
15 to 100	18.7
100 to 2000	11.5
2000 to 5000 (2-5 MW)	4.7

For hydropower, both the generation and export tariffs are guaranteed for 20 years and are not subject to the devaluation measures applied to other renewable energy generation. Both tariffs are index-linked to the retail price index. The Government says that while the tariff levels are designed to give a rate of return from 5-8%, the benefit of index linking may yield a nominal return considered to be from 7-10%. However, the exact rate of return is highly site specific.

Source of the Cashback

Licensed Electricity Suppliers with more than 50,000 domestic customers are mandated to join the FIT scheme (Mandatory FIT Licensees). Other licensed electricity suppliers can elect to join the scheme and become Voluntary FIT Licensees. They are collectively known as FIT Licensees.

FIT Licensees are obliged to purchase renewable energy from FIT accredited generators. The price paid for the electricity is greater than the price that the suppliers can sell on the market (typically 12p/kWh). Consequently, the expected result is that a proportion of the deficit will be passed to consumers through a general increase in energy bills.

Income Tax

The Finance Act of 2007 outlined the current income tax exemptions for domestic micro generation. In the 2009 Pre-Budget Report, the Chancellor stated, "households who use renewable technology to generate electricity mainly for their own use will not be subject to income tax on feed-in tariffs. This will save households paying the basic rate of tax £180 in 2010 (based on an average income of £900 in 2010)".

Eligibility for FITs

In order to receive FITs support, hydropower schemes must achieve accreditation, which demonstrates compliance with a rigorous set of standards designed to ensure reliable performance and consumer protection. The route to accreditation is dependent on the rated capacity:

- **Less than 50kW:** Projects must use products and installers certified under the Micro generation Certification Scheme (MCS) administered by Gemserv. Certified products and installers are listed on the MCS website
- **More than 50kW:** Projects are accredited by OFGEM through a process called 'ROO-FIT', which is based on that used in the Renewables Obligation. OFGEM requires the system design and details to be submitted online for their approval

Once the hydropower plant has been commissioned the installer will register the scheme on the central FIT register, administered by OFGEM, and the generator will then receive a certificate confirming FIT compliance. The generator then provides the certificate to their chosen FIT Licensee (electricity supplier). Once the FIT Licensee has cross-referenced the certificate with the central FIT register, payments can be made at intervals determined with the generator.

Future of FITs

In the October 2010 full spending review, the new Government accepted that any changes to the Feed-In Tariffs scheme could be damaging. It has therefore made no changes to the legislation, or to the tariff levels. The first review of the scheme will still be undertaken in 2012, to take effect from April 2013. In a statement about this future review the Government have said:

> *"Feed-In Tariffs will be refocused on the most cost-effective technologies saving £40 million in 2014-15. The changes will be implemented at the first scheduled review of tariffs unless higher than expected deployment requires an early review."*

In effect, this means that the Government have reserved the right to make an early cut of tariffs if the uptake is greater than expected. This is not particularly helpful, but it means that the best course of action for a potential developer is to proceed with FIT accreditation as soon as possible.

Budget Development Cost

Even for small scale hydropower schemes, it is common for a bespoke turbine to be manufactured based on site-specific design and at the feasibility stage it is too early to produce a complete specification of the system required. However, a budget development cost estimate is produced for each scheme, based on guideline prices from suppliers and information on recent installations. The costs can be grouped into three main categories – 1) civil works, 2) mechanical and electrical equipment, and 3) professional fees. A breakdown of the potential component costs is presented in

Table 3. This is not an exhaustive breakdown and not every scheme will require all components. For example, a very low head scheme may have no requirement for a pipeline. The preliminaries, in the list of civil works, include on site management, welfare facilities, site maintenance, plant equipment, and personnel transport.

Part of the preliminaries cost include the application for an abstraction license to the Environment Agency. These charges will total less than £500. The costs to apply for planning permission will vary widely

Table 3 Development Budget Cost components

Civil Works	Mechanical and Electrical Equipment	Professional Fees
• Preliminaries • Temporary Works • Access Track and Bridge • Site Storage Compound • Intake • Header Tank • Pipeline • Turbine Platform • Powerhouse • Outfall • Installation of M&E • Electrical Cabling • Remedial Works	• Turbine • Gearbox and Coupling • Generator • Control System • Electrical Protection • Sluice Gate • Coarse Screen • Emergency Brake • Remote Monitoring System • Delivery • Installation • Commissioning • Testing	• Feasibility Study • Detailed Design • Control of CDM Regulations • Construction Drawings • Licence Applications • Planning Application • Tendering • Contractual Negotiations • Project Management

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Consultation bodies: Planning Permission and Licensing

The Environment Agency

The Environment Agency aims to ensure that hydropower schemes include appropriate measures to protect the local environment and comply with environmental and other legislation. For any scheme the Environment Agency need to consider:

- **Abstraction** – agreement needs to be reached on the amount of water that a scheme can take from a river to flow through a hydropower turbine
- **Impoundment -** any new or raised weir will change the water levels and flows in the river. These changes need to be agreed
- **Flood risk** – the Environment Agency need to give consent to any works in or near rivers that have the potential to increase flood risk
- **Fish passage -** many schemes require a fish pass to allow fish to pass safely up and down the river

It is recommended that the latest Environment Agency Good Practice Guidelines are followed for any development, and these can be found at http://publications.environment-agency.gov.uk/pdf/GEHO0310BSCT-E-E.pdf

The Environment Agency has a Pre-application Enquiry system in place which helps to ensure that they have all the information necessary. The pre-application enquiry forms can be found at

http://www.environment-agency.gov.uk/research/planning/33580.aspx

Planning

It is recommended that the relevant Local Planning Authority is contacted to determine the likelihood of the proposed development receiving planning permission.

As far as planning permission is concerned, the key features of a small hydro scheme include:

- a water intake above a weir or behind a dam
- a pipe or channel to take water to the turbine
- a turbine, generator and electrical connection
- an outflow, where the water returns to the watercourse

These elements raise a number of important planning issues and planning permission will usually be needed. The elements of a small-scale hydro electricity scheme create potential impacts on landscape and visual amenity, nature conservation, and the water regime.

Some form of environmental assessment is essential when it comes to applying for planning permission and environmental licenses. Under the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988, the planning application for any development that the planning authority considers likely to have a significant impact on the environment must be accompanied by an Environmental Statement. An ecologist will be able to advise on the extent of environmental investigation required e.g. an Environmental Statement, Impact Assessment or Appraisal. 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.

Building Regulations

Building regulations will normally apply to aspects of the installation of a small scale hydro facility. For example work associated with the electrical installation. It is advisable to contact an engineer who can provide the necessary advice.

Section B: Stage 1 Studies

1. Waddow weir
2. Roughlee weir
3. Clough Bottom farm
4. Chipping Mill
5. Kirk Mill, Chipping
6. Backsbottom farm
7. Abbeystead reservoir
8. Whalley weir
9. Primrose mill, Clitheroe
10. Skerton weir
11. Higherford Mill
12. Hurst Green Bobbin Mill
13. Littlemoor Mill, Clitheroe
14. Low Mill, Caton
15. Gresgarth Mill, Caton
16. Slaidburn sawmill
17. Stonyhurst College
18. Castle Mill farm, Quernmore
19. Langden Intake
20. Hareden Intake
21. Greendale Mill, Grindleton
22. Earby Youth Hostel
23. Millhouses, Wray
24. Willow Mill, Caton
25. Lappet Mill, Calder Vale
26. Oakenclough paper mill
27. Black Moss reservoir
28. Hougher Fall farm, Longridge
29. County Brook Mill, Foulridge
30. Ribblesdale Park, Gisburn
31. Gilberton farm, Tarnbrook
32. Bank House Fly Fishery
33. Calder Intake
34. Marshaw old watercourse
35. Crossgill village weir
36. Holden Clough village weir
37. Ogden reservoir

Section C: Stage 2 Studies

1. Higherford Mill, Barrowford

2. Waddow Weir, Waddington

3. Primrose Lodge, Clitheroe

4. Abbeystead Reservoir

5. Skerton weir, Lancaster