

Maximising the benefits of Hydropower by developing the North-West England Hydro Resource Model

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Introduction

This paper describes the development of a system to promote the exploitation of hydro power in North-West of England. The system is composed a series of integrated models addressing the barriers to installation of devices as seen through different disciplines. The information is linked through an economic assessment which identifies different turbine options, assesses their suitability for location and demand and combines the different styles of information in a way that supports decision making.

The system is structured into five components; the hydrological resource is modelled using Low Flows 2000 and is being extended to improve coverage of smaller un-gauged rivers, the turbine options will be identified from hydrological, environmental and demand requirements and the consequences of the different solutions will be fed into the other components so that the environmental impacts and public acceptability can be assessed and valued. The system will also feed information into the hydrological resource estimates so that the consequences of multiple installations can be assessed.

The modelling approaches being employed will differ within each component, using mathematical, statistical and cost-benefit approaches. The outputs will be presented in a range of formats enabling use of the results to be made by different users. The model is seen as a tactical tool that will operate at the level of individual low- and ultra-low head hydro installations and there is interest from potential users across a range of scales from large utilities and national agencies to local manufacturers.

The development of the model will include field validation of any forecast figures and will identify the necessary monitoring and gauging to identify measures that can rapidly and easily be taken to confirm the confidence in the proposed solution. It is intended that the system, once initiated, could be developed further for use outside North-West England.

1. Background

Hydro power is a mature and proven technology that helped shape the landscape of North-West England but it is now viewed as a resource with limited opportunity. In the past it determined the location of industry and provided reliable power to carry out a range of tasks. However, since the end of the 19th century its importance has declined. The resource that supported the Industrial Revolution is still contained within the landscape and can still be harnessed to our advantage. With current calls for diverse clean supplies of energy, all resources should be examined and exploited wherever economically possible. By identifying the potential capacity and defining methods of exploitation, it is possible to circumvent the barriers to development. North-West England has both suitable drainage systems and consistent demand making hydro, and more especially low-head hydro, an attractive proposition.

There is no single barrier to the utilisation of small hydro power but several obstacles which together impede development. Indeed, the North-West of England currently does generate a limited amount of hydropower (14 sites, generating 8.2 GWh of electricity from hydro power, with an installed capacity of 4.3 MW according to regional statistical figures of 2004) and occasionally new sites are investigated, both by Utilities or private investors. The

obstacles can be thought of as a series of questions that would be posed when deciding whether to develop systems or not. The questions require expertise from a number of disciplines to answer with sufficient confidence and their responses have to be integrated through an economic evaluation to produce a decision.

There are a number of potential users of a resource model who will each benefit from the model despite their different perspectives. These range from the Environment Agency who, as regulators, control the issue of licences for abstraction, are responsible for the chemical and biological condition and quality of the water, but are also mandated to encourage use of clean renewable power as mitigation for climate change. Large organisations such as United Utilities and Hyder may see the opportunity to exploit market potential, using the tool to target opportunities. At smaller scale, a number of North-West of England organisations are keen to be involved in the expansion of a new system; these include manufacturers, engineers and consultants.

This paper addresses research issues across a number of disciplines that intend to form a framework on which other projects will hang to investigate new turbine designs, the impacts of climate change on North-West of England hydrology, standardised environmental impact assessment and the dynamics of public attitudes.

2. Objectives

The project will develop a tactical tool that will identify hydropower options for specific sites (e.g. individual properties) with explicit levels of confidence so that it can be widely used. The underpinning system will contain models, data and interpretations that can be applied at a region or sub-region scale for more strategic planning. For consistency the sources of data used will be explicitly identified and where possible be openly available to the user. Once datasets have been identified, the Environment Agency will negotiate conditions for their use at no cost.

The project's general aims will be achieved through the following specific objectives:

1. To develop a generic and fundamental understanding of the barriers to deployment of hydro systems in the North-West. The evaluation criterion will be a publication summarising the decision process for installation of hydro systems. The report will identify how our understanding of the decision processes for selecting turbines for specific locations is improved and how effectively we can support decisions.
2. To integrate the different disciplines involved so that their information needs are met and conclusions can feed into the decision process in combination with other disciplines. The evaluation criterion will be a report detailing the flow of information, integration of model results and methods of communication to users. The effectiveness of the individual components will be detailed along with the inputs and outputs linking the whole system.
3. To benchmark the output of the model and compare with actual decisions. The evaluation criterion will be a report defining the standards in a way that they can be utilised to support decision making (from different perspectives) and comparing different options proposing optimal configuration.
4. To design the model as a functional tool so that its output is timely and valued by users. The evaluation criterion will be a report providing feedback from users.
5. To develop forms of output in consultation with users so that they are relevant to their needs. The evaluation criterion will be a report containing a range of outputs in different formats.

The study will be designed to operate for any application in North-West of England, including water treatment and sewage works, mining run-off, etc. The development will be made to address real catchments / sub catchments and involve assessment of opportunities. Where the system suggests the decision should be taken to install, we will endeavour to indicate possible available funding to support development (e.g. Rural Regeneration for farms).

3. Methodology

The information involved in the decision process for installation of a hydro system is illustrated below:

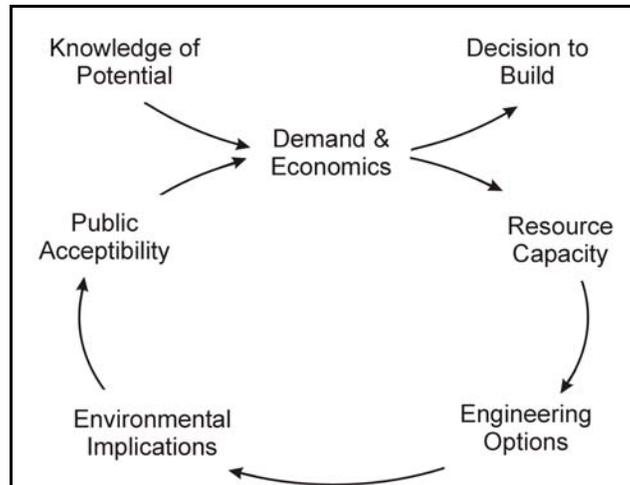


Fig. 1. Information involved in the decision process for installation of a hydro system.

Each component requires expertise from an individual discipline, often with input from several different disciplines.

The individual components are described below.

3.1 Demand & economics

The contribution from economics will address essentially two issues. The first relates to the narrowly identified costs and revenues associated with different turbine technologies, both existing and nascent. The second relates to the wider environmental aspects of the programme, in particular the costs and benefits for the community e.g. loss of amenity, degradation of the physical environment etc.

In order to address these questions, we shall develop a model that captures the micro-economic aspects of the process of transforming inputs into outputs. In developing this model we shall take into account both demand and supply considerations. More particularly, we shall identify the factors that determine demand for generating output, and the output that can be generated under different technological conditions.

This will enable us to compare different systems in terms of their profitability. More generally, we shall use data from the other sections of the project along with publicly available data to address the environmental issues that arise from the use of the different technologies. The information derived within this section will be formulated so as to support decision making.

3.2 Resource capacity

Within the United Kingdom there are over 250,000 river reaches mapped at a scale of 1:50,000. In contrast there are approximately 1600 permanent gauging stations and thus the majority of catchments are ungauged. The North-West is typical of the UK in that there are gauging stations on each of its major rivers that enable flow duration curves to be developed but the majority of smaller river systems are ungauged. However, it is within these smaller catchments that the majority of opportunities for low head and small hydropower exist.

To address this need the Centre for Ecology and Hydrology have developed software systems for estimating hydropower generation potential (the HydrA package) based upon estimates of the flow duration curve for ungauged catchments (the Low Flows 2000 system). Low Flows 2000 is the standard system used by the Environment Agency for generating estimates of river flows within ungauged catchments and incorporating the impacts of water use (reservoirs, abstractions and discharges) upon these natural estimates of river flow. Whilst Low Flows 2000 estimates provide a good basis for identifying potential hydropower sites, for detailed design and estimation of environmental consequence there remain a number of research issues that currently constrain development opportunities:

1. The uncertainty in the prediction of flow duration curves needs to be constrained to minimise the uncertainty in energy production to demonstrate the viability of a scheme. Currently this is undertaken in an ad hoc manner with little rigour. The challenge is to identify how short record flow data (down to individual flow measurements) can be used to constrain the uncertainty in the prediction of flow duration statistics within ungauged catchments in North-West of England, and to determine how this hydrological uncertainty propagates through to an uncertainty in the estimation of energy production.
2. Current scheme viability is defined on long-term estimates of flow regimes. A more pertinent question is what will be the likely evolution of energy generation over the period of capital borrowing and payback, and whether this can be estimated within ungauged catchments.
3. In pursuit of generation capacity scheme promoters are looking at the utilisation of higher flows. . However the question remains of how robust designs are to the impact of high flows (and in some locations high flow-induced sediment transport).
4. Finally, for larger schemes the potential impact of catchments and climate change on energy generation (though the latter might not be significant over the design lifetime of a scheme) needs to be answered. This is currently ignored within current design practices.

3.3 Engineering Options

Accepting that economic benefit is the driver for installation, what is needed is a scoping of the turbine options for different resource, environment and demand at any specific location [1-15]. A model will be developed that will take data generated by other components of the system namely hydrology (e.g. water levels, heads, flow duration curve), demand (e.g. household size) and characteristics of physical environment (e.g. geology, bed stability) and devise parameters to filter different designs for their suitability. Each design will have its own specific characteristics and major components including storage, culvert, penstock, power station and tailrace system whose values will be adjusted for each location.

The options will be passed on to other sections of the overall system so that they can be assessed for their environmental implications, public acceptability and overall economic cost. Data will also be supplied to the resource capacity section so that any impact on the hydrological resource can be relayed for inclusion in future estimates.

Once a decision has been proposed, selecting one of the turbine designs the situation will be reassessed and the specification for the installation will be worked up in detail. Characteristics of size, construction and reliability will be derived and detailed costing for optional modification of the design assessed. One of the big areas of uncertainty will be the full economic cost of the plant and its installation. We need to include financing charges, the cost of connection to the grid, access to the site, maintenance costs, decommissioning and site remediation in addition to the cost of the rotating plant. The exploitation mode will influence the development and options for different strategies will be included. For example the electrical connection may be isolated from the grid, linked directly to the grid or passed through a household supply (considering safety issues connected with feeding a supply back into a house wiring system) and only pass to the grid when the demand is satisfied. Additional characteristics will be considered so that full life cycle analysis of the device can be calculated.

3.4 Environmental Implications

Environment is often seen as a major stumbling-block with need for an Environment Statement (under Town & Country Planning Regulations – Assessment of Environmental Effects). Currently the ill-defined requirements for environmental protection with regard to hydro schemes need to be reviewed and re-formulated. The *ad hoc* approaches to defining the impacts of hydro schemes on the in-stream requirements of aquatic flora and fauna are often cited by developers as the most significant barrier to the successful promotion of schemes need to be revised and a framework developed. There are a number of tools in use for this such as the River Habitat Survey (UK Environment Agency, 2003), RIVPACS (Centre for Ecology and Hydrology) and Mean Trophic Ranking (Centre for Ecology and Hydrology) which can be applied to measure the current environmental state. These cover both the physical environment, through the River Habitat Survey, and the biological environment, through RIVPACS and

Mean Trophic Ranking. The Water Framework Directive requires that water bodies be maintained in, or improved to, good status. Good status includes chemical, biological and physical components and it is therefore unlikely that a large number of undeveloped sites would be considered by the Environment Agency for low-head hydro-electric installations.

Outputs from the environmental component are needed to identify the effect the environment has upon the physical components of the turbine installation. High sediment loads, eutrophic waters, or highly acidic waters may reduce the life of the turbine or increase the required maintenance. This would reduce the economic efficiency of the turbine, possibly below the level acceptable for installing the turbine in the first place. It is important that these environmental factors be considered throughout the decision making process and monitoring of stream characteristics will be performed prior to, during and post installation.

Research issues:

1. Examine different options to EIA (RIVPACS, RHS, MTR, number and timing of visits) to guarantee effectiveness for different styles and sizes of turbine.
2. Design of monitoring system to identify impacts once systems have been installed (and relating them back to EIA).
3. Co-ordinate regional datasets and spatially co-register.
4. Investigate environmental and biological effects of changing river flow.
5. Develop fuzzy decision tree.

3.5 Public engagement

How the public engage with hydro technology is a crucial question for implementation in practice. Ordinary people are:

1. potential adopters of the technology at a micro household level
2. potential participants in collective community processes for the adoption of technology at a micro level (for example for community buildings or groups of households) and
3. potential neighbours of technology installations at micro or meso levels who may in some circumstances be concerned about the local impacts of the installation (visual, ecological, noise etc...).

In all three respects comparatively little is known about how members of the public might view hydro technologies, either in the general abstract or in particular forms in particular physical and social contexts. There is therefore an important research task to develop these understandings, to try and identify key factors which shape perceptions and potential patterns of adoption or resistance, and to develop processes of engagement (which might include various forms of communication, participation, facilitation of collective action etc.) which are appropriate for different technologies, scales and contexts of installation. In this respect it will be important to recognise the diversity of both publics and of stakeholder groups who may have an interest in the installation and impacts of low head hydro technologies (such as fisheries groups, landowners, tourism industry, conservation groups, local councils).

This aspect of the research will interface closely with an ongoing 3-year project on public engagement with renewable energy, funded under the TSEC programme and involving Lancaster as a partner. There will be considerable synergies for both research programmes.

3.6 Timeliness

The Energy Review Report published in July 2006 in the UK [16], reassesses national policy on energy and reinforces the Government's call for research into diverse sources of power. Hydro is an area offering a relatively untapped resource available throughout the North-West. One large benefit of individuals being more closely

involved with meeting their own energy needs is that their view of energy use changes and they tend to become more conservative.

3.7 Novelty

The novelty of this approach is that it is looking to identify appropriate solutions to different situations and locations. The outputs will not be a standard 'one-size fits all', but offer a range of options that will have different costs and values. The approach will identify the advantages of different solutions, not only in financial terms but also through environmental, cultural and wider economics.

4. Benefits to the North-West of England

The North-West of England will benefit in a number of ways from the success of this project:

1. The project will lead to improved utilisation of the renewable resources available to the North-West of England and offer an increased diversity of supply of power that will help meet national Government's targets.
2. Increased use of hydro power will offer economic benefits to the North-West of England through increased jobs (in manufacture, installation and maintenance).
3. Individuals and local communities will benefit from the utilisation of small scale hydro as the systems will be in their ownerships. This will include farmers who are still recovering from the pressures of BSE and foot and mouth.
4. The local generation of power also alters people's attitude to efficiency and waste and will benefit the North-West of England in general.
5. Once the system has been developed, it can be marketed beyond the North-West of England as a form of technology transfer.

5. Conclusions

As bulk electricity supply from large utilities became more generally available many small hydro schemes fell into disuse. Since 1980, small hydro schemes have shown strong development in many countries, supported by favourable political measures. Today, revival of similar schemes in Britain by re-planting into existing infrastructure or refurbishment of old plants can be cost effective and make a useful contribution to renewable energy production; there are also a large number of previously unconsidered sites. Small hydro is also well suited for integration into existing infrastructure, and particularly on water supply schemes since major civil engineering structures are already in place. An imaginative development of such schemes leads to power generation where the energy was previously dissipated. The development of a model is described that integrates the disciplines necessary to develop the hydro application in the North-West of England.

The model is composed of a series of integrated sub-models addressing the barriers to installation of devices as seen through different disciplines. The information is linked through an economic assessment which identifies different turbine options, assesses their suitability for location and demand and combines the different styles of information in a way that supports decision making. There are five sub-model components; the hydrological resource is modelled using Low Flows 2000 which is being extended to improve coverage of smaller un-gauged rivers, the turbine options will be identified from hydrological, environmental and demand requirements and the consequences of the different solutions will be fed into the other components so that the environmental impacts and public acceptability can be assessed and valued. The model also feeds information into the hydrological resource estimates so that the consequences of multiple installations can be assessed.

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