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

George Aggidis
Renewable Energy Group
Dept of Engineering
Lancaster University
Bailrigg
Lancaster
LA1 4YR
England

David Howard
Centre for Ecology & Hydrology
Lancaster Environment Centre
Bailrigg
Lancaster
LA1 4AP
England

Robert Rothschild
Management School
Dept of Economics
Lancaster University
Bailrigg
Lancaster
LA1 4YR
England

Martin Widden
Renewable Energy Group
Dept of Engineering
Lancaster University
Bailrigg
Lancaster
LA1 4YR
England

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:

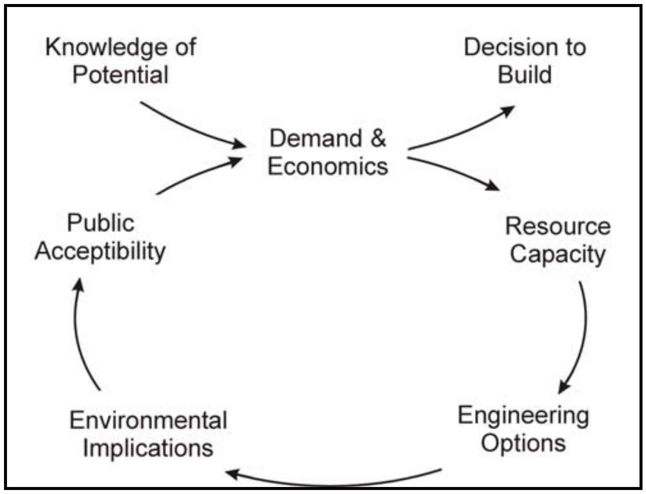

Fig. 1.Information involved in the decision process for installation of a hydro system.

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 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 and 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 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.

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

Acknowledgements

The authors wish to express their appreciation of the support of the Joule Centre for Energy for the research reported in this paper through the Joule Grant Ref JIRP106/07.

References

1. **Aggidis, G. A.,** "Current Situation & Perspectives of the British & European Hydro Turbine Industry & Technology for Small Hydro Power Generation", (Keynote Paper), *Proceedings*, IMechE International Conference, London, November 2002.
2. **Aggidis, G. A.**, "Technological Developments on Small Hydro", *Invited Paper*, IMechE, Fluid Machinery Group, London, May 2001.
3. **Widden, M. B., French, M. J., and Aggidis, G. A.,** "Economic Low Head Hydro Power by Conversion to air Pressure", *Proceedings*, World Renewable Energy Congress, ISBN 0-080-44671-X, May 2005.
4. **Aggidis, G. A., Stallard, T., and Rothschild, R.,** "A comparative study of wave energy technologies", *Public workshop:* "Making waves: the economic and social impacts of marine renewables", EPSRC SuperGen Marine Energy Research Consortium, University of Strathclyde, Glasgow, 2 December 2005.
5. **Cattley, R., Widden, M. B., and Aggidis, G. A.** "Low Head Hydropower Developments", *Proceedings*, World Renewable Energy Congress, ISBN 0-080-44671-X, May 2005.
6. **Stallard, T., Rothschild, R., Bradshaw, A., and Aggidis, G. A.,** "Comparison of Equivalent Capacity Wave Energy Schemes", *Proceedings*, World Renewable Energy Congress, ISBN 0-080-44671-X, May 2005.
7. **French, M. J., and Widden, M. B.,** "The Exploitation of Low-Head Hydropower by Pressure Interchange with Air, Using Siphons", *Journal of Power and Energy*, Proc IMechE, 2001.
8. **Widden, M. B., French, M. J., and Aggidis, G. A.,** "Economic energy from low head water by conversion to air pressure", *Proceedings*, International Hydro Power Symposium, IMechE, London, 9th December 2004.
9. **Aggidis, G. A.,** "The Facts and Fiction of Renewable Energy", *Proceedings*, UK Energy Policy Conference "Will the Lights go out?", Lancaster University, 14 December 2004.
10. **Aggidis, G. A., Graves C.P., and Porter N.I.,** "Small Hydro Technology and its Application in Greece", *Proceedings*, Academic Conference on Renewable Energy, Athens, Greece, April 2000.
11. **Aggidis, G. A., Graves C.P., and Porter N.I.,** "Experience of Innovation & Technological Developments Meeting Small Hydro Needs Today", *Proceedings*, International Conference on Small Hydro, Athens, Greece, November 1998.
12. **Aggidis, G.A.** named inventor, on Patent Applications filed for Gilbert Gilkes & Gordon Ltd, Kendal, UK under the title: "Improvements in or relating to turbines and in particular Pelton wheel turbines"**.**
    UK Patent: UK Patent Application 0304556.4, 28 February 2003
    Canadian Patent: Canadian Patent Application 2,459,626, 28 August 2004
    EU Patent: European Union Patent Application, EC: F03B1/02, IPC: *F03B1/02***;** (IPC1-7): F03B1/02, Publication info: CA2459626 - 2004-08-28, 28 August 2004
    US Patent: United States, 20050084367, 21 April 2005, USPTO 415089000, International Class F04D001/14 Patent
13. **Wilson, P.,** "Gilkes 1853 to 1975 - 122 Years of water turbine and Pump Manufacture", Science Museum, London 1975.
14. **Nechleba, M.,** "Hydraulic Turbines, Their Design and Equipment", Constable London 1957.
15. **Mosonyi, E.,** "High Head Power Plants", Academiai Kiado, Budapest 1991.
16. **UK Department of Trade and Industry**, "The Energy Challenge: The Energy Review Report 2006, Cm 6887, July 2006.

The Authors

Eur Ing **George Aggidis** BEng(Hons), MSc, REng, GTC (TEE), MASME, CEng, FIMechE, is a Senior Lecturer in Engineering at Lancaster University, and Director of Lancaster University Renewable Energy Group & Fluid Machinery Group. His previous career included 25 years industrial and academic experience, of which 9 years were outside the UK. He started his engineering career with Weir Pumps Ltd Manchester (formerly Mather & Platt Ltd), followed by appointments both in the UK and abroad. His final position in industry was Director and Engineering Development Manager for Gilbert Gilkes & Gordon Ltd. Educated in Greece, USA and UK; he joined Lancaster University in 2004 with research, design, and development contributions in the field of fluid machinery, and renewable energy. He developed turbines for Green Field Hydro Power Generation projects in Greece exceeding 12 MW in power. He has physical research prototypes of fluid machinery operating successfully worldwide, a patent for power generation water turbines, and a 1.5 MW demonstration prototype turbine in operation since end of 2003 at Lochaber Hydro Power Station. He is Fellow of the Institution of Mechanical Engineers, Board member of its Fluid Machinery Group, and a Board of Governors member of the Joule Centre for Energy. His research interests include energy, renewable energy, wave energy, tidal energy, hydropower, energy policy and fluid machinery.

Dr **David C Howard** is one of the co-directors of the UK Energy Research Centre leading the theme on Environmental Sustainability and the director of the Lancaster Environment Centre's Centre for Sustainable Energy. He is author of 30 refereed papers, 96 contract reports and 50 other assorted publications, and editor of four books. He has been involved in a range of projects looking at the capacity of energy generation from the natural resources and the impact of energy capture and use. Projects include GB potential for wood energy (short rotation coppice), wind turbines and alternate crops, carbon sequestration and inventory, impacts and externalities of atmospheric deposition and the externalities of transport. David is also on the Board of Governors of the Joule Centre and on the committee of the UK chapter of International Association for Landscape Ecology (IALE-UK).

Prof **Robert Rothschild** - Professor of Economics, PhD Programme Director, Director of Doctoral Programmes and research training programme. A graduate of the University of Cape Town, and former Research Student at Emmanuel College, Cambridge, he has worked in industry in both the UK and Germany. He has held visiting posts at Case Western Reserve University in Cleveland, USA, at the Australian Graduate School of Management in Sydney, Australia, Curtin Business School in Perth, Australia, and at the North-West Polytechnic University in Xian, China. He has also spent a period on research leave at the University of British Columbia, Vancouver, Canada. His principal research area is in industrial organization analysis, with particular reference to cartel behaviour and competition in product-differentiated markets. On these and related topics he has published widely.

Martin Widden is Head of Engineering at Lancaster University, and Senior Lecturer in mechanical engineering. He has lectured in fluid mechanics for 25 years and is the author of a published book on the subject. He has been involved in renewable-energy research at Lancaster University for the last ten years, initially working on low-head hydro devices and more recently on wave power and devices like the PS Frog. He is an author of a number of papers on wet renewable energy topics.