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EUROPEAN ATLAS OF SMALL HYDROPOWER POTENTIAL PHASE II

Interim Report to European Small Hydropower Association

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Executive Summary

The European Atlas of Small Hydropower Potential will enable local authorities, water resource planners and potential investors to assess the feasibility of developing small hydropower schemes anywhere in the European Union (EU). The Atlas, which will be presented as a menu-driven software package for an IBM-compatible PC (486 or equivalent), will incorporate methods for deriving flow duration curves at ungauged sites and will provide a means of using these curves to estimate the hydropower potential.

The Atlas is being developed in three phases. The first phase, which was completed in February 1993, included a review of data and procedures available for each EU country. The second, and current, phase focuses on developing the Atlas for two countries (Spain and the UK) and a prelimanary database for one other (Italy). Phase III of the project will extend the Atlas to the remaining EU countries.

Work within Phase II has been undertaken by a consortium of contractors (the Institute of Hydrology, UK, Internacional de Ingeniera y Estudios Tecnicos, SA (INTECSA), Spain and Verdeacqua, Italy) under the project management of Wilson Energy Associates Ltd, UK. This document, the Interim Report from the Institute of Hydrology, describes the progress in Phase II from 1 February to 31 August, 1994.

The principal activities within the reporting period have concentrated on the collation of appropriate data from Spain and Italy, the preliminary statistical analysis of UK data and the specification, design and development of software modules. Progress can be summarised as follows:

1. The transfer of gauged daily flow data to the Institute of Hydrology from subcontractors in Spain and Italy has been undertaken;

2. The completion of a pilot exercise to confirm the integrity of digitised catchment boundaries provided by the subcontractors yielded satisfactory results. The transfer of a limited number of digitised catchment boundaries for selected Spanish catchments has been completed;

3. Maps of rainfall (annual and monthly), potential evaporation and hydrogeology have been supplied for Spain. The maps have been digitised by the Institute of Hydrology;

4. Linear least square multiple regression analysis has been undertaken using the low flow statistics and the hydrological response of the catchment from gauged daily flow records of selected gauging stations in the UK;

5. User requirements for the Atlas have been agreed, software design specifications have been completed and programming is in progress.

Phase II of the development of the Atlas has progressed satisfactorily to date. Activities scheduled over the next two to three months will, however, prove more critical in ensuring that the Atlas is completed on time and within budget. These will include finalising the gauging station selection, the loading and quality control of time series data and digitised catchment boundaries for all selected gauging stations, assembly of a catchment characteristic database, analysis of the river flow data and catchment characteristics for estimating the mean flow and flow duration curves at ungauged sites in Spain and finally, implementing the design procedures within the software.

Preface

This report discusses the progress made during the second phase of the development of the European Atlas of Small Hydropower Potential and refers to the period 1 February to 31 August 1994. The work has been undertaken on behalf of the European Small Hydropower Association (ESHA) by the Institute of Hydrology in the UK (acting as technical coordinators), INTECSA in Spain and Verdeacqua in Italy under the general project management of Wilson Energy Associates Ltd., UK and funded by the EU (DGXVII) Altener Programme.

The output from Phase II will be an Atlas, in the form of a PC-based software package, for the UK and Spain which will incorporate a database of flow and catchment characteristic data and methods for estimating the hydropower potential of ungauged sites, with a preliminary database of time series and spatial data for Italy. Subject to the success of the current development, Phase III will extend the Atlas to the remainder of the European Union.

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1 Introduction

The European Atlas of Small Hydropower Potential will enable local authorities, water resource planners and potential investors to assess the feasibility of developing small hydropower schemes anywhere in the European Union (EU). The Atlas, which will be presented as a menu-driven software package for an IBM-compatible PC (486 or equivalent), will incorporate methods for deriving flow duration curves at ungauged sites and will provide a means of using these curves to estimate the hydropower potential.

The first phase of the Atlas, completed in February 1993, was a review of hydrological and catchment data available within the European Union and included a critical evaluation of the limited number of methods available for deriving flow estimates and hydropower potential at ungauged locations. It recommended that the flow estimation procedures incorporated into the Atlas should be applicable to all EU countries, be inexpensive to implement for individual, small-scale, hydrological design schemes, be simple and easy to apply and require a minimum of hydrological knowledge. Phase I also recommended that the methodology proposed by the Institute of Hydrology, which uses simple relationships between flows and key hydrogeological catchment characteristics, was selected as the principal flow estimation component for the Atlas.

Under the second, and current, phase of the project the Atlas will be developed for the UK and Spain, to include a database of flow data and catchment characteristics and methods for estimating hydropower potential. A preliminary database will be established for Italy. The objective of Phase III, which will depend upon the success of Phase II and further EU funding, will be extend the Atlas to the rest of the EU member states.

The principal objectives of Phase II of the project are to:

1. Establish a database of river flow data, gauging station information, catchment boundaries, catchment characteristic data (rainfall, temperature, potential evaporation etc) from which to develop statistical techniques for estimating the flow regime at an ungauged site for the UK, Spain and Italy;

2. Undertake statistical analyses of the assembled data for Spain and the UK to develop methods for estimating the flow regime, as expressed by the flow duration curve, for ungauged catchments within these countries;

3. Identify current engineering methods for estimating hydropower generation potential at the ungauged site from the flow duration curve;

4. Develop software to allow easy application at the ungauged site of the methods developed and identified in 2 and 3.

This report is the first interim report on Phase II of the project and reports on the progress made during the period 1 February 1994 and the 31 August 1994. The principal activities within the reporting period have concentrated on the collation of all appropriate data from Spain and Italy, the preliminary statistical analysis of UK data and the specification, design and development of software modules.

The progress towards meeting these objectives is presented in the following chapters. Chapters 2 and 3 present the progress which has been made in the collation and quality assessment of gauged river flow data and spatial data from the UK, Spain and Italy. Regional relationships between the catchment characteristics and low flow statistics have been investigated for the UK and discussed in Chapter 4. Chapter 5 discusses some of the technical components for the design of the Atlas, with the implementation within the software. Chapter 6 summarises the future progress during the next reporting period and Chapter 7 draws some conclusions as a result of the progress made to date.

2 River flow database

2.1 INTRODUCTION

The basic requirement for the development of statistical relationships between the flow regimes and the catchment characteristics is a database of river flow data of acceptable quality. The key steps in the development of a coherent, high quality database are listed as:

1. The selection of 200-300 gauging stations in each country which satisfy the following criteria: catchment size less than 2000 km^2; good hydrometric quality; minimal artificial influences; complete daily flow records of 10 years or more;

2. Compilation of a master list of gauging stations including the following details for each of the stations selected in 1: river name; site name; location in UTM coordinates; catchment area; mean rainfall;

3. Development of unique station numbering scheme for gauging stations throughout Europe;

4. Transfer of the flow data in a standard format to the database at the Institute of Hydrology;

2.2 PROGRESS WITHIN THE PERIOD

The principal activities during the period have been in connection with the transfer of data from Spain and Italy. In accordance with the agreed work-plan, gauged river flow data for both countries have been received by the Institute of Hydrology. Details of the data transferred are presented below.

Italy
The Italian data consisted of gauged daily flows for 180 catchments for the period 1958-67, equivalent to a total of 1639 station years, each provided in a separate file (ie in 1639 individual files) which has led to severe processing difficulties. This problem would have been alleviated if the agreed transfer of sample data from five stations had been achieved. The spatial distribution of stations over Italy is very good but the absence of any data from Italy after 1967 is disappointing. Longer records would improve the estimates of sample flow statistics and more recent data would be of higher accuracy as a result the improvement in the accuracy and processing of data associated with advances in hydraulic practice and computing facilities in recent years.

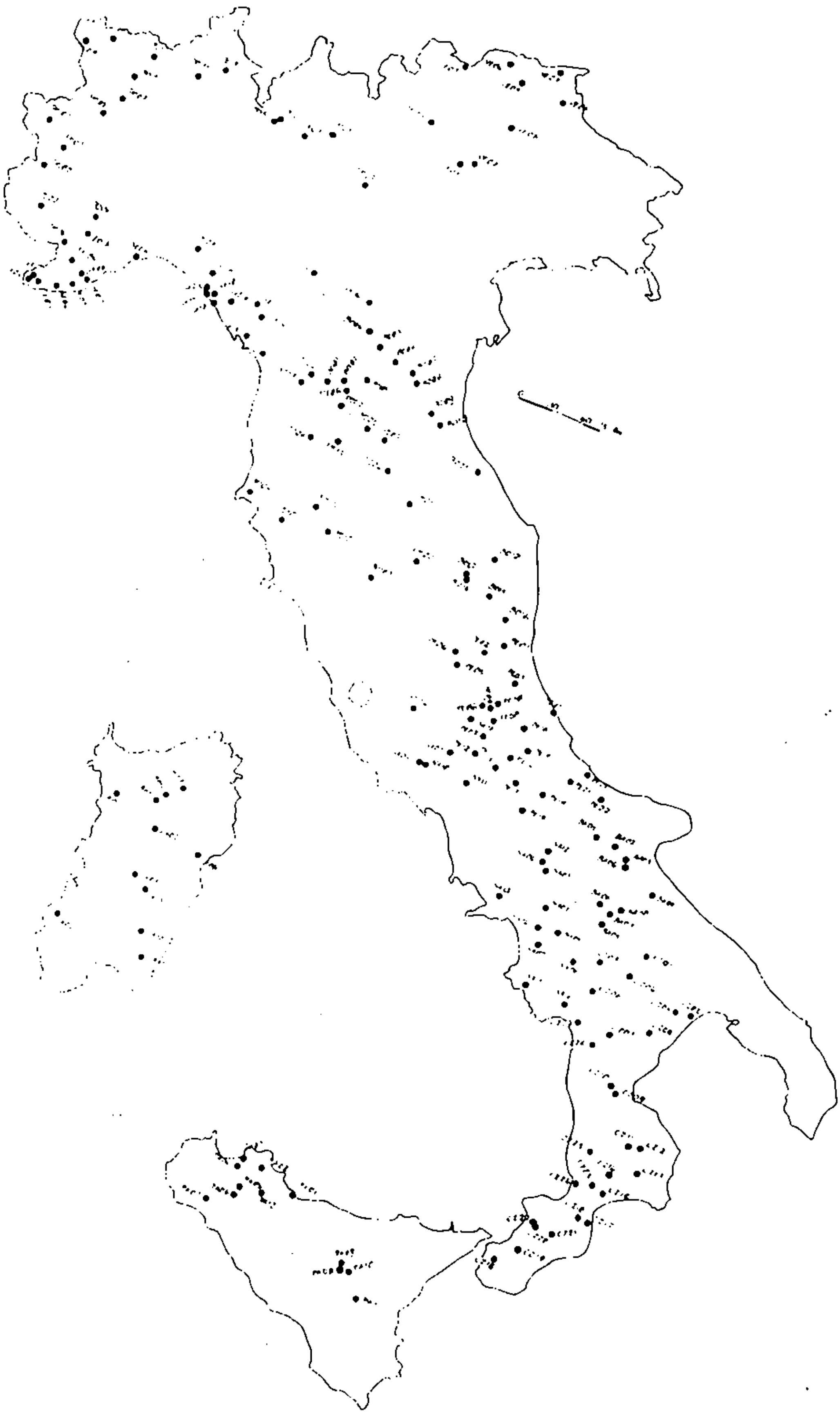


Figure 2.1 Location of gauging stations in Italy

Details of the gauging stations which accompanied the flow data consisted of the river name, site name and duration of record only. A map that was provided, illustrated in Figure 2.1, contained insufficient detail to accurately locate the gauging stations. The Institute will be contacting Verdeacqua to obtain the appropriate coordinate data and additional station details.

Spain

The Spanish data consisted of gauged daily flow data for 179 catchments, the majority having data for a 10 year period from the mid seventies (circa 1974) to the mid eighties (circa 1985). Unique numbers have been allocated to each gauging station according to the FRIEND numbering scheme. The data was provided in the required format and is currently in the process of being loaded onto the ORACLE database management system at the Institute.

UK

Within the UK, gauged flow data is available up to the end of 1993 from the National River Flow Archive. A station list of 730 gauging stations has been selected which satisfy the selection criteria. The quality of the gauging station records has been assigned using criteria defined by Gustard et al (1992).

3 Spatial database

3.1 INTRODUCTION

A central component of estimating catchment characteristics is the ability to overlay digital catchment boundaries for the selected gauging stations over raster thematic maps of catchment characteristics. Phase I of the project identified the catchment characteristics that would be significant for the development of procedures for estimating low flow statistics, notably:

(i) The hydrological response of a catchment;

(ii) Rainfall (annual & seasonal);

(iii) Potential/Actual Evaporation (annual & seasonal);

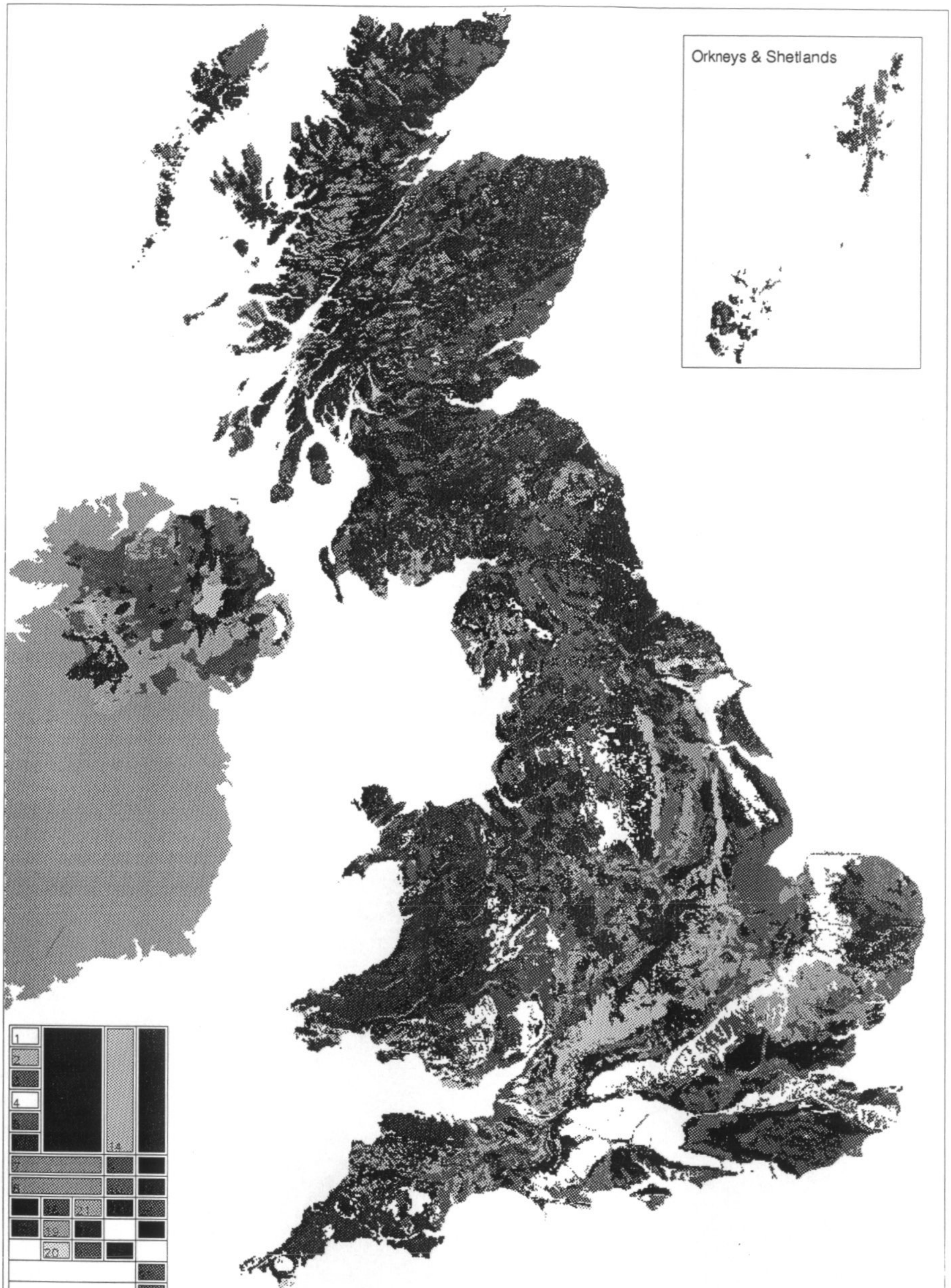
(iv) Topographic catchment boundaries.

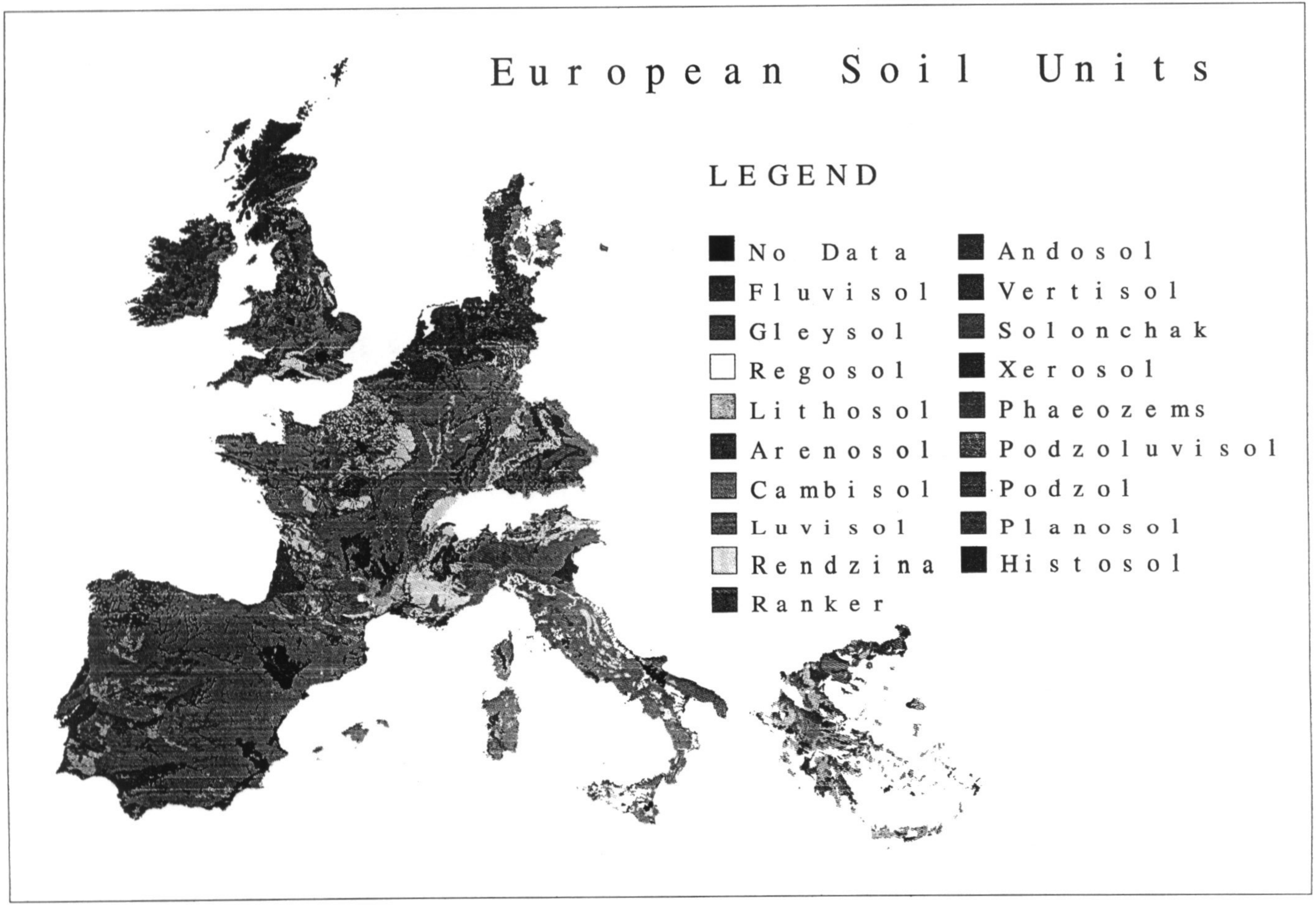
Within the UK all of these data are readily available digital form. The hydrological response of UK catchments is characterised by the Hydrology of Soil Types (HOST) classification (Boorman and Hollis, 1990) derived from 1:250 000 soil association maps, illustrated in Figure 3.1. In previous UK studies this has only been available in a provisional form, however, the recently published final version (Boorman et al, 1994), is being used for this study.

***Figure 3.1 (opposite)** Hydrology of Soil Type (HOST) classification for the UK*

***Figure 3.2 (following)** CEC European soil map for Europe*

Dominant HOST Class on 1km Grid




European Soil Units
LEGEND
No Data
Fluvisol
Gleysol
Regosol
Lithosol
Arenosol
Cambisol
Luvisol
Rendzina
Ranker
Andosol
Vertisol
Solonchak
Xerosol
Phaeozems
Podzoluvisol
Podzol
Planosol
Histosol

For Spain and Italy, the subcontractors have been requested to identify and collate climatic maps (rainfall, potential evaporation) and to undertake the task of digitising catchment boundaries for the gauging stations selected for the study. National soil maps are available for most EU countries but classification systems vary between countries and many maps are not available in digital form. As a result, the digitised soil map derived from the FAO classification of European soils (1:1 000 000 scale) (CEC, 1985), illustrated in Figure 3.2, will be used for the development of a hydrogeological classification of soils for this project.

3.2 PROGRESS WITHIN THE PERIOD

The principal activity within the specified period of Phase II has been to obtain national maps within these countries and to digitise the appropriate catchment characteristic data.

3.2.1 Catchment boundaries

In order to ensure that accurate and consistent drawing and digitising of catchment boundaries from the base maps, a pilot exercise was undertaken in which the contractors were requested to digitise the topographic boundaries of three UK catchments for which accurate boundaries already exist. INTECSA were also asked to digitise three additional Spanish catchments to be compared with boundaries defined by IH.

A specification for digitising the boundaries and transferring the data, including acceptable standards of error, was drafted by the Institute of Hydrology and distributed to the consultants for the work to be undertaken during February and March. The results of the pilot study are summarised below.

Spain
The catchment boundaries were digitised and transferred to the Institute of Hydrology in February, 1994. All six were successfully loaded onto the ARC/INFO Geographical Information System for checking. One of the catchments boundaries was found to have a minor digitising error consisting of two unconnected lines, which was rectified within ARC/INFO.

To evaluate the accuracy of the digitising procedure, the catchment boundaries were compared visually with boundaries digitised by the Institute and with boundaries derived from the Digital Terrain Model (DTM). The area of the transferred boundaries were found to compare favourably with the existing boundaries, with differences of less than 6% compared with the Institute boundaries and less than 3% compared with the DTM presented in Table 3.1.

Digitised boundaries for the three selected Spanish catchments were not held by the Institute, therefore these were required to be digitised by the Institute before a comparison of the boundaries could be undertaken. The calculated area for two catchment boundaries were within 3% of the IH estimates. However, the remaining catchment was found to have a significantly higher catchment area (by 50%), but following an investigation, this was found to be as a result of incorrect gauging station coordinates supplied to the Institute.

Table 3.1 *Comparison of UK digitised catchment boundaries*

	Area (km^2)			Differences (%)		
Catchment	DTM	IH	Contractor	IH vs DTM	Contractor vs DTM	Contractor vs IH
INTECSA						
53006	151.6	150.3	150.2	-0.8	-0.9	<-0.1
53023	77.7	74.8	79.0	-3.7	+1.7	+5.6
53028	99.4	100.9	102.2	+1.5	+2.5	+1.3
Verdeacqua						
53006	151.6	150.3	153.3	-0.8	+1.1	+2.0
53023	77.7	74.8	73.7	-3.7	-5.1	-1.5
53028	99.4	100.9	100.7	+1.5	+1.3	-0.2

Hydrometric areas for the whole of the Iberian Peninsula have been defined, illustrated in Figure 3.3. INTECSA have provided digitised boundaries for 42 catchments in the Norte and Primero regions.

Italy

Three UK catchment boundaries were digitised and transferred to the Institute of Hydrology in April, 1994 where they were successfully loaded onto the ARC/INFO Geographical Information System for checking. As with the Spanish data, the catchment boundaries were compared with boundaries digitised by the Instute and those defined by the DTM. The boundaries compared favourably with the IH boundaries. Differences in catchment area were less than 2% compared with the Institute estimates and less than 5% compared with the DTM, as presented in Table 3.1.

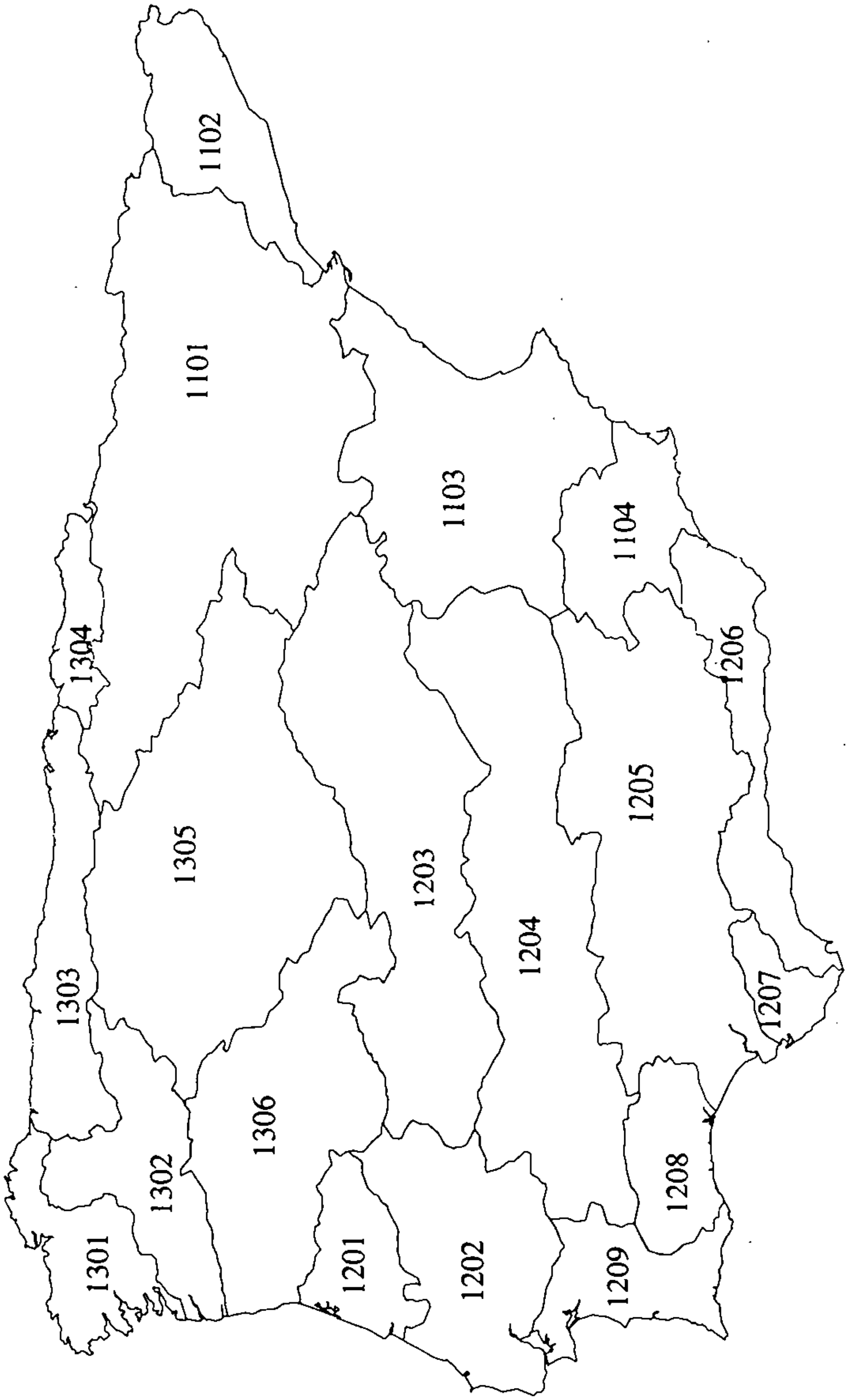
The results of the exercise confirmed that both subcontractors were capable of digitising the catchment boundaries. Both INTECSA and Verdeacqua were notified of the conclusions.

3.2.2 Database of catchment characteristics

Italy

Hydrogeological and climatic maps of annual and monthly potential evaporation and rainfall at a scale of 1:25 000 have been requested from Italy. These maps have not yet been received.

Figure 3.3 Hydrometric area boundaries in Spain



Spain
The Atlas Climático de España containing maps of mean annual and monthly rainfall at a scale of 1:3 000 000 and other climate data (at the 1:3 000 000 or 1:6 000 000 scale based on 1931-1960 data from 5000 measuring stations) have been supplied by INTECSA. In addition, a hydrological map (Mapa Hidrológico de España for 1:1 200 000 scale) has been provided which illustrates the major rivers and reservoirs within the region. All the climatological maps have been digitised by the Institute of Hydrology. INTECSA have been asked to check the availability of larger scale climatic maps.

Further catchment characteristic maps, notably the IIASA maps of 0.5° x 0.5° gridded temperature, rainfall and cloud cover notionally based on 1931-60 data average in each cell are already available at the Institute.

UK
Thematic maps of HOST (1:250 000 scale), potential evaporation (1:2 000 000 scale) and standard period average annual rainfall (1: 625 000) are held in digital format on ORACLE at the Institute.

4 Relationship between river flow and catchment characteristics

4.1 INTRODUCTION

The first step towards the estimation of the hydropower potential in small, ungauged catchments is to derive a flow duration curve, based on the relationship between the flow regime and catchment characteristics, from which the power/efficiency statistics can be estimated for a site. Demuth (1994) and Gustard (1992, 1993) have illustrated how national and regional design procedures can be developed within Europe. The advantage of these approaches was that they made use of the best available data in each region covered.

In the UK, the procedure utilises precipitation and evaporation to estimate the mean flow and multivariate regression analysis to identify relationships between the low flow response of a catchment, represented by the 95 percentile flow (Q95), and the hydrogeological response of the soils, represented by the Hydrology of Soil Type (HOST) classification (Gustard et al, 1992). Initially, this approach made use of a provisional HOST data set which was based on a single map unit of 1km^2 to which the HOST classes were ascribed. Since the development of equations to estimate low flow statistics from hydrological characteristics, the HOST database has been revised and updated to take into account increased coverage in Northen Ireland, the use of all map units in each grid square to estimate the proportions of HOST classes, the reclassification of urban areas and the reassignment of some soil series to different HOST classes.

In addition, since the original study, the available data has increased as a result of three years of additional data and an increased number of gauging stations, which include Northern Ireland. Therefore, this Chapter discusses the preliminary results of the relationship between flow statistics and hydrogeological characteristics using the revised HOST classification and the increased available data set.

4.2 PROGRESS WITHIN THE PERIOD

Linear least square multiple regression analysis has been undertaken to relate the Q95 statistic (the flow exceeded 95% of the time) with the Hydrology of Soil Type (HOST) classification. The analysis has been undertaken using the flow records from730 gauging stations in the UK. Low flow statistics have been calculated for these stations, using data to the end of 1992. The percentage coverage of the 29 HOST classes for each of the 730 catchments were derived by overlaying the digitised catchment boundaries onto the revised HOST database.

The parameter estimates derived from the regression analysis are presented in Table 4.1. The results are comparable with the results obtained from the previous study. In 1992, the relationship developed using the provisional HOST classification explained 59% of the variance. The use of the revised HOST classification and increased gauging stations explains 54% of the variance. Some regional and climatic factors may account for the difference.

Table 4.1 *Q95 estimates for HOST classes*

HOST class	Q95 Parameter	s.e of Parameter	HOST class	Q95 Parameter	s.e of Parameter
1	37.0	1.7	17	14.6	2.3
2	28.7	2.8	18	12.5	2.3
3	54.7	3.8	19	23.9	8.1
4	28.2	3.2	20	41.3	16.6
5	55.6	4.9	21	5.9	1.8
6	34.8	6.3	22	-12.2	13.9
7	-14.6	12.8	23	-3.5	8.7
8	-17.1	19.8	24	7.7	1.4
9	30.5	17.3	25	-3.5	3.2
10	30.4	10.9	26	4.0	3.1
11	60.4	37.2	27	-11.3	11.3
12	-18.6	7.9	28	29.1	11.6
13	56.6	13.0	29	9.1	2.7
14	7.1	18.9	97	18.9	2.7
15	14.9	2.7	98	89.3	29.7
16	24.4	12.6			

R^2 = 54.46%
standard error = 7.422

The poor representation of certain HOST classes, in terms of the proportional area within a catchment, are reflected in the results of the analysis with high standard errors in the parameter estimates of the Q95. For example, the highest standard error of the Q95 are associated with HOST class 11 which represents less than 15% coverage within gauged catchments. The regression analysis also identified that HOST classes with similar soil and hydrogeological characteristics with respect to their low flow response possess similar parameter estimates.

Gustard et al (1992) recommended that the HOST classes could be grouped into a smaller number of low flow response units. These units were a combination of HOST classes with similar physical characteristics, which, in some case, were supported by the results of the regression analysis. One strategy which was investigated was to place the revised HOST classes into 10 Low Flow HOST Groups, presented in Table 4.2. Multivariate analysis has been undertaken between the low flow statistic and the Low Flow HOST Groups. The results of the analysis are presented in Table 4.3

Table 4.2 Assignment of HOST classes to Low Flow HOST Groups

Low Flow HOST Group	Constituent HOST classes
LFHG1	HOST1
LFHG2	HOST2
LFHG3	HOST3, HOST5
LFHG4	HOST4
LFHG5	HOST6, HOST13
LFHG6	HOST7, HOST8, HOST9, HOST10, HOST11
LFHG7	HOST14, HOST16, HOST17, HOST18, HOST19, HOST21, HOST22, HOST24
LFHG8	HOST20, HOST23, HOST25
LFHG9	HOST15
LFHG10	HOST12, HOST26, HOST27, HOST28, HOST29
LFHG11	HOST97
LFHG12	HOST98

When the Q95 is regressed against the Low Flow HOST Groups, the standard errors of the parameter estimates are reduced compared with the full HOST data set. In addition, no negative parameter estimates have been calculated. In general, the parameter estimates are different from each other, with the exception of parameter estimates for Low Flow HOST Groups 2 and 4. Future analysis will include the investigation of different grouping strategies to try to improve the variance explained by the smaller number of hydrological groups.

Table 4.3 *Q95 estimates for Low Flow HOST groups*

Low Flow HOST Group	Q95 Parameter	s.e of Parameter
1	38.10	1.7
2	29.18	2.5
3	58.06	2.8
4	27.63	3.1
5	41.13	5.2
6	12.07	5.0
7	9.69	0.8
8	1.95	1.9
9	15.73	2.3
10	6.08	1.5
11	15.25	2.4
12	62.31	27.5

R^2 = 51.31%
standard error = 7.571

5 Software design and development

5.1 INTRODUCTION

The principal output from the project will be a user-friendly menu-driven software package, which will enable users with little hydrological knowledge to apply the flow duration curve and hydropower potential estimation methods to all EU countries.

5.2 PROGRESS DURING THE PERIOD

In association with Wilson Energy Associates Ltd a software specification has been developed by the Institute of Hydrology detailing the operating environment for the software, the target user and defining the methodologies to be incorporated into the software. In response to the specifications document, further documents have been produced by the Institute which define the scope and identify the feasibility/requirements of the software in order to develop the functional design of the software.

A modular approach to the software has been adopted, consisting of three modules:

(i) The catchment characteristics estimation module;

(ii) The flow duration curve estimation module;

(iii) The power estimation module.

The software is being written in QuickBASIC package and will run under Windows V3.0 or above. Beta versions of the flow duration curve and power modules are approaching completion 2 months ahead of schedule. The key principles in the design procedure are discussed in the following sections. For further information refer to the complete Software Specifications enclosed in Annex 1.

5.2.1 Estimation of the flow duration curve

The detailed procedures for deriving flow duration curves at the ungauged site, currently being developed through Phase II of the project, will vary for each country within the EU. However, the general principles required for the derivation of the flow duration curve are summarised below:

1. For selected catchment identify the catchment boundary and estimate the catchment area;

2. Overlay the catchment boundary onto gridded catchment characteristic maps to estimate catchment average values of annual average rainfall, potential evaporation and the fractional extent of individual soil units;

3. Estimate the mean flow using a simple water balance model incorporating the average annual rainfall and potential evaporation;

4. Calculate a standardised low flow statistic using the appropriate relationship between flow and soil characteristics (assigned to hydrological response units as appropriate);

5. Using the estimated low flow statistic, identify a standardised flow duration curve from a set of representative flow duration curves;

6. Rescale the standardised flow duration curve by the estimate of mean flow to give the flows in absolute units (m^3s^{-1}).

In order to utilise the results of the flow duration curve, it is proposed that the estimated flow duration curve will be defined by seventeen plotting positions along a curve which will be stored and transferred into the power equations.

5.2.2 Estimation of hydropower potential

The Software Specifications (Annex 1) specifies the steps required for calculating the maximum power and capacity of different turbines, a comparison of which will give an indication of the generating potential of any site along a river network, provided the flow duration curve could be established and some hydraulic characteristics could be defined.

The procedure can be summarised as follows:

1. Identify suitable turbine types for the given hydraulic head and mean flow conditions and identify the flow-efficiency curves for the selected turbine types;

2. Calculate the useable region of the flow duration curve defined by the mean flow, a minimum residual flow required to maintain acceptable environmental and economic conditions in the water course and the minimum flow requirements for the selected turbine types, illustrated in Figure 5.1;

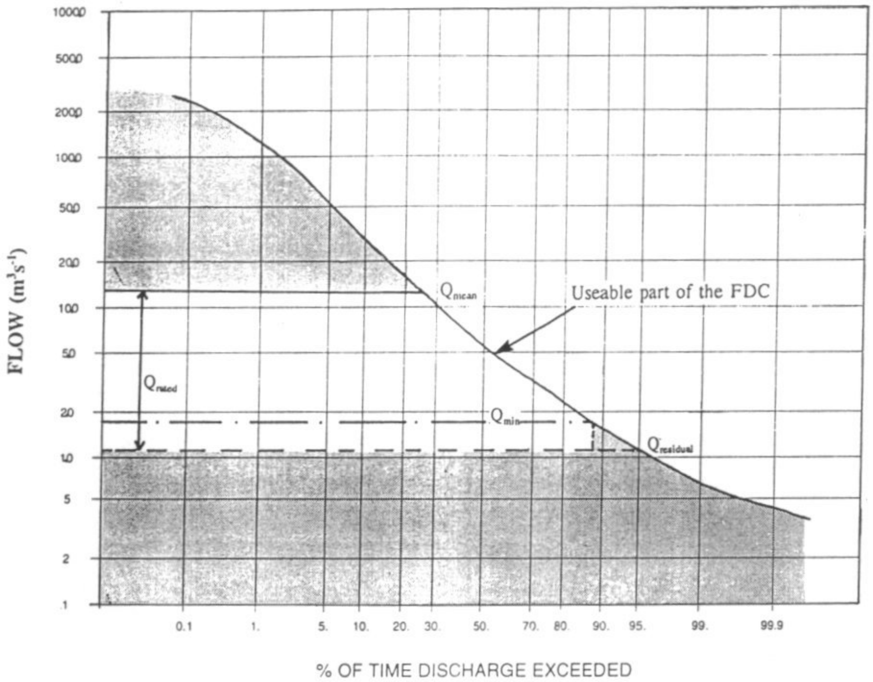


Figure 5.1 *Definition of the useable portion of the flow duration curve*

3. Estimate the average annual energy potential over the useable portion of the flow duration curve and the peak power generation capability of the site, taking into account the flow-efficiency relationship, hydraulic head and acceleration due to gravity where:

(i) the gross average energy, E in kWh, is given by:

$$E = fn\,(Q, H, \eta_{turbine}, \eta_{gearbox}, \eta_{generator}, \eta_{transformer})$$

where:

Q	= flow (in m^3s^{-1}) for incremental steps on the flow duration curve
H	= specified head (in m)
$\eta_{turbine}$	= turbine efficiency, a function of Q
$\eta_{gearbox}$	= gearbox efficiency, constant for specified turbine type
$\eta_{generator}$	= generator efficiency, constant for specified turbine type
$\eta_{transformer}$	= transformer efficiency, constant for specified turbine type

(ii) the net average annual energy is calculated, expressed in MWh, by deducting 5% from the gross energy for maintenance, repair, downtime and dividing by 10^3.

(iii) the maximum turbine power, P_t in kW, and the rated capacity, C_r in kW, are calculated using:

$$P_t = Q \cdot H \cdot \eta_{turbine} \cdot \gamma$$

$$C_r = P_t \cdot \eta_{gearbox} \cdot \eta_{generator}$$

where:

γ = specific weight of water (9.81 kNm^{-3})

6 Future programme of work

The project to develop the European Atlas of Small Hydropower Potential has progressed largely in accordance with the Scheme of Technical Activities specified in the Phase II proposal document, Annex 1 (Gustard and Young, 1993). The activities were divided into four distinct groupings: project management; analysis of river flow data; analysis of catchment characteristics and development of design procedures and software. Estimates of the percentage of each task which has been completed and outstanding activities within each group are shown in Table 6.1. The key elements of the remaining work schedule are as follows:

6.1 ANALYSIS OF RIVER FLOW DATA

1. Finalising the compilation of the master list of gauging station data, to include all required information, is essential. INTECSA have already supplied a preliminary list of 179 gauging stations and a revised version will be available during the week beginning 26 September, 1994. Additional information will be required for the 180 gauging stations selected by Verdeacqua. This will include the station location in UTM coordinates, catchment area, and average annual rainfall estimates for each catchment;

2. The gauged daily flow records provided by both INTECSA and Verdeacqua are in the process of being loaded onto the central database at the Institute of Hydrology. Some difficulties have been encountered with the way in which the Italian data were presented, but these problems are not unsurmountable. However, there is concern that the period represented by the Italian data (1958-1967) may no longer be representative of the hydrological regime in the region and the Institute of Hydrology will need to contact Verdeacqua to check the availability of more recent data;

3. Once the data have been loaded onto the archive, quality checks will be undertaken to ascertain the suitability of the data for regional analysis.

Table 6.1 *Schedule of activities completed during the period*

	Activity	Estimate % completed	Comments	Action
1	**PROJECT MANAGEMENT**	50		WEAL
2	**ANALYSIS OF RIVER FLOW DATA**			
2.1	Finalise design procedure with ESHA	100		
2.2	Compile master list of gauging stations	80	179 Spanish stations selected but a revised station list is expected w/b 26-09-94.	INTECSA
			180 Italian stations selected. Additional information required for stations.	IH, VA
2.3	Gauging station selection	80	See 2.2. IH to request report on selection procedures adopted	IH
2.4	Gauging station numbering scheme	90	Italian hydrometric areas to be defined	IH
2.5	Identify status of flow record	100	All data available in digital form	
2.6	Letters requesting transfer of flow record	100	All permissions granted	
2.7	Transfer of flow data from other organisations	80	IH to query availability of recent Italian flow data	IH, VA
			Additional Spanish data available subject to 2.3	INTECSA
2.8	Reformatting data into standard format	80	Dependant on 2.2, 2.7	
2.9	Transfer and load flow data onto database	10	In progress; some difficulty encountered with Italian data; dependant on 2.4 and 2.7	IH
2.10	Quality control flow data	0	Dependant on 2.9, 2.11 and 2.12	IH
2.11	Plot hydrographs	0	Dependant on 2.9	IH
2.12	Plot flow duration curves	0	Dependant on 2.9	IH
3	**ANALYSIS OF CATCHMENT CHARACTERISTICS**			
3.1	Draw catchment boundaries from national maps	20		INTECSA, VA
3.2	Digitise catchment boundaries	20	Digitised boundaries for 42 Spanish catchments received. Target date for transfer of all boundaries to IH (179 Spanish and 180 Italian) 30-09-94.	INTECSA, VA
3.3	Assemble national AAR and seasonal rainfall maps	50	Spanish maps received.	
			Italian maps due at IH by 30-09-94, no additional information forthcoming	VA

Table 6.1 contd *Schedule of activities completed during the period*

	Activity	Estimate % completed	Comments	Action
3.4	Digitise AAR and seasonal rainfall maps	50	Spanish rainfall maps digitised at IH Digitised Italian data due at IH by 30-09-94	 VA
3.5	Compile and digitise maps of average annual p.e.	50	Spanish p.e. maps digitised at IH Digitised Italian data due at IH by 30-09-94	 VA
3.6	Develop hydrological response map of European soils	30	Map derived for UK. Dependant on 2.9, 2.10, 3.2	IH
3.7	Computer overlaying of catchment characteristics	30	Analysis conducted for UK. Dependant on 2.9, 2.10, 3.2	IH
3.8	Assemble database(numerical) of catchment characteristics	30	Established for UK. Dependant on 3.6, 3.7	IH
4	**DEVELOP DESIGN PROCEDURES AND SOFTWARE**			
4.1	Develop procedures to estimate mean flow	20	Established for UK. Dependant on 2.9, 2.10, 3.7	IH
4.2	Relate flow duration curves to catchment characteristics	20	Analysis conducted for UK. Dependant on 2.9, 2.10, 3.7	IH
4.3	Develop methods for estimating power/energy	100		
4.4	Develop menu driven software	50	Work in progress. Dependant on 4.1, 4.2, 4.7	IH
4.6	Produce User Guide in 3 languages	0		IH
4.7	Load national database onto software	0	UK data available but not loaded. Dependant on 3.8	IH

Key :

WEAL	Wilson Energy Associates Ltd., Stockport, UK
IH	Institute of Hydrology, Wallingford, UK
VA	Verdeacqcua, Cuneao, Italy
INTECSA	INTECSA, Madrid, Spain

6.2 ANALYSIS OF CATCHMENT CHARACTERISTICS

1. The provision of digitised catchment boundaries is the key to the analysis procedure. Both Verdeacqua and INTECSA have agreed to transfer all digitised catchment boundaries to the Institute by 30 September 1994. A total of 42 digitised catchment boundaries have already been supplied by INTECSA;

2. Maps, both on paper and in digitised format, of average annual rainfall, seasonal rainfall and potential evaporation for Italy are anticipated to arrive at the Institute by 30 September 1994;

3. With most of the UK analysis complete, work will focus on developing a map of the hydrological response of soils in Spain;

4. The catchment characteristic database will then be assembled by overlaying the boundaries onto the digitised maps of climate, soils and hydrogeology.

6.3 DEVELOPMENT OF DESIGN PROCEDURES AND SOFTWARE

1. Following the analysis of the river flow data and the catchment characteristics, methods for estimating the mean flow at ungauged sites will be developed for Spain. The analysis will also consider the way in which individual catchment characteristics relate to the flow duration curve at gauged sites. In establishing this relationship, it will then be possible to estimate the flow duration curve at an ungauged site;

2. The modular design of the software allows the development of the software to proceed independently of the key activities listed above. As a result, the flow duration curve and power estimation modules are approaching completion and will shortly be available for Beta-testing. With the UK analysis almost complete, applying the UK design procedures for estimating mean flow and flow duration curves should be straightforward. The development of the design procedure for Spain is, therefore, considered to be a critical activity in the Schedule.

7 Conclusions

Although progress within the first half of Phase II has, generally, been satisfactory, a number of activities due for completion within the next few weeks will be critical for the project to be completed on time and within budget.

As discussed in Chapter 6, attention will now focus on developing procedures for estimating mean flow and flow duration curves at ungauged sites in Spain. This work will rely heavily on the timely provision of data by the Spanish subcontractors, INTECSA.

Although not as time-critical to the development of the Atlas, a number of issues will need to be resolved with the Italian data. The concerns regarding the time series data will need to be addressed and essential station details will need to be provided. No details have been provided by Verdeacqua as to the progress made with the digitising of catchment boundaries and the collation of climatological maps. All such digitised data are scheduled to be transferred to the Institute by the end of September 1994.

Gauged daily flow data for the selected stations in both Italy and Spain have been received at the Institute and is in the process of being loaded onto the ORACLE database for analysis. As part of the quality control procedure, The Institute will be asking both subcontractors to provide a detailed account of the gauging station selection procedure.

The analysis of UK time series and spatial data has progressed well. The algorithm for estimating flow at ungauged sites in the UK will shortly be available for inclusion in the software. Assuming that this activity proceeds smoothly, the development of low flow estimation procedures using the Spanish data which will be most time-critical.

According to the original work schedule the target for completion of the project is 30 April 1995. The deliverables will be the final report, the European Atlas of Small Hydropower Potential software and User Guides in English, Spanish and Italian. In the intervening period, the Institute will continue to keep WEAL informed of progress through the series of monthly progress reports and technical notes.

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Annex 1

European Atlas of Small Hydropower Potential
Software Requirement

1 Introduction

In assessing the hydrological potential of a proposed site for a small hydropower scheme, the objective of the designer is to assess how much water is available to drive the generating turbines. This assessment is normally achieved by estimating the flow duration curve for the site. A flow duration curve, or cumulative frequency diagram, shows the relationship between any given discharge and the percentage of time that the discharge is exceeded. The objective of the Atlas is to estimate the full flow duration curve at the ungauged site from catchment characteristics which will provide input into power/efficiency calculations to assess a site's potential hydropower power output.

The final version of the Atlas will be applicable to all EEC countries. As there are a large number of potential sites for small hydropower schemes where often design resources are limited, the Atlas will use methods and models that are quick and easy to apply requiring a minimum of hydrological knowledge. The Atlas will take the form of a software package, with the hydrological estimation methods and power efficiency calculations embodied within it. The software will be accompanied by a user manual and report detailing the development and application of the methods.

The software will enable the flow duration curve to be estimated at an ungauged site and to be used in conjunction with the head and turbine characteristics to establish energy potential and likely installed capacity.

2 Hardware platform requirements

The potential users of the software will range from large consulting companies through to engineers unfamiliar with hydroelectric design. To reflect this the target hardware platform will be an IBM Personal Computer (or compatible) meeting the minimum requirements of:

Memory:	640 Kb (conventional)
Processor:	80386SX chip @ 20 MHz
Hard disk:	20 Mb
Graphics card:	VGA, EGA or compatible
Operating system:	DOS 5.0 or above
Floppy disc drive:	3 $^1/_2$ " DD
Output device:	Flexible; industry standard output devices should be supported

3 Software requirements

3.1 TECHNICAL REQUIREMENTS

There are two aspects of the design procedure: (i) estimation of the flow duration curve and (ii) estimation of turbine specific power output based on the estimated flow duration curve. Due to the variations in hydrological regimes across Europe a number of methods may be required to estimate (i) whereas there will be a single method for estimating (ii). It is proposed that a modular approach should be taken with the software development to allow various methods, and associated data, for estimating the flow duration curve to be implemented. The modules within the software will henceforth be referred to as the FDC modules and POWER module.

3.2 GENERAL SOFTWARE REQUIREMENTS

The software is to be a public domain Windows package running under Windows 3.1 or above and will be supplied on 3 $^1/_2$ " DD diskettes. It is essential that the software is:

(i) Robust, as the typical user will not be supported by a maintenance contract;

(ii) Compact, both in terms of the number of distribution diskettes and memory usage. The objective here is to minimise the costs of supply and avoid possible memory conflicts with other software;

(iii) Easy to install, with automatic configuration of the machine and user specification or auto-detection of output devices, ports, hardware graphics card, etc;

(iv) The option for a more advanced package with a maintenance contract may be an option for further development.

SI units are to be adopted for all numerical parameters.

4 FDC Modules

At the time of writing it is not possible to define the detailed software requirements of the FDC modules as these will be determined by the hydrological methods developed under the contract. Figure 1 shows schematically the general procedure for applying the methods. Variations on this may include the use of hydrological catchment characteristics to define the flow duration curve and incorporation of digital catchment characteristics grids.

The estimated flow duration curve will be defined by seventeen (flow,percentile point) plotting positions along the curve. The output from the flow duration curve module will be:

(i) Graphical representation of the FDC on the screen with optional hardcopy on the supported output device. Figure 2 show the required presentational style for the FDC;

(ii) Optional printout of the seventeen FDC plotting positions;

(iii) Transfer of the Plotting positions to the POWER module.

5 POWER Module

5.1 INTRODUCTION

In essence the POWER module is required to:

(i) Identify suitable turbine types for the given hydraulic head and mean flow conditions. The allowed turbine types are given in Table 1;

(ii) Identify flow-efficiency curves for the selected turbine types;

(iii) Calculate the useable part of the flow duration curve based on the mean flow, required environmental residual flow in the water course and the minimum flow requirements for the selected turbine types;

(iv) Integrate over the useable part of the FDC, taking into account the flow-efficiency relationship, hydraulic head and acceleration due to gravity, to estimate the total power generation and peak power generation capability of the site.

This section details the technical methods to be incorporated.into the module and the required inputs and outputs for the module.

Table 1 *Turbine types*

Turbine Type	Q_{min} (% Q_{rated})
Francis Spiral Case (SC)	30
Francis Open Flume (OF)	30
Semi Kaplan	30
Kaplan	20
Cross Flow	15
Pelton	10
Turgo	10
Propeller	65

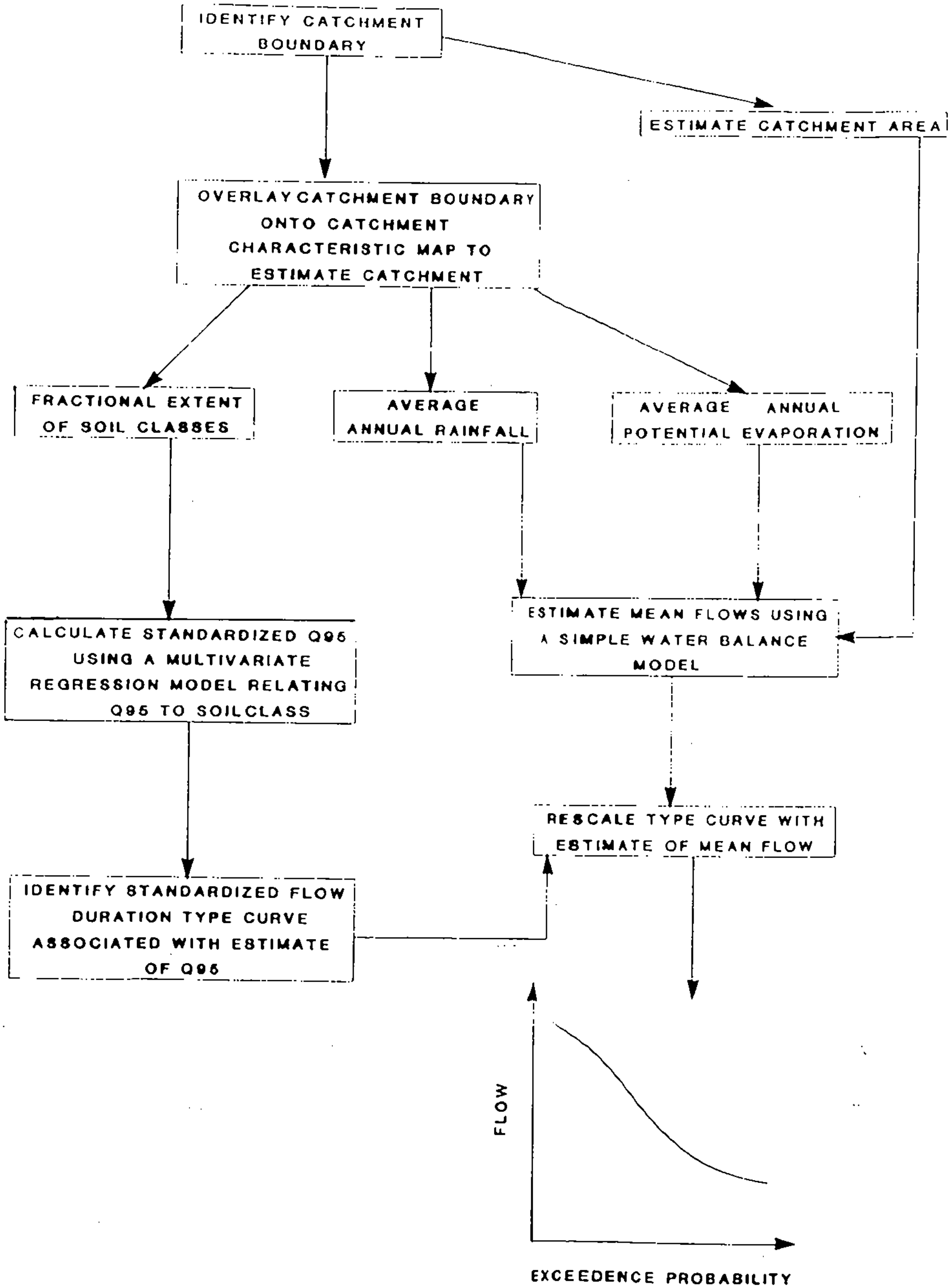

Figure 1 *General method for estimating the flow duration curve*

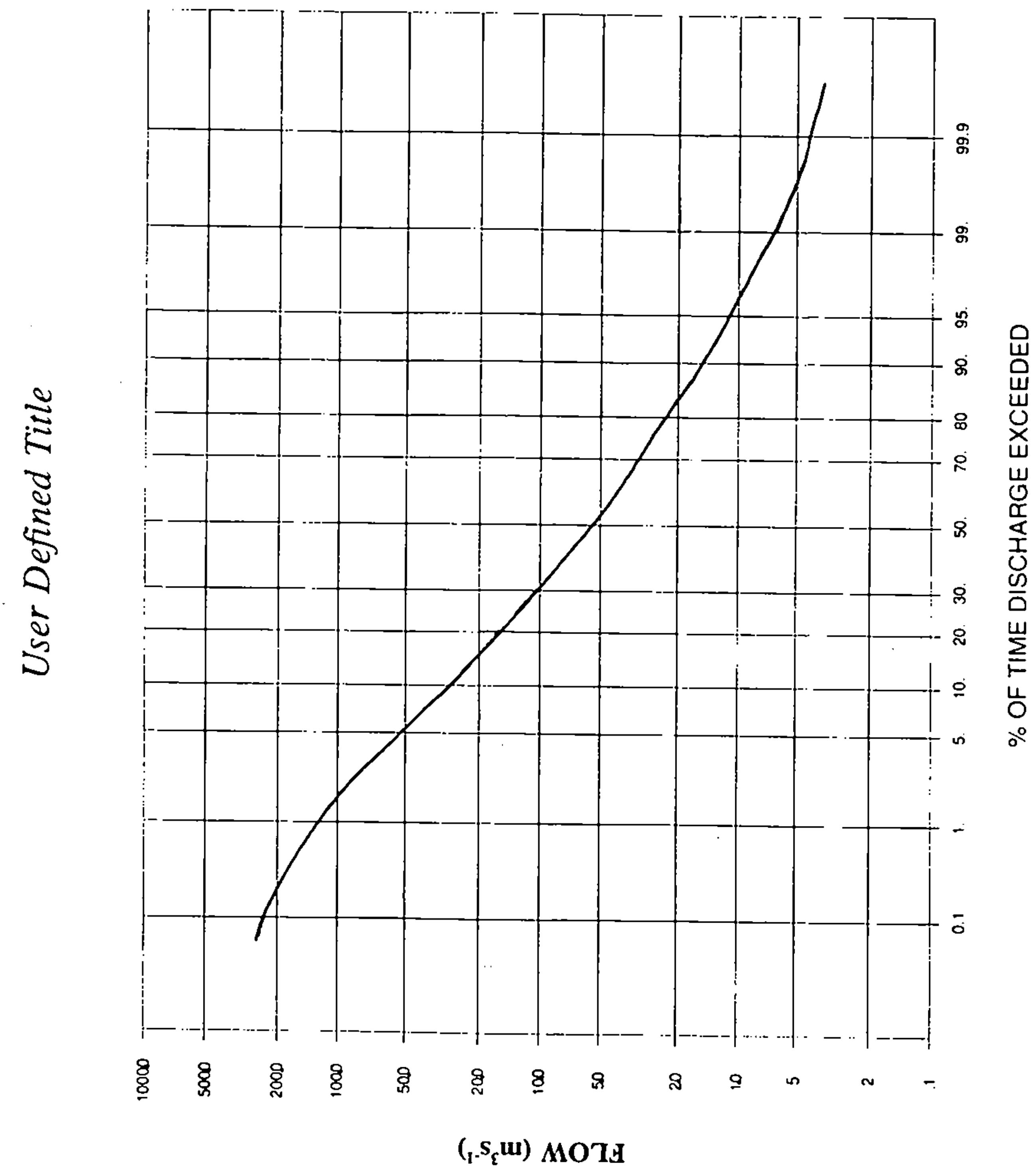

Figure 2 *Required flow duration curve display*

5.2 REQUIRED INPUTS

The required input data for the POWER module are those of :

(i) Hydraulic head (H');

(ii) Provisional rated flow (Q_p) for the turbine type;

(iii) Head-flow (H-Q) operational envelopes for the allowed turbine types; Figure 3;

(iv) Flow efficiency ($Q - \eta_{turbine}$) curves for the various turbine types; Figures 4a to 4h;

(v) Minimum operational flows (Q_{min}) for the turbine types; see Table 1;

(vi) Residual river flow ($Q_{residual}$);

(vii) Flow duration curve plotting positions. ;

(viii) Mean flow estimate.

Data items (i) & (vi) will be user defined; items (iii), (iv) and (v) will be held within the Power Module; items (vii) & (viii) transferred from the FDC module. The default value for item (ii) will be the estimate of mean flow transferred from the FDC module with the facility for entering a user defined override value.

5.3 METHOD OF POWER ESTIMATION

This section details the estimation methods to be used within the Power module:

Step 1
Set an environmental residual flow $Q_{residual}$ for the river. This flow maybe defined by the user either as a flow or as an exceedance percentile. If the input is a flow, the software will be required to check that the flow lies on the flow duration curve. If the input is an exceedance percentile the software will be required to derive the corresponding flow from the FDC;

Step 2
Set a provisional rated flow Q_p. The default will be the mean flow estimate from the FDC module, with a user override allowed. The override flow may be defined by the user as either a flow or as an exceedance percentile with the same checking/conversions procedures as detailed in Step 1;

Step 3.
Calculate the rated flow (Q_{rated}), see Figure 5, where:

$$Q_{rated} = Q_p - Q_{residual}$$

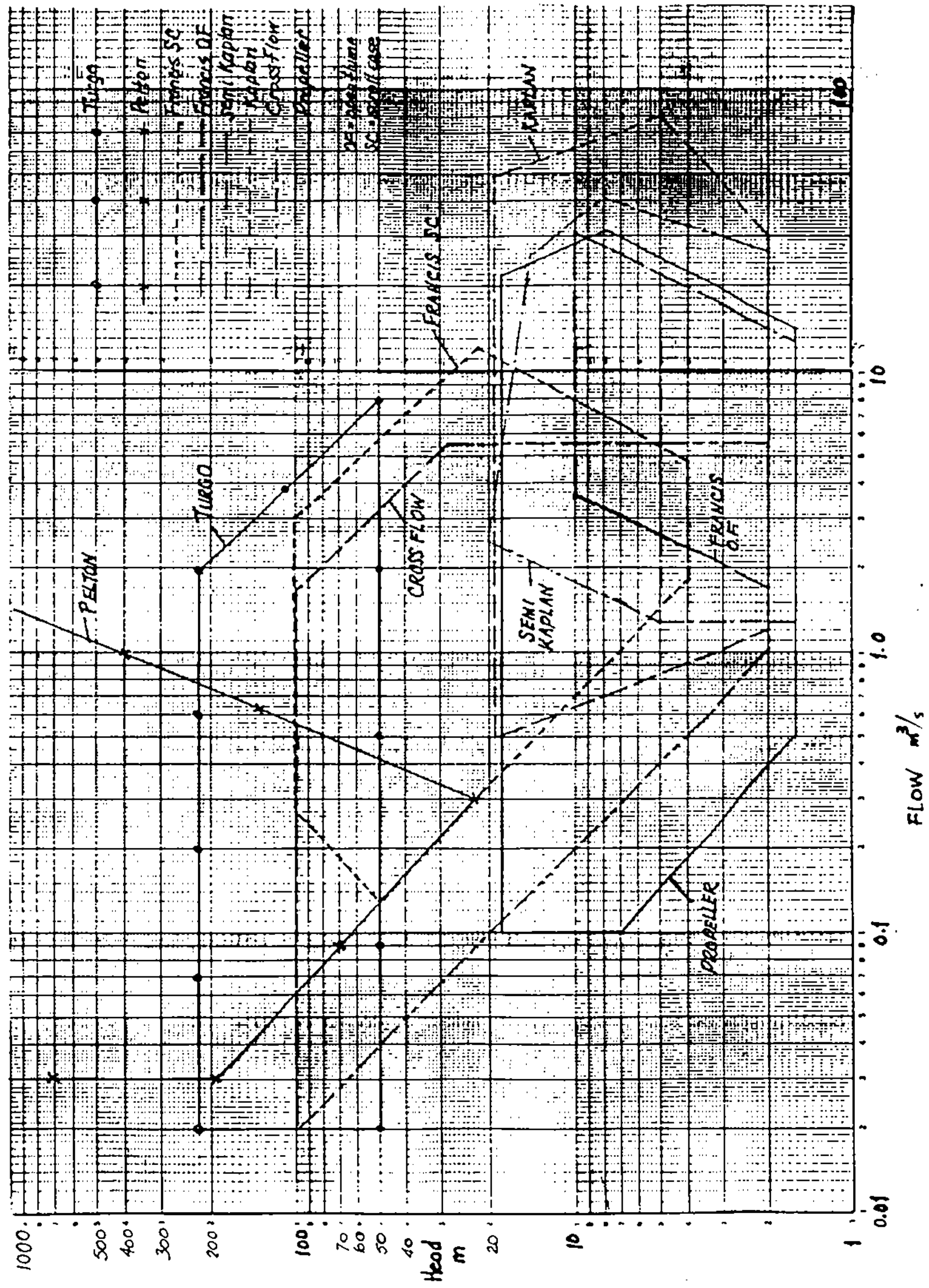

Figure 3 *Turbine Head-Flow operational envelopes*

Step 4.
Set the available gross hydraulic head H', defined by the user, and calculate the rated net head, H, where:

$$H = 0.9H'$$

Step 5
Using H and Q_{rated} identify suitable turbines from the H-Q operational envelopes (Figure 3). For example; if H = 10 m and Q_{rated} = 1.0 m^3s^{-1} suitable turbines, from Figure 3, would be the Cross Flow, Francis SC, Kaplan and propeller types;

Step 6
For each suitable turbine type identify the corresponding flow turbine efficiency curves (Q - $\eta_{turbine}$ curves) and Q_{min} flows;

Step 7
Using Q_{rated} , Q_{min} and $Q_{Residual}$ identify the useable part of the flow duration curve for each turbine type; Figure 5;

Step 8
For the first turbine type selected; divide the area under the useable flow duration curve into 5% incremental strips starting from the origin. The final strip will intersect the FDC at Q_{min} or $Q_{residual}$, which ever is the largest, (Figure 5) and will have a width of β where β ≤ 5%. For each strip calculate the median flow Q_{median} and the corresponding $\eta_{turbine}$ value from the relevant efficiency curve;

Step 9
For each strip calculate the energy contribution, ΔE, of the strip.

If the turbine type is cross flow, Kaplan or Semi-Kaplan ΔE is given by:

$$\Delta E = W * Q_{median} * H * \eta_{turbine} * \eta_{gearbox} * \eta_{generator} * \eta_{transformer} * \gamma * h$$

where:

W	= strip width	= 0.05 for all strips except the last one where W = β (in the range 0.05 - 0.005)
h	= hours in a year	= 8760
$\eta_{gearbox}$	= gearbox efficiency	= 0.975
$\eta_{generator}$	= generator efficiency	= 0.96
$\eta_{transformer}$	= transformer efficiency	= 0.985
γ	= specific weight of water	= 9.81 kNm^{-3}

If the turbine type is Francis, Pelton or Turgo ΔE is given by:

$$\Delta E = W * Q_{median} * H * \eta_{turbine} * \eta_{generator} * \eta_{transformer} * \gamma * h$$

All parameter values are the same.
NB: $\eta_{turbine}$ is a function of Q_{median}

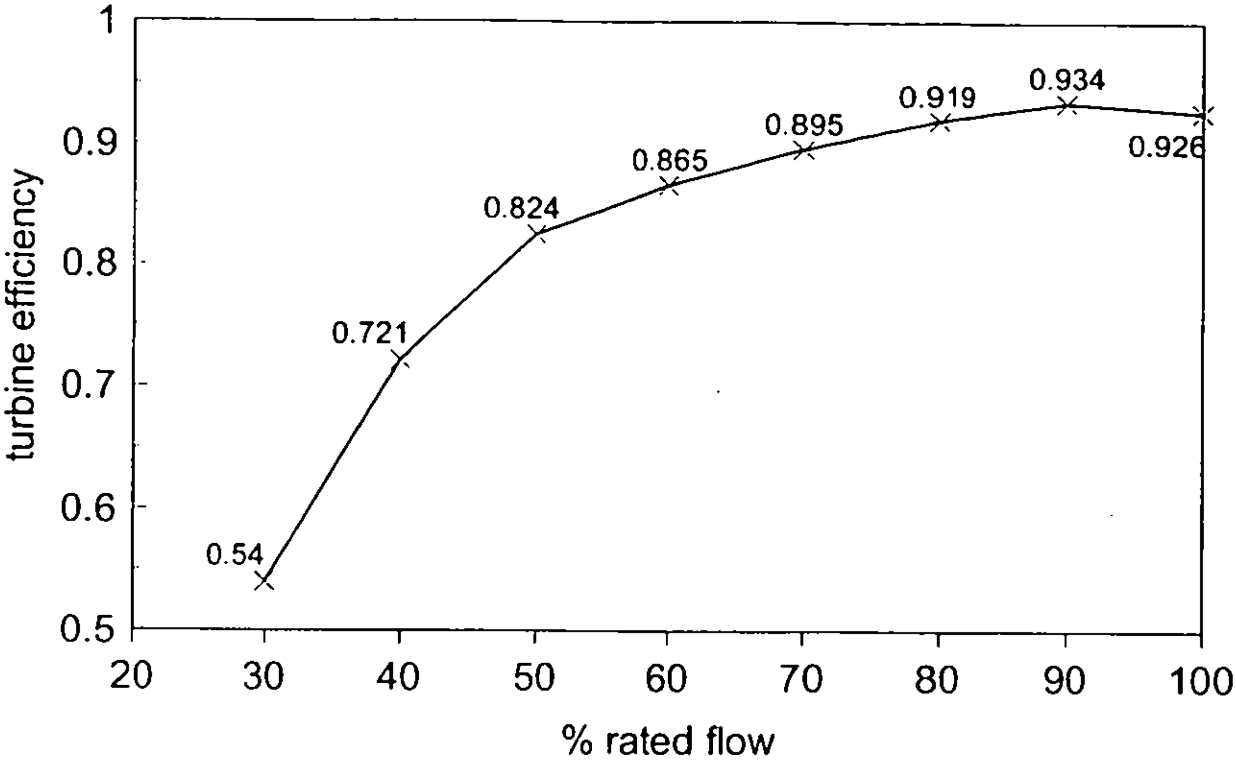

Figure 4a *Turbine efficiency curve for the Francis Spiral turbine*

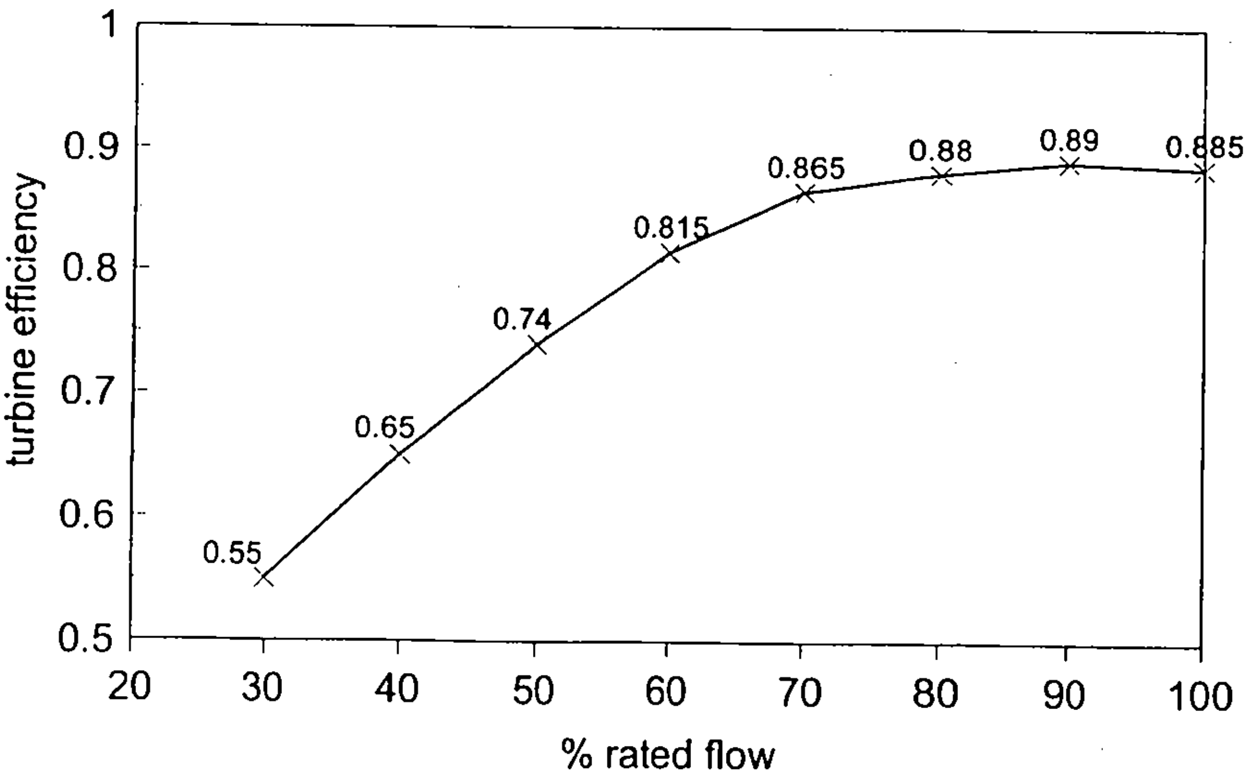

Figure 4b *Turbine efficiency curve for the Francis Open Flume turbine*

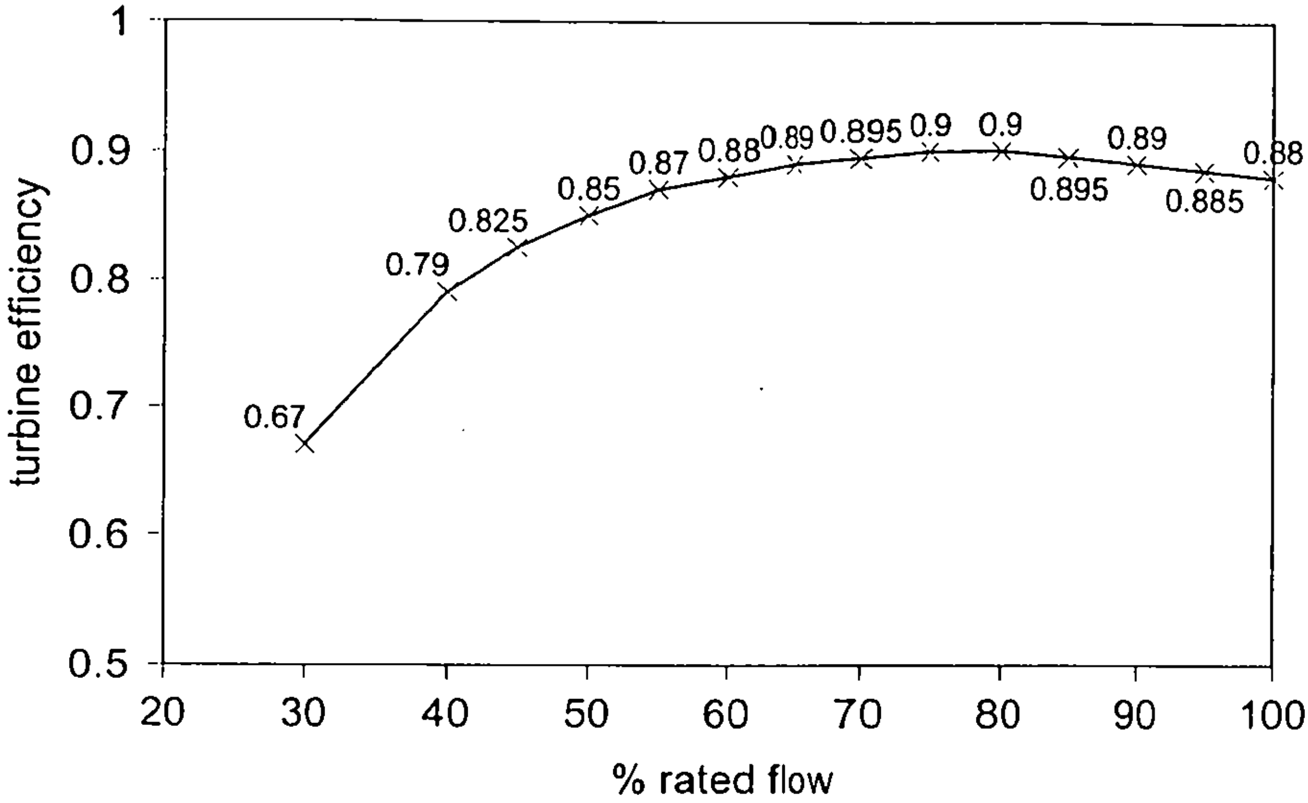

Figure 4c ***Turbine efficiency curve for the Semi-Kaplan turbine***

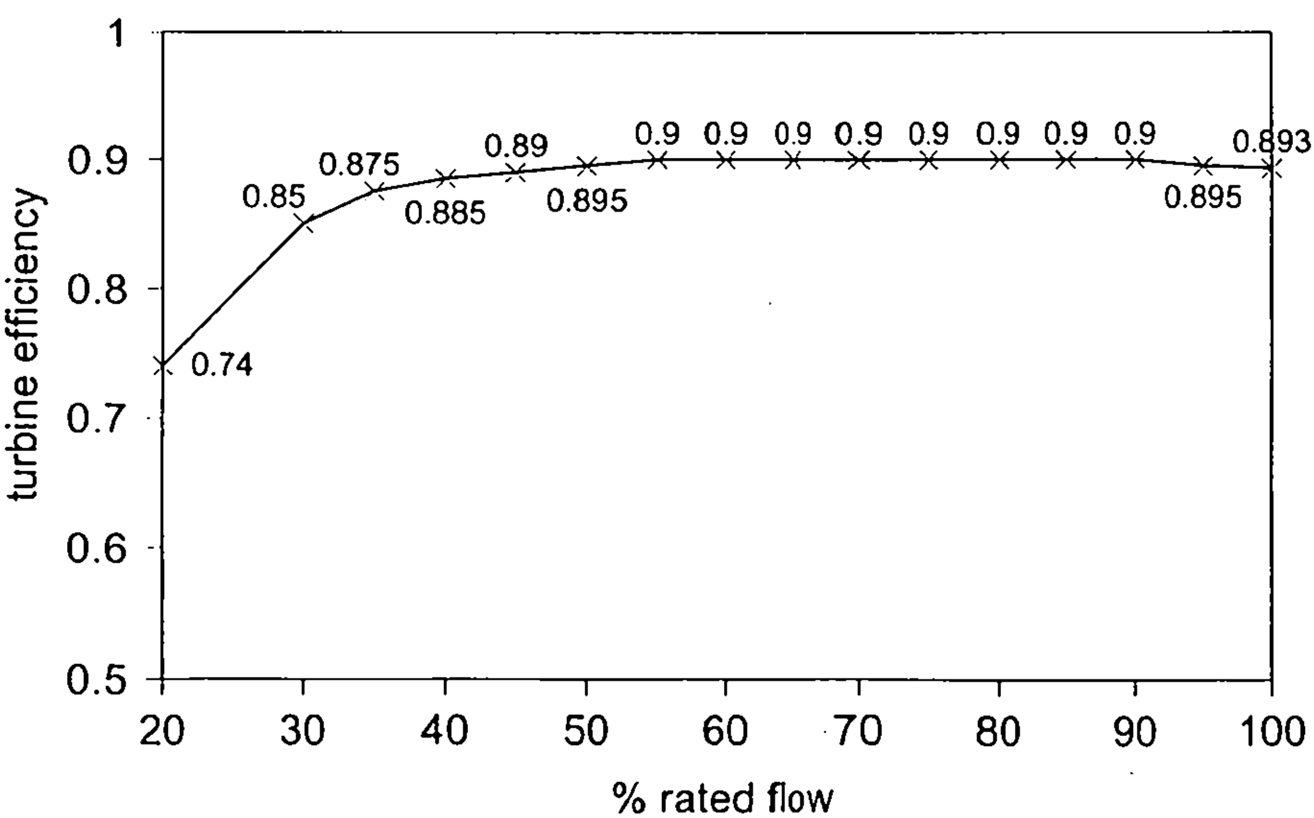

Figure 4d ***Turbine efficiency curve for the Kaplan turbine***

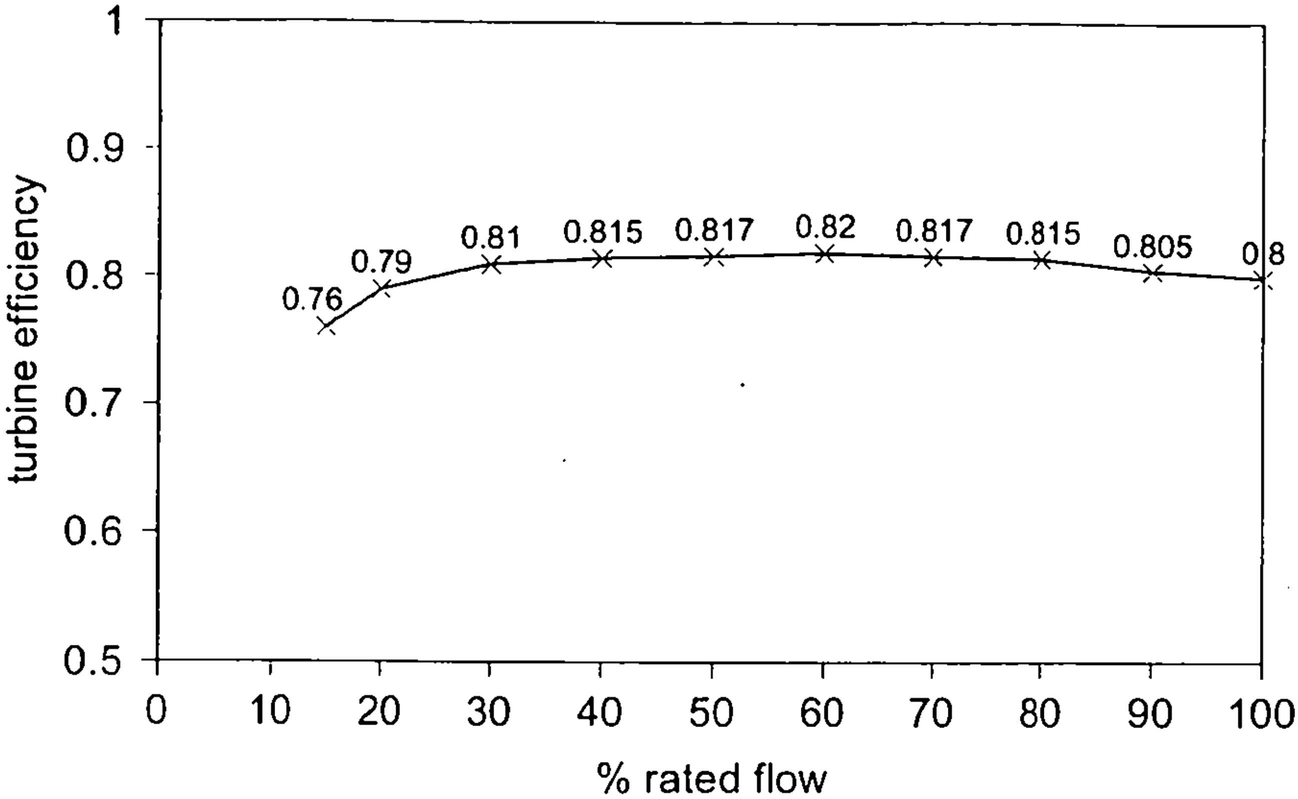

Figure 4e *Turbine efficiency curve for the Cross Flow turbine (at design head)*

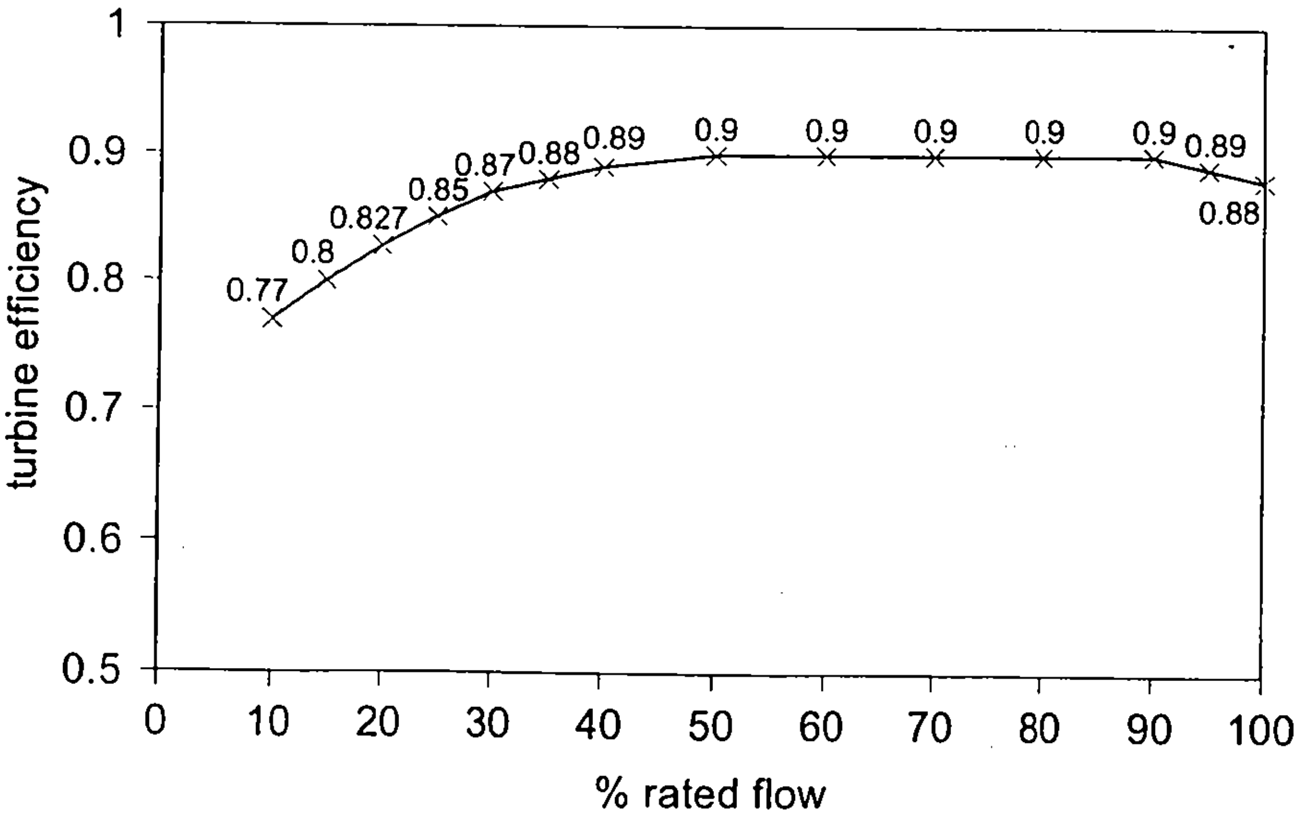

Figure 4f *Turbine efficiency curve for the Pelton turbine*

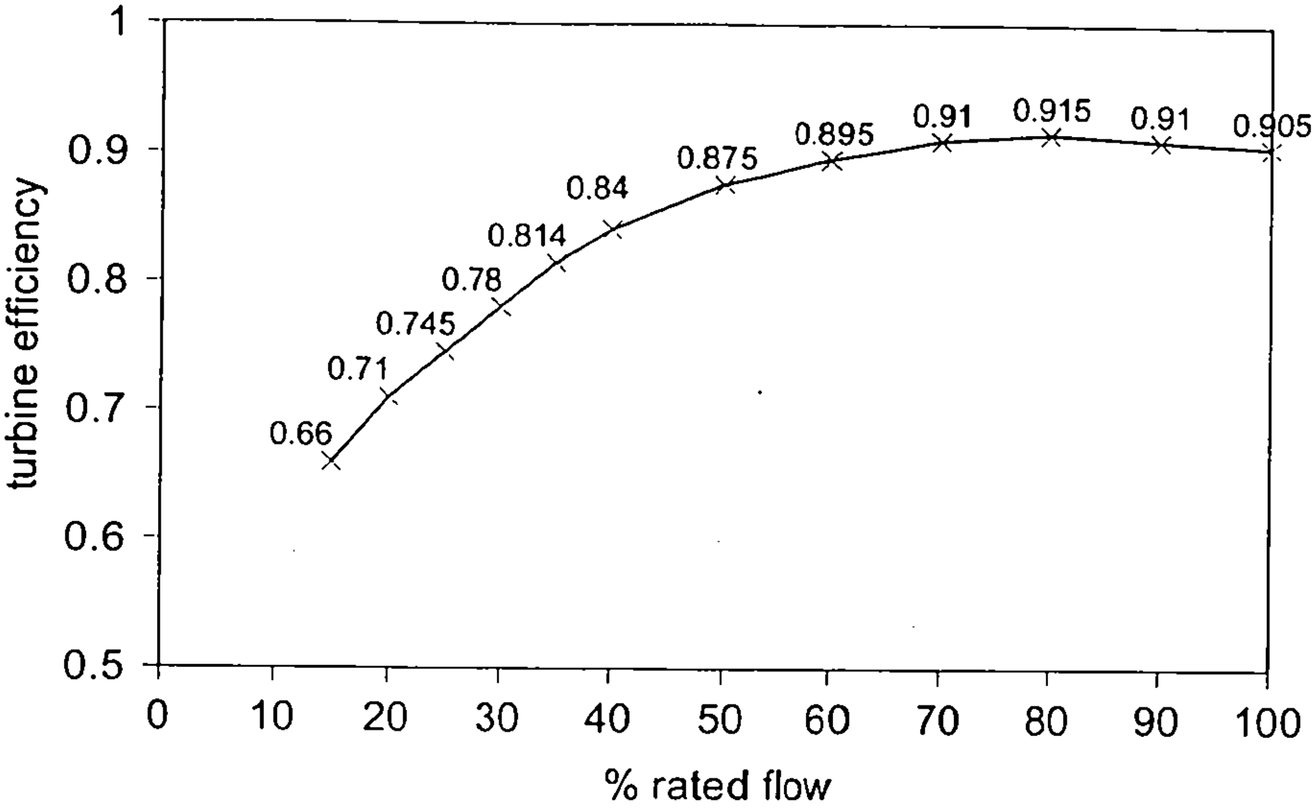

Figure 4g *Turbine efficiency curve for the Turgo turbine*

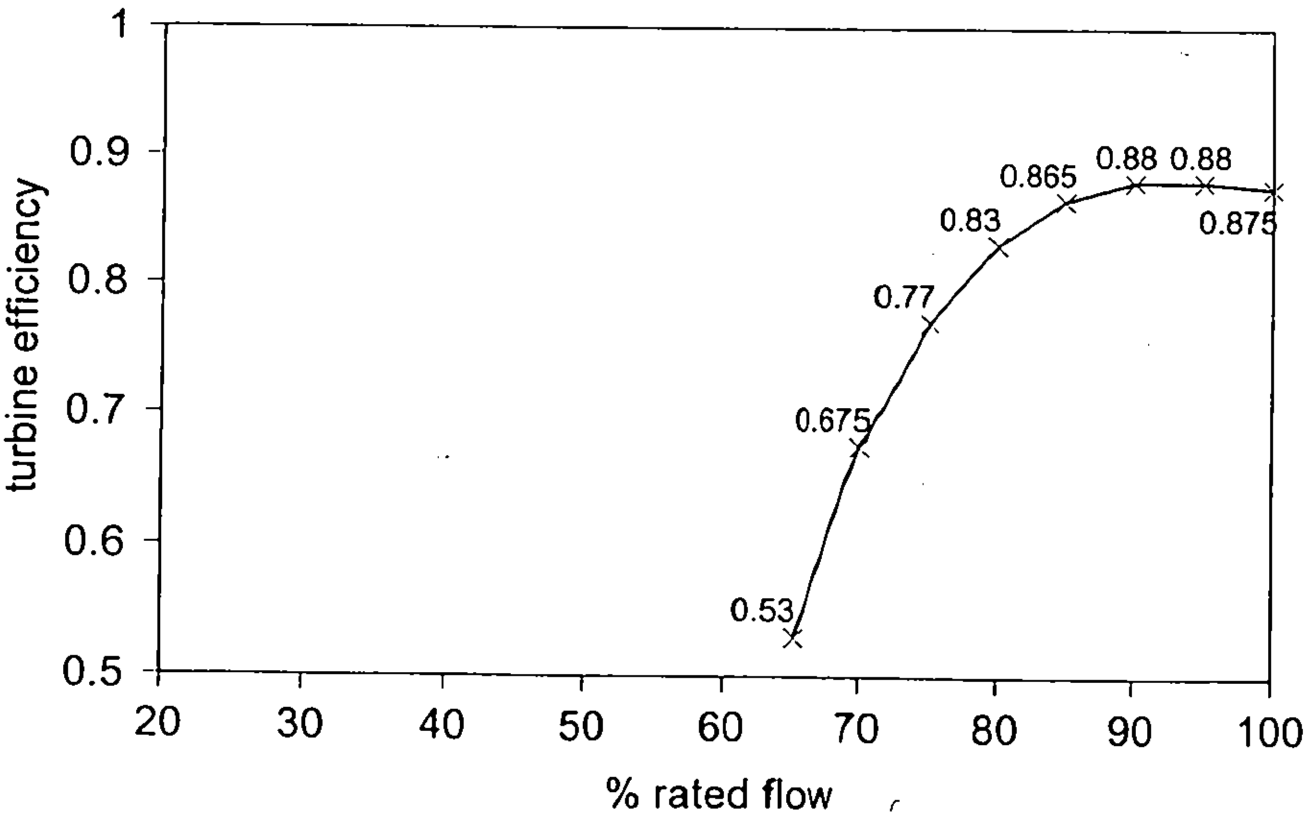

Figure 4h *Turbine efficiency curve for the unregulated propeller turbine*

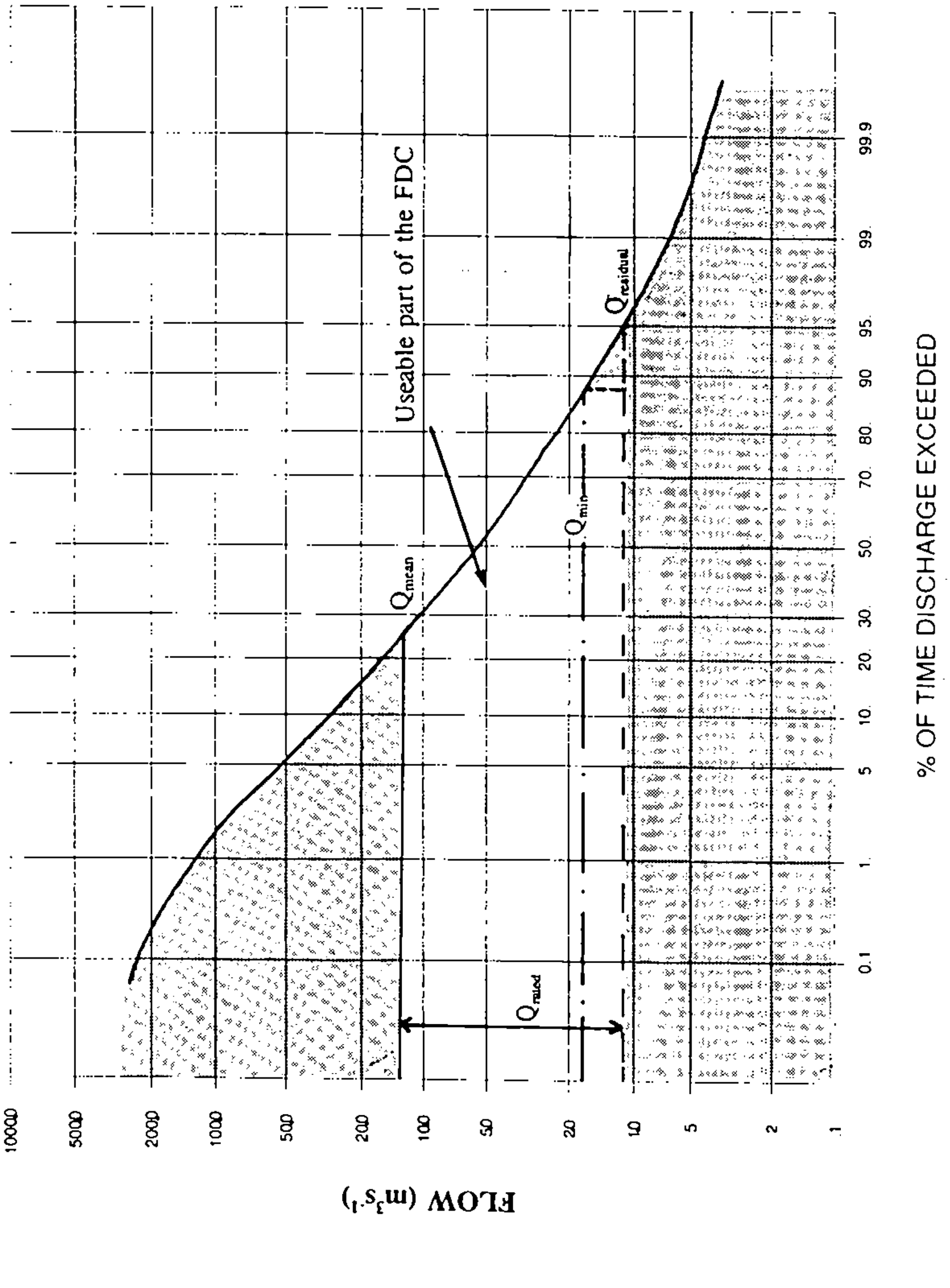

Figure 5 *Useable part of the flow duration curve*

Step 10
Sum all ΔE values; this is the Gross Average Annual Energy in kWh that can be generated, using the turbine selected, from the water under the usable flow duration curve;

Step 11
Calculate the Net Average Annual Energy in MWh by deducting 5% from the gross energy for maintenance, repair, downtime and dividing by 10^3;

Step 12
Calculate the Maximum Turbine Power P_t and the Rated Capacity C_r where:

$$P_t = Q_{rated} * H * \eta_{turbine} * \gamma \qquad (kW)$$

and C_r is given by:

$$C_r = P_t * \eta_{gearbox} * \eta_{generator} \qquad (kW)$$

if the turbine type is Cross Flow, Kaplan or Semi-Kaplan, or

$$C_r = P_t * \eta_{generator} \qquad (kW)$$

if the turbine type is Francis, Pelton or Turgo.

Step 13
Repeat Steps 7 to 12 for the remaining turbine types selected under Step 5.

5.4 REQUIRED OUTPUTS

i) Screen display of selected turbine types and estimates, with units, of AVERAGE NET ANNUAL ENERGY, MAX TURBINE POWER and RATED CAPACITY for each of the selected turbine types. Values are to be displayed to a precision of 1 decimal place;

ii) Hardcopy facilities for the data identified in (i).

6 Schedule of work

The detail for the schedule is to be defined by the Software Development Section, however the major objective dates are:

(i)	31/7/94	Detailed software design for the Power Module
(ii)	31/1/95	Beta test version of the Power Module software
(iii)	31/1/95	Detailed software specification for the FDC Module
(iv)	1/3/95	Detailed software design for the FDC Module
(v)	1/8/95	Beta test version of complete software.

Atlas of hydro-electric potential
Feasibility Assessment

Introduction

This project has been initiated in response to a sub-contracting requirement from the european small-scale hydro-electric power association. The low-flows section has requested that software be written to encapsulate the algorithms which they have devised to support the hydrological and power-generation aspects of calculating hydro-electric potential.

Aim

This document assesses the feasibility of developing the application according to the requirements specification.

Outline of Requirements

The development of the application splits readily into the two planned components:

- ☐ Flow duration curve calculation
- ☐ Hydro-power potential calculation

The clearance to develop the software as a *Windows*-based application (16 / 6 / 94) will significantly improve its openness, robustness, and usability.

The algorithms to generate the fdc are being developed by the Flow Regimes section. The manual input of catchment characteristics will not impact their planned future derivation from grids, or from a digital terrain model. The reference flow duration type curves will be stored in as compact a manner as possible, dependent on the impact on performance of uncompressing / compressing them. The provision of specifications for the inputs, algorithms, and outputs of this module in the Autumn of 1994 will not hinder development of the application shell and power estimation module.

The power estimation module will use the 17 reference coordinates of the flow duration curve, and the mean flow estimate calculated from it, produced by the flow duration curve module. The head / flow plot and turbine efficiency curves for the defined set of generating turbines will be stored in as compact a manner as possible, dependent on the impact on performance of uncompressing / compressing them. Values for hydraulic head and residual flow will be input through dialogues with the user. There is scope for providing a customisable means of including information about the associated fdc as a report option from this module. The calculation and presentational requirements for the details of appropriate turbine types, their flow-efficiency curves, and estimates of power generation potential pose no special problems.

User / Platform requirements

The widespread and general ease of use of *Windows* will support the use of the application by any interested party, from large consultancies to individuals, as public-domain software. It will have a head-start in intuitiveness, robustness, compactness, and supportability, and will run effectively on any personal computer with a specification as powerful, or more powerful than the basic platform detailed below. It will also be readily usable with the range of peripherals supported by this operating layer.

	Minimum:	**Recommended:**
Processor	386 SX 20 MHz	486 SX 25 MHz +
RAM	2 Mb	4 Mb
Hard Disc Drive	20 Mb	100 Mb
Graphics card	VGA / EGA	SVGA
Operating system	DOS 5.0 + Windows	DOS 6.0 + WFWG 3.11
Floppy Disc Drive	3.5"	3.5"
Output devices	Flexible, industry-standard	Flexible, industry-standard

It is possible that potential users with older machines might have less than 2Mb of RAM installed: such users would require a memory upgrade in addition to the Windows software for satisfactory performance. If these constraints should be considered excessive, the application could be written for DOS, although the associated requirement for additional development effort would entail extra overheads in cost and time for the design, development and testing phases.

Software requirements

☐M The number of 3.5" discs necessary for an installation should be the minimum possible, and the installed software should occupy as small an amount of memory as possible:

The code, data files and associated routines will be compressed by a standard method onto 3.5" discs, for automatic unzipping at the start of the installation process. A balance will be sought between the space occupied by code and data files, the extent to which they are compressed on the pc, and the impact on performance of decompressing them for use, so that the application does not run unduly slowly.

☐M The installation procedure should be straightforward and automatic:

The application will be installed by a standard process written using the *Windows* installation library: this will require minimum input by the installer, with *Windows* assisting in the automatic configuration of the system.

☐M The software design should allow for forward development and enhancement to a more advanced application in the future:

The modular design planned for the aplication will support onward development according to evolving reqirements.

☐M The application should be developed with the aim of maximising its robustness and user-friendliness, in order to minimise the support requirement:

1 July 1994

The use of the *Windows* operating layer and GUI will provide significant benefits in this area minimal experience of using this system is necessary for users to exploit an application to its full potential.

☐HD The planned use of the application in a variety of countries means that foreign language versions should be possible with minimum technical impact:

All text and messages will be stored separately from the code, so that language conversion will be a simple matter of specifying a filename in a 'preferences' dialogue. Messages will be referenced by alphanumeric identifiers within the source routines.

☐HD The above requirements suggest that the software documentation should be paper-based, with a relatively rudimentary help utility:

The *Windows* Help-text facility will support the provision of basic assistance in the operation of the application. Paper documentation will expand on these hints.

☐HD Maximum use should be made of icons / symbols in the interface, in order to reduce the translation effort necessary:

Attention will be paid to optimising the interface, such that minimal textual references are necessary.

☐HD The fdc and power potential reports should be user-tailorable, to the level of switching on / off a list of parameters and range of information fields to be included on them:

The variety of interests and rage of expertise of potential users will be considered when designing the options for report formats.

☐M No further software should be required to run the application, other than *Windows*:

The application will not rely on other software for the provision of its full functionality: however, it is planned to afford users the flexibility of being able to export / import data and information to / from spreadsheets, word processors, or graphics applications, as appropriate to its type.

☐M SI units are to be used for all numerical parameters:

The specification of SI units has no implications to the design of the application.

Flow duration curve calculation

☐M Store standardized flow duration type curves:

Probably stored in a protected file as a set of 20 2D flow / exceedance arrays, each with 17 pairs of co-ordinates: expected to be inefficient / unnecessary to compress this file

☐M Accept input catchment characteristics: these will include the area, fractional extent of soil classes, average annual rainfall, average annual potential evaporation of the catchment: it is envisaged that they will initially be calculated manually by the user:

Accomplished using *Windows* dialogue facilities in a separate routine: future enhancements will then be able to choose more advanced methods of obtaining these characteristics

☐M Use models to calculate standardized Q95, to identify standardized flow duration type curve, estimate mean flows, and rescale the type curve:

Awaiting specifications

☐M Generate graphical display of the curve (defined by 17 plotting positions):

This will be achieved through a set of routines to be accessible from both modules, through *Windows* and code utilities, which will handle the generation of graphics for presentation on the screen, or out to a file or printer

☐M Generate tabular report of 17 plotting positions:

This will be achievable through a set of routines to be accessible from both modules

☐M Supply results (fdc plot and mean flow) to power potential estimation module:

The 17 co-ordinate pairs will initially be available to the power estimation module as global variables, and subsequently from an identifiable file, on their being saved by the user

☐M Support output to printers / plotters:

Through *Windows*

☐HD Support ability to save results as text:

The 17 co-ordinate pairs may be stored as a 2D flow / exceedance array, together with the mean flow estimate, in a file named by the user: it may be useful to store the data and time of the fdc run, for reference purposes. It may be useful to calculate the equations for the straight-line approximation to the curve between each of the co-ordinate pairs and store those as well, to save repetitive processing in the power estimation module. Saving will occur following selection of a menu option, or response to a prompt on attempting to exit the module

☐D Support ability to save results in portable tabular / spreadsheet format:

Possible by saving as comma-separated file, or using *Windows* and code utilities

☐D Support ability to save results in portable graphics format:

Possible by saving as a metafile using *Windows* utilities

☐HD Support ability to start power estimation module from menu option:

Possible by activating a menu option on completion of processing

(Full specification to be provided in Autumn 1994)

Hydro-power potential calculation

☐HD Support ability to start module from fdc module, or from program manager

The module will be available from either start point: from the fdc module, processing should begin using the recent fdc results by default, by presenting the flow and head parameter dialogue box (see below)

☐M Store operational details for a range of turbine types:

i turbine type operational envelopes on head / flow graph

Probably stored in a protected file as a set of polygonal descriptors: expected to be inefficient / unnecessary to compress this file

ii flow / turbine efficiency (Q - $\eta_{turbine}$) curves for each turbine type:

Probably stored in a protected file as a set of 2D flow / efficiency arrays: expected to be inefficient / unnecessary to compress this file

iii minimum operational flows, Q_{min}, for each turbine type, as percentage of Q_{rated}:

iv gearbox / generator / transformer efficiency constants

Probably stored together in a protected file as a set of identified numbers in a standard format: expected to be inefficient / unnecessary to compress this file

☐M Store constants for hours in a year, specific gravity of water and width of strip to use fdc integration, and 'β-width' for each type of turbine:

Probably stored with the turbine details

☐HD Provide means of maintaining / adding to these details:

This will be achieved through a routine written to be activated by selecting a menu option to alter turbine operating parameters, which will present a dialogue to alter appropriate details, then update the datafile accordingly. The addition of turbine types would require the accompanying addition of an operating envelope boundary on the head / flow graph, and of a turbine efficiency curve: it will not, therefore, be possible for users to do this themselves

☐M Pass values calculated in fdc module to power estimation module

The flow / exceedance plot and estimated mean flow will be available as global variables, if the power estimation module is being run following selection of an option to do so from the fdc module, or from the file into which they were saved by the user following a previous such run: this file will be selected from a listing of all similar files presented in a browse box

☐M Allow user to input residual flow parameter as flow or exceedance percentile, and validate accordingly from flow duration curve:

☐M Use mean flow estimate from previous module as default for provisional rated flow parameter: allow user to over-ride default for provisional rated flow parameter, using flow or exceedance percentile, and validate accordingly from flow duration curve:

☐M Allow user to input gross available hydraulic head: use to calculate rated nett head:

This will be achieved through a dialogue box, which will allow the user to input appropriate values into fields for each option: apppropriate validation of either flow or exceedance percentile will be possible by reference to the x- and y-axis limits of the fdc plot

☐M Use flow estimate from previous module to calculate a range of flow parameters:

Straightforward calculations

☐M Use flow and head parameters to identify turbine types from graph:

This will be calculated by comparison of the head and flow parameters with the formulae of the lines bounding the turbine operating envelope, if these formulae are available: otherwise achieved by established point-in-polygon positional comparison routines

☐D Provide measure of how far within each turbine envelope the flow / head parameters plot, as measure of confidence:

Might be useful in providing a measure of how far within an operating envelope the head and flow plot, perhaps by comparing distances to each edge of the envelope (all similar suggests near centre): the turbine within whose envelope the plot was nearest the centre would presumably be that best suited to the flow environment, and the set of possibles could be ordered accordingly:

☐M Identify usable part of flow duration curve for each turbine type, integrate below it to calculate gross / nett average annual energy potential:

Slightly convoluted calculation involving much use of the straight-line approximations to the fdc along its length between the y-axis and its intersection with Q_{min} or $Q_{residual}$: this processing has the greatest potential for slowness, and will bear scrutiny at the detailed design stage

☐M Use to calculate maximum turbine power and rated capacity for each turbine:

Straightforward calculations

☐M Provide means of presenting these results as a report:

The means of presenting the results will depend to some extent on the language chosen for coding the module, but there is no obstacle to achieving this

☐M Support output to printers / plotters:

Through *Windows*

☐HD Support ability to save results as text:

Through *Windows*, following selection of a menu option, or response to a prompt on attempting to exit the module

☐D Support ability to save results in portable tabular / spreadsheet format:

Possible by saving as comma-separated file, or using *Windows* and code utilities

☐D Support ability to save results in portable graphics format:

Possible by saving as a metafile using *Windows* utilities

☐D Provide means of presenting flow duration curve on screen from this module, including indication of usable area:

☐D Provide means of including flow duration curve in power potential report:

Possible through *Windows* utilities, if the fdc has been saved in an appropriate format

☐ Note: no requirement to be able to alter constants for calculation of rated nett head H from H', number of hours in year (no requirement to allow for leap years),

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specific gravity of water or strip width for integration of useable area beneath fdc:

Atlas of hydro-electric potential

Requirements Specification

Introduction

This project has been initiated in response to a sub-contracting requirement from the european small-scale hydro-electric power association. The flow regimes section has requested that software be written to encapsulate the algorithms which they have devised to support the hydrological and power-generation aspects of calculating hydro-electric potential.

Aim

The project will aim to design, develop, test and release a user-friendly application to support the estimation of hydro-electric generation potential within Europe.

Outline of Requirements

The application will comprise two principal components:

- ☐ Flow duration curve calculation
- ☐ Hydro-power potential calculation

The first will produce a curve which illustrates the relation between flow and the amount of time for which it is exceeded, calculated for ungauged sites from catchment characteristics. The catchment characteristics will initially be input by the user following manual calculation, but may in the future be derived from grids, or possibly a digital terrain model. The initial phase of the project will concentrate on the provision of a model for Britain and Spain, and on the analysis of data availability in Italy. The inputs, algorithms, and outputs of this module will be provided by the flow regimes section in the Autumn of 1994.

The second module will use the flow duration curve and mean flow estimate calculated by the flow duration curve module, a series of operational parameters relating to a defined set of generating turbines, and user-defined values for hydraulic head and residual flow, to identify appropriate turbine types for a site, identify the usable part of the flow-duration curve, and from this estimate total and maximum power generation potentials.

User requirements

The application is targetted for use by any interested party, from large consultancies to individuals, as public-domain software. The emphasis will therefore be on maximising the ease of use, robustness, compactness, and supportability of the application, which should run effectively on a relatively basic personal computer. The original requirement specified a DOS-based application, but clearance has been given to use a Windows-based approach, in order to increase the above factors, and provide a range of software- and hardware- related utilities, which would otherwise be expensive and complex to develop as part of this project.

Platform requirements

The general requirement that the application should run on what might be expected to be the lowest specification of machine in use with any potential user is recognised: the processing and presentational requirements should not present a problem for the specified hardware configuration

	Specified:	Recommended:
Processor	386 SX 20 MHz	386 SX 20 MHz +
RAM	0.64 Mb	2 Mb
Hard Disc Drive	20 Mb	20 Mb +
Graphics card	VGA / EGA	VGA / EGA
Operating system	DOS 5.0 +	DOS 5.0 + WFWG 3.11
Floppy Disc Drive	3.5"	3.5"
Output devices	Flexible, industry-standard	Flexible, industry-standard

The choice of operating system, however, has greater implications for the nature of the released software. The requirements for user-friendliness, robustness, compactness, portability, and openness to output devices, as well as the project constraints of financial and time budgets, combine to present a strong case for the development of the software as a Microsoft Windows-based application. The wide availability and comprehensive support infrastructure of the system, and the range of utilities which are included with it, mean that Windows is a 'good buy' in any case, at approximately £50. It is possible that potential users with older machines might have less than 2Mb of RAM installed: such users would require a memory upgrade in addition to the Windows software for satisfactory performance. If these constraints should be considered excessive, the application could be written for DOS, although the associated requirement for additional development effort would entail extra overheads in cost and time for the design, development and testing phases.

Software requirements

- ☐M The number of 3.5" discs necessary for an installation should be the minimum possible, and the installed software should occupy as small an amount of memory as possible:
- ☐M The installation procedure should be straightforward and automatic:
- ☐M The software design should allow for forward development and enhancement to a more advanced application in the future:
- ☐M The application should be developed with the aim of maximising its robustness and user-friendliness, in order to minimise the support requirement:
- ☐HD The planned use of the application in a variety of countries means that foreign language versions should be possible with minimum technical impact:
- ☐HD The above requirements suggest that the software documentation should be paper-based, with a relatively rudimentary help utility:
- ☐HD Maximum use should be made of icons / symbols in the interface, in order to reduce the translation effort necessary:
- ☐HD The fdc and power potential reports should be user-tailorable, to the level of switching on off a list of parameters and range of information fields to be included on them:
- ☐M No further software should be required to run the application, other than Windows:
- ☐M SI units are to be used for all numerical parameters.

Flow duration curve calculation

□M Store standardized flow duration type curves:

□M Accept input catchment characteristics: these will include the area, fractional extent of soil classes, average annual rainfall, average annual potential evaporation of the catchment: it is envisaged that they will initially be calculated manually by the user:

□M Use models to calculate standardized Q95, to identify standardized flow duration type curve, estimate mean flows, and rescale the type curve:

□M Generate graphical display of the curve (defined by 17 plotting positions):

□M Generate tabular report of 17 plotting positions:

□M Supply results (fdc plot and mean flow) to power potential estimation module:

□M Support output to printers / plotters:

□HD Support ability to save results as text:

□D Support ability to save results in portable tabular / spreadsheet format:

□D Support ability to save results in portable graphics format:

□HD Support ability to run power estimation module from menu option on completion of fdc calculation:

(Full specification to be provided in Autumn 1994)

Hydro-power potential calculation

□HD Support ability to start module from fdc module, or from program manager:

□M Store operational details for a range of turbine types:

- i turbine type operational envelopes on head / flow graph (obtain formulae for envelope boundaries?):
- ii flow / turbine efficiency ($Q - \eta_{turbine}$) curves for each turbine type:
- iii minimum operational flows, Q_{min}, for each turbine type, as percentage of Q_{rated}:
- iv gearbox / generator / transformer efficiency constants

□M Store constants for hours in a year, acceleration due to gravity, width of strip to use in fdc integration, and 'β-factor' for each type of turbine:

□HD Provide means of maintaining / adding to these details:

□M Allow user to input residual flow parameter as flow or exceedance percentile, and validate accordingly from flow duration curve:

□M Use mean flow estimate from previous module as default for provisional rated flow parameter: allow user to over-ride default for provisional rated flow parameter, using flow or exceedance percentile, and validate accordingly from flow duration curve:

□M Use mean flow estimate from previous module to calculate a range of flow parameters:

□M Allow user to input gross available hydraulic head: use to calculate rated nett head:

□M Use flow and head parameters to identify turbine types from graph:

□D? Provide measure of how far within each turbine envelope the flow / head parameters plot, as a measure of confidence: the turbine within whose envelope the plot was nearest the centre is presumably that best suited to the flow environment:

□M Identify usable part of flow duration curve for each turbine type, integrate below it to calculate gross / nett average annual energy potential:

□M Use to calculate maximum turbine power and rated capacity for each turbine:

□M Provide means of presenting these results as a report:

□M Support output to printers / plotters:

□HD Support ability to save results as text:

□D Support ability to save results in portable tabular / spreadsheet format:

□D Support ability to save results in portable graphics format:

□D Provide means of presenting flow duration curve on screen from this module, including indication of usable area:

□D Provide means of including flow duration curve in power potential report:

□ Note: no requirement to be able to alter constants for calculation of rated nett head H from H', number of hours in year (no requirement to allow for leap years), specific gravity of water or strip width for integration of useable area beneath fdc:

1 July 1994