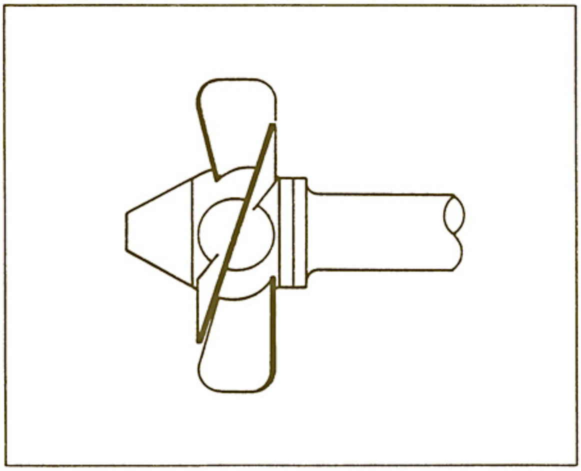
THE WATT COMMITTEE ON ENERGY

REPORT NUMBER 15

SMALL-SCALE HYDRO-POWER



MARCH 1985

ISBN 0 946392 16 1
ISSN 0141-9676

The views expressed in this Report are those of the authors of the papers and contributors to the discussion individually and not necessarily those of their institutions or companies or of The Watt Committee on Energy Ltd.

Published by:
The Watt Committee on Energy Ltd
18 Adam Street
London WC2N 6AH
Telephone: 01–930 7637

This edition published in the Taylor & Francis e-Library, 2005.

"To purchase your own copy of this or any of Taylor & Francis or Routledge's collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk."

ISSN 0141-9676
ISBN 0-203-21033-6 Master e-book ISBN

ISBN 0-203-26815-6 (Adobe eReader Format)

THE WATT COMMITTEE ON ENERGY
REPORT NUMBER 15

SMALL-SCALE HYDRO-POWER

Papers presented at the Sixteenth Consultative Council meeting of the Watt Committee on Energy, London, 5 June 1984

The Watt Committee on Energy Ltd

A Company limited by guarantee: Reg. in England No. 1350046

Charity Commissioners Registration No. 279087

MARCH 1985

Contents

Member Institutions of the Watt Committee on Energy
March 1985

* British Association for the Advancement of Science
British Ceramic Society
* British Nuclear Energy Society
British Wind Energy Association
* Chartered Institute of Building
* Chartered Institution of Building Services
* Chartered Institute of Transport
* Combustion Institute (British Section)
* Geological Society of London
* Hotel Catering and Institutional Management Association
* Institute of Biology
Institute of British Foundrymen
Institute of Ceramics
* Institute of Chartered Foresters
* Institute of Cost and Management Accountants
* Institute of Energy
* Institute of Home Economics
* Institute of Hospital Engineering
Institute of Internal Auditors (United Kingdom Chapter)
Institute of Management Services
* Institute of Marine Engineers
Institute of Mathematics and its Applications
* Institute of Metals
* Institute of Petroleum
* Institute of Physics
* Institute of Purchasing and Supply
* Institute of Refrigeration
Institute of Wastes Management
* Institution of Agricultural Engineers
* Institution of Chemical Engineers
* Institution of Civil Engineers
* Institution of Electrical and Electronics Incorporated Engineers

* Institution of Electrical Engineers
* Institution of Electronic and Radio Engineers
Institution of Engineering Designers
* Institution of Gas Engineers
Institution of Geologists
* Institution of Mechanical Engineers
* Institution of Mining and Metallurgy
Institution of Mining Engineers
* Institution of Nuclear Engineers
* Institution of Plant Engineers
* Institution of Production Engineers
* Institution of Public Health Engineers
Institution of Structural Engineers
* Institution of Water Engineers and Scientists
* International Solar Energy Society—U.K. Section
Operational Research Society
* Plastics and Rubber Institute
* Royal Aeronautical Society
* Royal Geographical Society
* Royal Institute of British Architects
* Royal Institution
* Royal Institution of Chartered Surveyors
* Royal Institution of Naval Architects
* Royal Meteorological Society
* Royal Society of Arts
* Royal Society of Chemistry
* Royal Town Planning Institute
* Society of Business Economists
Society of Chemical Industry
* Society of Dyers and Colourists
Textile Institute

* *Denotes present and past members of The Watt Committee Executive*

Members of Small-Scale Hydro-Power Working Group

J.V.Corney	Institution of Civil Engineers, Chairman
N.A.Armstrong	Institution of Electrical Engineers and Institution of Mechanical Engineers
H.W.Baker	Institution of Civil Engineers
A.T.Chenhall	Institution of Electrical Engineers
D.J.Hinton	Institution of Civil Engineers
R.W.Horner	Institution of Public Health Engineers
M.J.Kenn	Institution of Mechanical Engineers
E.C.Reed	Institution of Water Engineers and Scientists
J.Taylor	Institution of Electrical Engineers
Prof E.M.Wilson	Institution of Civil Engineers

Acknowledgements

Commander G.C.Chapman, Mr J.A.Crabtree and Mr O.M.Goring attended several meetings of the working group as representatives of the National Association of Water Power Users.

The Watt Committee working group on Small-Scale Hydro-Power is indebted to many individuals and organisations in the United Kingdom from whom information and comments were obtained in the course of this project, including the Central Electricity Generating Board, North of Scotland Hydro-Electric Board, South of Scotland Electricity Board, regional Water Authorities and (in Scotland) regional councils and River Purification Boards.

The Watt Committee on Energy acknowledges with thanks financial assistance by the Department of Energy, which helped to defray the costs of the proceedings of the working group, and the advice given by Dr P.J.Fenwick of that Department.

Note

The data included in this *Report* were correct, to the best of the authors' knowledge and belief, in January 1985.

Foreword

At any moment in time the Watt Committee has four or five working parties, each tackling a specific project. Those under discussion at the meeting of the Watt Committee Executive of 24th January 1985 were technician education, waste disposal in the energy industry, the second phase of our study of acid rain and passive solar building design. Two other projects awaited firm proposals, and a further two were temporarily suspended because they would be more realistic at a later date.

The present *Report* on Small-Scale Hydro-Power contrasts strongly with its two immediate predecessors, which dealt with nuclear energy and acid rain respectively.* It shares with them, however, the desire to clarify what at the moment could hold up development. Our only previous report devoted entirely to renewable energy sources was No. 5 *Energy from the Biomass*. Reports No. 1 and, to a less extent, No. 2 include sections on renewable sources; Report No. 4 *Energy Development and Land in the United Kingdom* contains two coloured maps showing alternative source distribution in the United Kingdom and suggests locations for wind, solar, wave, tidal and geothermal installations.

Discussions with a number of individuals about small hydro-electric generating capacity suggested that it was something of a Cinderella in that it was unlikely to save much fossil fuel, and the cost per kilowatt could vary greatly with the site and with the amount of outside help that would be required. Furthermore, there was no simple statement of the legal obligations.

Like windmills (now elevated to 'aero-generators'), small hydro-power has suffered a long period of neglect illustrated by idle water-mills and mill-ponds used to supply fish rather than energy. A great deal of money has been spent on aero-generator design and a full-scale unit is under construction in the Orkney Islands. If it comes up to expectations we shall see more schemes being built and used to save energy. The same should be true of hydro-power.

To add to this Foreword would mean drawing on the *Report* itself. I end, therefore, with my personal thanks and those of the Executive to the numerous people who have given information, time and voluntary effort to add to our understanding of the problems and the wider potential of small-scale hydro-power.

February 1985

J.H.Chesters
Chairman, The Watt Committee on Energy

* Particulars of previous *Reports* of the Watt Committee on Energy are given on pages 61–62.

Introduction

Despite the abundance of sites in the United Kingdom where small-scale hydro-power could be exploited, only a very small proportion of such potential is at present developed.

The Watt Committee on Energy was concerned at this lack of exploitation of a valuable resource and therefore decided to establish a working group to examine the potential for development of further small-scale hydro-power as a useful addition to the energy resources of the United Kingdom. Its object was to identify obstacles which may have inhibited development in the past and to make suggestions for further study/action, with the eventual objective of helping to overcome the main obstacles and stimulate new schemes.

The working group was free to make its own definition of what was implied by ‘small-scale’, and decided, in broad terms, that this should be any resource below the size which the electricity boards had themselves considered worth developing. In electrical terms we considered this to be from 5 to 5000kW.

We also decided, in order to limit the field of our study, that we would not include wave or tidal power, as these could properly form the subject of separate studies. The papers forming this *Report* have been prepared by various members of the working group and explore the potential for small-scale hydro-power development in the whole of the United Kingdom. Topics covered include the technical problems and legal, institutional, environmental and economic aspects which may have inhibited development in the past.

The working group has been greatly helped and encouraged by the information and assistance provided by members of the National Association of Water Power Users who have direct experience of constructing and operating small private schemes. The number and variety of such schemes provide concrete evidence of the practicability of such development. The members of this Association are enthusiasts and have for the most part constructed and operated their schemes themselves. Whilst clearly beneficial to their owners as they stand, they would not all necessarily satisfy current economic criteria.

Our studies have been purposely limited to developments in the United Kingdom, but many aspects will be equally applicable to developing countries, particularly where a public electricity supply is not available in the vicinity and the choice lies between hydro-electricity or, as an alternative, diesel generation with high-cost fuel. The papers in general deal with water power for the generation of electricity, as it is in this form that it is easiest to assess its value as a power source; however, where an alternative use for the power exists it may be simpler to harness the power for such use, as was done in the past, rather than to use it for electricity generation.

The technology involved in the development of water power is not new, but there are few people who have experience of both the engineering and the legal aspects, which are complex and varied. It is the hope of the working group that, by bringing together these subjects in one report, the problems facing potential developers of hydro-power will become better understood and many more successful schemes will result.

J.V.Corney

Chairman, Watt Committee Working Group on Small-Scale Hydro-Power

THE WATT COMMITTEE ON ENERGY

REPORT NUMBER 15

Section 1
Potential for small-scale hydro-power in the United Kingdom

E.M.Wilson

Department of Civil Engineering

University of Salford

Salford

Potential for Small-Scale Hydro-Power in the United Kingdom

1.1
Introduction

The United Kingdom is not a country rich in hydro-electric resources. Only in Scotland and Wales are there mountains and rainfall on a scale large enough to offer opportunities for hydro-electric development of tens of megawatts. However, over the whole country there are hundreds of sites where modest amounts of hydro-electric energy could be generated, at powers measured in tens of kilowatts.

The problem of assessing potential requires, first, some arbitrary definition of what 'small-scale' means, since many of the surveys made in the past have considered schemes only if their power capacity exceeded fixed values, frequently in megawatts. So far as this paper is concerned, 'small-scale' means from 5 to 5000kW. An arbitrary sub-division can be made to mini- and micro-hydro, with capacities above and below 500kW respectively.

During the last five years several studies have been made of small-scale hydro-power in various parts of the U.K. These have supplemented many previous investigations: for example, there have been at least six sets of estimates of Scottish hydro potential in one form or another, though most of them did not include small-scale projects by the definition above. The range of such estimates reflects uncertainty about the premise on which they should be based. Francis, of the Department of Energy,[1] has suggested that there are three broad categories in which estimates may be placed, namely:

(a) Gross river potential is approximately the summation of annual runoff times potential head.

(b) Exploitable technical potential is Category *(a)* less that energy which it is technically impossible to exploit; it includes, for example, losses due to efficiencies of plant less than 100%, and heads too low for available plant. Category *(b)* tends to move towards Category *(a)* with time.

(c) Economic exploitable potential is Category *(b)* less the energy which it is uneconomic to develop. Economic circumstances differ from case to case, so there is no firm boundary separating Categories *(b)* and *(c)*. Much depends on the cost of energy being displaced: for example, displacement of public supply at 4p/kWh enhances the value of a scheme compared with sale to the Electricity Board at 2p/kWh.

It is worthwhile to recall an extract[2] from the Report of the Mackenzie Committee (1962) in assessing hydro-electric potential in Scotland: 'To have any real meaning, the estimates of potential water power must be related to economic considerations…'

Most published studies deal with Category *(b),* and, since regional investigations cannot by their nature deal with site-specific details and economic analyses, guidelines based on minima for flow and head have to be adopted.

In trying to assess the small-scale potential of a region the researcher has to use all the evidence he can find. For this paper, the existing hydro-electric capacity has been determined, together with published and unpublished assessments of further moderate potential; from these, an estimate has been made of small-scale potential. In the case of Wales and England there is better evidence, in the form of recent small-scale potential surveys,[3,4] and these have helped in the extrapolations required. However, it must be said that in all that follows there is room for considerable error and the judgements made are inevitably subjective.

1.2 Hydrology

Estimates of the occurrence and volume of flow passing a proposed hydro-electric site must be made if the development is to be properly sized and assessed. River flows are determined by the hydrology of the catchment and the consequent runoff and groundwater contributions.

The river flow from a catchment is dependent upon area, location, orientation, rainfall, climate, topography and geology. In considering small hydro sites it is impracticable to consider all these variables in detail, and it is usual to resort to one of a number of estimating techniques. However, in some locations there may be an established Water Authority gauging station nearby where daily flow records over several years are available. Provided the gauging point (usually a weir or a calibrated river section) is not very far distant, a simple areal correction may be all that is required to adjust the measured flows to those at the required site. An HMSO publication[5] details the location of established gauges—most are located on larger well-developed rivers. The local Water Authority may have additional gauges which could prove useful, and in every case an approach to the Water Authority is worthwhile to obtain flow data and to establish if there are any requirements for compensation flow.

For run-of-river hydro-electric projects, the daily flow duration curve (FDC) provides the required data. The FDC shows the percentage of time that certain values of discharges are equalled or exceeded. Duration curves for long periods of runoff (in excess of 5 years) are utilized in deciding what proportion of flow should be used for generation, since the area under the curve represents volume and hence directly affects energy output. Figure 1.1 shows FDCs for the River Itchen at Allbrook, near Winchester, and the River Ogwen, near Bethesda, North Wales.

The shape of the curve is also of importance: a generally flat curve represents a river with few flood flows, probably extensively supplied from groundwater; a steep curve indicates a 'flashy' river with frequent flood flows and comparatively low flows during dry weather. Such characteristics indicate the system of flow adjustment that is required to utilise the flows available. In cases such as the River Itchen where flows are relatively steady, a daily adjustment of flow may be all that is necessary. However, for 'flashy' rivers such as the Ogwen, continual flow adjustment may be necessary to utilise all that is available.

In general, where there are no constraints on the scale of development, the 30% exceedance flow from the FDC may be adopted as a first estimate of the designed capacity for the scheme. Following the evaluation of costs, energy outputs and value of energy production for several capacities, both above and below that corresponding to the 30% exceedance flow, the design parameters may be modified to optimise the size of installation. For run-of-river sites, the FDC is fundamental to the calculation of energy output.

Where long-term flow records at a particular site are not available, it is necessary to estimate the FDC from other readily available data, using an empirical method. Such methods of flow estimation depend on physical and climatic conditions affecting the catchment. Rainfall data are often utilised, as they are generally widely available and cover longer periods than river discharges.

One such method is through the use of unitised FDCs.[6] FDCs from established gauging points are unitised by dividing through the relevant catchment area and annual rainfall so that they represent flow from 1km^2 of catchment with an annual rainfall of 1 metre. Such unitised curves can be used to represent the general flow conditions of a particular region. When applied to a specific catchment within that region, the unitised curve is factored by the appropriate catchment area and weighted annual rainfall. This method has the advantage that FDCs are produced from which energy can be directly calculated. The accuracy of the FDC produced is dependent on the similarity of the particular catchment to the gauged catchment, since even within the same region significant hydrological differences can exist.

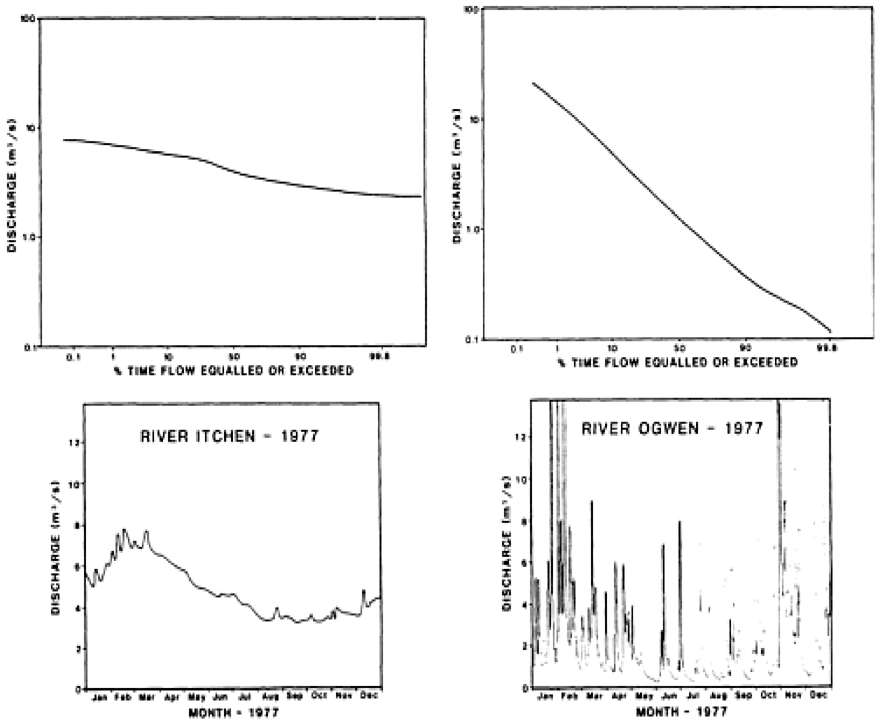


Figure 1.1 Flow duration curves: river with few flood flows *(left);* 'flashy' river *(right).*

1.3 Scotland

The first published estimate of hydro-power potential was that of the Water Resources Committee in 1921.[7] The potential was estimated at 1700GWh per annum. This is the lowest of the Scottish estimates, probably because of the rudimentary nature of Scottish electrification in 1921 and, perhaps, the strong lobbying of non-resident Scottish landowners.

In 1942, the Cooper Committee suggested a potential of 4000GWh per annum, and shortly afterwards the Hydro-Electric Development (Scotland) Act 1943 was passed setting up the North of Scotland Hydro-Electric Board (NSHEB). When NSHEB published its development scheme in 1944, it foresaw 102 projects producing 6270GWh per annum. This figure was revised again by Williamson,[9] who suggested that the annual output could exceed 8000GWh.

In 1962, the Mackenzie Committee reported a technically viable potential of 7250GWh per annum, and in 1981, with a resurgence of interest in hydro development—after a 20 year lull—NSHEB re-estimated the Scottish potential and concluded in a paper to the Economic and Social Research Council that the technical potential was 8500GWh per annum (2700MW installed) and that the economic exploitable potential was 5100GWh (1630MW installed). Since this last study considered the lower power limit to be 50kW, it is clear that there is a large number of quite small sites in Scotland that have not yet been assessed. This is hardly surprising, since small schemes do not justify the transmission lines and access roads which are necessary in many parts of the country.

From such evidence as exists already, it is probable that small-scale schemes in Category *(b)* with a total potential output of at least 180MW are technically exploitable, though the proportion of these which would also merit a Category *(c)* classification, as being economically viable, could only be an informed guess —perhaps a third, or 60 MW, producing, say, 260GWh per year.

Table 1.1 Total potential hydro-electric power in the United Kingdom

	Existing hydro-electric installations		Further major developments proposed but not built		Estimated small-scale (5kW–5MW) sites			
	Technically exploitable*		Economically exploitable*					
	MW	GWh/y	MW	GWh/y	MW	GWh/y	MW	GWh/y
Scotland	1270	4000	350	1100	180	790	60	260
Wales	120	246	230[8]	390	70	300	25	110
England	9†	20	–	–	32	160	14	75‡
Northern Ireland	Negl.	1	40	110	35	150	18	75
Total	1399	4267	620	1600	317	1400	117	520

Notes

* Power capacity estimated at 30% exceedance, which on most British rivers gives a 50% plant factor or thereabouts,

†includes Kielder scheme (under construction).

‡These values reflect the high utilisation factors of water supply schemes, which are typically >60%.

1.4 Wales

In Wales, as in England, public electricity supply is the responsibility of the Central Electricity Generating Board. The present installed capacity of CEGB hydro-power stations in Wales is 114MW, producing annually about 215GWh. In addition, there are Water Authority schemes totalling about 5.7MW, producing 41GWh per annum. The load factors represented by these figures, 0. 22 and 0.82 respectively, demonstrate only that the CEGB values peaking capacity highly, whereas Water Authorities are using near-constant discharges to produce and sell energy to their Electricity Boards.

The hydrometric areas covering Wales have recently been examined for their small-scale potential for the Department of Energy by Salford University.[3] Some 565 sites were identified: they would have a combined capacity of about 70 MW and an annual energy output of 300GWh. The arbitrary lower power limit in this study was set at 25kW and the estimate of scheme capacities ranged from that figure to 3200kW, It is estimated that up to 50% of these sites might come within Category *(c)*.

1.5 England

The first published data about the hydro-electric resources of England were again those of the 1921 Water Resources Committee, which suggested an energy production of 180 GWh per annum. The Committee made it clear that this was by no means the total potential, which they were unable to estimate.

A recent study[4] of the English water industry commissioned by the Department of Energy, and again limited to powers of 25kW or above, has revealed 66 sites with power potential of 8.4 MW and potential energy of 48 GWh per annum. The economically exploitable proportion of these is indeterminate, but it may be about two-thirds. There are, in addition, certainly some hundreds of sites unconnected with the water industry that could be developed, and many others would generate powers of less than 25kW, the total of which has not been estimated since data are widely dispersed and have not been systematically examined. To provide a first indication, it would be reasonable to quadruple the water industry potential and to assume that one-third of these extra sites would be economic. These assumptions lead to Category *(b)* and *(c)* figures of 32MW, 160GWh and 14MW, 75GWh respectively.

1.6 Northern Ireland

There has been no recent study of small hydro potential in Northern Ireland. More than 200 existing weirs are technically exploitable, but there are few examples where electricity is being generated. There are several excellent sites on the Six Mile Water and Blackwater Rivers which would almost certainly be economic also.

The western part of Ulster was not fully developed for water power during the industrial revolution; nor were the upland sites on the Antrim plateau. It is estimated that there may be up to 100 new sites for small-scale installations. Based on topography, rainfall and comparison with similar areas more intensively studied, it would be reasonable to assume a technical potential of about 150GWh per annum. This is equivalent to about 3% of current Northern Ireland electrical generation. A Category *(c)* figure might be about half of this.

Two larger schemes on the Lower Bann and the River Mourne have been well researched and would certainly now be economic. They would have a total installed capacity of 40MW and would generate 110GWh per annum.

1.7
Summary

The information given in this paper is summarised in Table 1.1.

The estimates in this paper are based on the sources cited, on the references and on private communications from A.T. Chenhall and F.G.Johnson of the North of Scotland Hydro-Electric Board and Dr S.R.Cochrane of Queen's University, Belfast, which dealt, respectively, with Scotland and Northern Ireland.

It is now reasonable to assume that there are upward of 500 sites in the U.K. where small-scale hydro-power could be developed with a better-than-even chance of economic viability.

References

1. Francis, E.E. Small-scale hydro-electric development in England and Wales. In *Conference on Future Energy Concepts,* Institution of Electrical Engineers, London, Jan 1981.
2. *Electricity in Scotland: Report of the Committee on Generation and Distribution in Scotland.* HMSO, Cmnd 1859, London, November 1962 (the 'Mackenzie Report').
3. Department of Energy. *Report on small-scale hydro-electric potential of Wales.* University of Salford, Department of Civil Engineering, Oct 1980.
4. Department of Energy. *Report on the potential for small-scale hydro-electric generation in the Water Industry in England.* University of Salford, Department of Civil Engineering, April 1984.
5. Department of Environment. *Surface Water: United Kingdom, 1976–80.* HMSO, London, 1981.
6. Wilson, E.M. *Engineering Hydrology,* 3rd Edition, p. 117. Macmillan, 1983.
7. *Report of the Water Resources Committee.* HMSO, London, 1921.
8. *Hydro-electric works in North Wales. Further developments.* Report to North Wales Power Company, September 1944. Freeman, Fox & Partners and James Williamson, 25 Victoria Street, London SW1. Internal Report No. 54.
9. Williamson, J. Water power development in Great Britain. *I.C.E. Joint Summer Meeting,* Dublin, 1949.