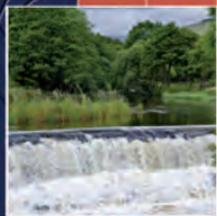


Hydra 2™

Estimating hydropower potential



User Guide

WHS

Wallingford HydroSolutions Ltd

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Design: platform1design.com

Hydra 2™

User Guide

May 2011



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This user guide has been prepared by Wallingford HydroSolutions with all reasonable skill, care and diligence. It has been designed to enable you to operate the software and to provide you with an overview of the methods used in the software. You are responsible for the interpretation of the information presented in this user guide and formal training in the use of the methods is strongly recommended.

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Development Team

Wallingford HydroSolutions Ltd. (WHS) software development team are responsible for the development of the Hydra 2™ software.

Document History

V1.0

May 2011

WHS Development Team

Technical Specification

Minimum recommended specification

Base computer

Intel or equivalent PC with CD drive

Chip

Pentium IV or equivalent

RAM

1Gb

Free drive space

20Mb

Operating system

Windows XP, Windows Vista, Windows 7



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Licence terms and conditions

The use of the Hydra 2™ software is governed by the terms and conditions of the licence agreement between Wallingford HydroSolutions Limited and the User. The User is required to accept the licence terms and conditions of use prior to installation and at runtime. These terms and conditions can be viewed at the login screen of the software and on the Licence Certificate. Your attention is particularly drawn to clauses relating to your responsibilities and licence termination.



1 Overview

The initial planning of hydropower schemes includes an assessment of the energy generation potential of a particular site on a river. This is primarily dependant on two site conditions; the flow regime (which defines the amount of water available throughout a year) and the hydraulic head (the change in elevation between intake and outlet of the scheme). Environmental constraints, such as maximum take and residual flow conditions may also apply and impact on the predicted annual energy production. Typically, the viability of a number of sites is compared and a number of turbines trialled to identify the optimum scheme.

Hydra 2 is a decision-support tool that estimates annual energy generation for hydropower schemes. Flexible environmental flow constraints, consistent with current regulatory guidelines, can be added. Nett head conditions can be calculated using headloss formulae for trashracks, friction losses and minor losses. Appropriate turbines are automatically selected and analysed. Results are rapidly produced, enabling multiple schemes to be assessed in a consistent and timely manner.

The power calculations and headloss formulae implemented within Hydra 2 are consistent with the *Guide on how to develop a small hydropower plant* published by the European Small Hydropower Association (ESHA) (2004).

2 Appropriate use of Hydra 2™

Hydra 2 is a decision-support tool that enables the feasibility of small hydropower schemes to be assessed in a rapid, efficient and consistent manner. Hydra 2 is designed for run-of-river hydropower schemes without significant storage. The flows in the river that are able to generate power are assumed to be described by an annual flow duration curve (FDC).

The software should not be considered a substitute for professional expertise. It is strongly recommended that the software is used by competent hydropower engineers who have suitable training and experience in the development of hydropower schemes.

The energy estimates produced by the software are directly dependent on the supplied FDC and hydraulic head details. The hydrological and hydraulic expertise used to derive these data should be commensurate with the level of accuracy of the analysis.

The turbine operating envelopes and efficiency curve data included in the software are typical for the selection of turbines. These data may differ to turbine manufacturers' specifications for an individual turbine. The current version of Hydra 2 does not enable you to edit this turbine data.

The default component efficiency parameters are typical for small hydropower schemes and the associated turbine types. These data may differ to manufacturers' specifications for an individual component. These data can be edited.

Environmental regulatory standards will define the residual flow conditions for a scheme which will in turn constrain the amount of water that can be utilised for power generation. It is important that these residual flow conditions are agreed with the relevant authorities prior to modelling schemes with the software.

3 How to use this guide

This user guide describes how to setup the Hydra 2 software and the functionality of the system.

- **4 Getting started** shows you how to install and run the software.
- **5 Defining the river flow regime** describes how the river flow regime details are added via 'paste from clipboard' or imported directly from a LowFlows flow estimate file.
- **6 Setting the flow conditions** guides you through the process of defining the provisional rated flow and residual (environmental) flow conditions associated with the scheme.
- **7 Setting the hydraulic head conditions** illustrates how the nett system head can be defined either as a simple fixed percentage of the gross head or via headloss calculations (trashrack losses, friction losses and minor losses).
- **8 Hydropower energy estimates** puts it all together and shows you how the estimates of energy generation potential are displayed and can be exported from the system.
- **9 References** lists literature for further reading.
- **10 Glossary** contains details of commonly used terminology.

The table below shows the conventions used in the text.

Convention	Explanation
Grey Bold	Text/name appearing in the screen currently displayed.

4 Getting started

4.1 Installing the software

To install the Hydra 2 software place the CD in your CD drive and run the **setup.exe** file.

The installation will prepare to install the software, displaying the **Preparing to install...** screen. The **Installation Welcome** screen will then be displayed. Continue with the installation to the **Licence Agreement** screen, Figure 4.1. You must read and accept the Licence Terms and Conditions of the software prior to continuing with the installation.



Figure 4.1 Licence Agreement screen

The **Destination Folder** screen will then be displayed, Figure 4.2. You will be asked to specify where the software should be located; a default location is supplied.

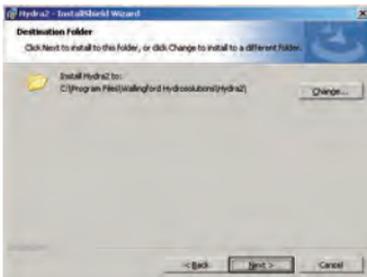


Figure 4.2 Destination Folder screen

The **Ready to Install** screen enables you to view the installation details. Continue by selecting **Install** which will begin the installation. Following completion, select **Finish**, after which you should restart your PC.

4.2 Activating the software licence and logging in

Hydra 2 is protected by a licence held on the USB dongle which is supplied with the software. You must insert the dongle into the computer whenever you run the software.

The first time you use the software, you need to click **Browse licence...** in the login screen (Figure 4.3) and browse to the **Hydra.lic** file on the USB dongle. During subsequent uses the software will automatically look for the licence in the same place. However, if the drive letter of the dongle changes (for example when you are using it on another computer) you may need to browse to the file again.

If the licence file is valid you will see a message on the login screen confirming that you have a valid licence for the software.



Figure 4.3 Login screen

You must then agree to the Licence terms and conditions before running the software. Click **Accept** to confirm that you have read and accepted the Licence terms and conditions presented in the login screen. The software will then start and you will see the **Set Data Origin** screen.

Hydra 2 enables you to save key information entered for a specific site as a project file. This file can then be recalled for subsequent analysis. For first time use of the software, you will need to choose to **Define a new Hydra 2 project**.

5 Defining the river flow regime

The Hydra 2 software produces estimates of energy generation potential based on a description of the flow regime for a point on a river. The first inputs required are an estimate of the annual flow duration curve (FDC) and an estimate of catchment annual mean flow (MF). These could be derived from gauged data using hydrometric analysis software such as HydroTools or estimated from hydrological models, such as the LowFlows suite, see the Glossary for details. You can enter the FDC data at the **Define River Flow Regime** screen by one of two methods: copy and pasting from a spreadsheet application or importing directly from a LowFlows flow estimate file.

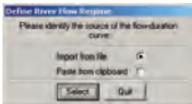


Figure 5.1 Specifying how the river regime data shall be entered

- If you choose to **Paste from clipboard**, enter an estimate of MF to the cell at the top of the **Paste Flow-Duration Data** screen. You should then highlight the required cells in your 'data' spreadsheet, copy these to clipboard, then select the **Paste** button on this screen to transfer the data from the clipboard to this screen. Data copied and pasted from a spreadsheet must conform to the following specifications:
 - Data must be numeric values arranged as two columns, no column headers or row headers.
 - The first column must contain flow percentile exceedence probabilities (values between 1 and 99). A value lower or equal to 1%ile should be included and a value greater than or equal to 99%ile should be included, to ensure the FDC is sufficiently well defined.
 - The second column must contain flow values in absolute flow units (m^3/s).
 - Flow percentiles should be arranged in ascending order and the

associated flow values should therefore be in descending order.

- The grey cells shown on Figure 5.2 illustrate the area of a spreadsheet which should be copied and pasted for data entry.

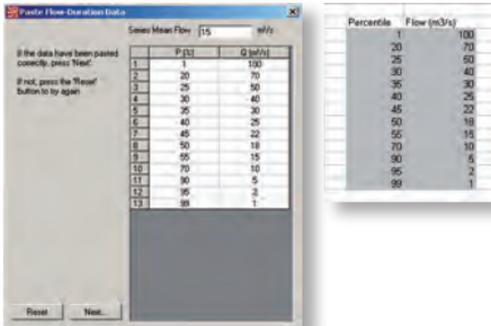


Figure 5.2 Entering a FDC using the 'Paste from Clipboard' function – copy and paste the area of grey cells from the spreadsheet.

- If you choose to **Import from file**, you should browse to and select the required LowFlows flow estimate file (*.csv format). You will see the FDC data and Mean Flow value extracted from this file displayed in the **Paste Flow-Duration Data** screen.

Once you have checked the data in the **Paste Flow-Duration Data** screen, click **Next** to proceed.

6 Setting the flows conditions

The energy generated by a hydropower scheme is dependent on the river flows available and the applicable residual flow conditions. The provisional rated flow ($Q_{provrtd}$) defines the upper limit of 'useable' flows from the FDC for the river. The residual flow (Q_{res}) defines the lower limit of flows that can be used. When the river flow regime falls to below the Q_{res} , water cannot be used to generate energy and must be left to support downstream environmental requirements.

The **Define Residual Flow** screen enables you to set the Q_{res} flow to be constant (ie. one value of Q_{res} applies across the full FDC) or varying (ie. the value of Q_{res} can vary across flow percentiles). This provides flexibility required to meet regulatory conditions.

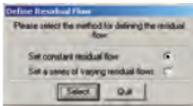


Figure 6.1 Choosing how to define the residual flow

- If you choose **Set constant residual flow** the **Set Flow Params – constant Q_{res}** screen will be displayed. You can edit both the $Q_{provrtd}$ and Q_{res} in cumecs. By default, the $Q_{provrtd}$ flow is set to the catchment annual MF and the Q_{res} is set to the annual Q_{95} . These conditions should be checked for compliance with regulatory requirements. You will see the calculated Rated flow (Q_{rated}) on this screen. Select **Save** to continue.



Figure 6.2 Setting a constant residual flow

- If you choose to **Set a series of varying residual flows** then the **Set Flow Params – variable Q_{res}** screen will be displayed. You need to enter a $Q_{provrtd}$ flow in the cell provided, this defaults to

the catchment MF. The variable Qres values are added by a 'paste from clipboard' function. You should highlight the required cells in a spreadsheet, copy these to the clipboard, then select the **Paste** button to transfer the data to this screen. The format of the data copied to clipboard must conform to the following specifications:

- Data must be numeric values arranged as two columns, no column headers or row headers.
- The first column must contain flow percentile exceedence probabilities (values between 1 and 99). These define the points at which Qres will vary across the FDC x-axis. These should be arranged in increasing order.
- The second column can define the Qres values in one of two ways. Firstly, as flow values in absolute flow units (m^3/s), see Figure 6.3 for an example. Secondly as percentages of the flow in the river (ie. the FDC) in %, see Figure 6.4 for an example.
- The maximum Qres value must be less than the Qprovrtf flow.

You should note that if the Qres line crosses the FDC more than once, only the portion of flow up to the first crossing point will generate energy.

If the Qprovrtf value is set to less than the Qres line, the portion of flow up to this point will not generate any energy.

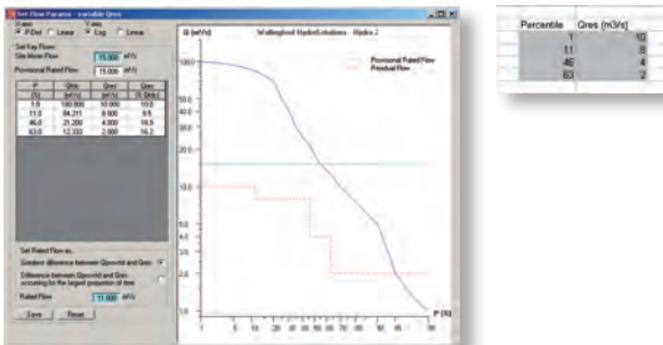


Figure 6.3 Qres defined as absolute flows (m^3/s)

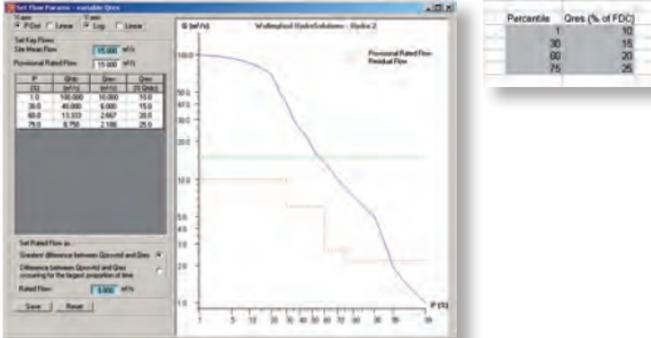


Figure 6.4 Qres defined as percentage of the FDC flows (%)

Once the flow conditions have been set you should select **Save** to continue and enter the hydraulic head conditions.

7 Setting the hydraulic head conditions

The energy generated from a hydropower scheme depends on the available flows and the available head. The gross head of the system refers to the change in elevation between the intake and tail race. The nett head is a smaller value which accounts for headlosses through the system between the intake and tail race.

The **Define Nett Head** screen provides you with two methods for defining nett head.

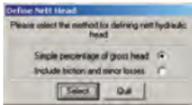


Figure 7.1 Choosing how to define the nett head

- You may choose to simply nominate the nett head as a **Simple percentage of gross head**. The percentage value entered here reflects the total headlosses in the system. Typical values are between 5–10%. The nett head is calculated, shown in blue highlight, and you proceed by selecting **Save**.



Figure 7.2 Setting nett head as a simple percentage of gross head

- If you wish to enter detailed information to calculate the nett head choose **Include friction and minor losses**. This allows you to estimate the headlosses for individual hydraulic components; an inlet trashrack, penstock sections and minor losses. You will need to enter data on the **Define Head Losses** screen (Figure 7.3) which consists of a number of panels described below:
 - **Summary** – You need to add the **Gross Hydraulic Head** (m) in this panel. The previously calculated **Qrated** is shown and the **Nett Hydraulic Head** (m) is updated as you add information to define the headloss components. Cells appear in pink highlight if the

values calculated are currently not 'valid', for example a negative nett hydraulic head.

- **Trashrack Parameters/Losses** You need to specify the trashrack parameters in this panel. The **Area** (m²) of trashrack and **Total Trashrack Head Loss** (m) are calculated based on the dimensions and inlet velocity you select, see Glossary for more details. Note that if no trashrack exists in your system then you do not need to enter data in this panel and trashrack losses will be set to zero.
- **Friction Losses** The friction losses are calculated for each pipe section of penstock based on Mannings equation. You can use up to a total of five (5) pipe sections by clicking on the **Add...** tab. Pipe sections are removed using the **Delete Pipe** button. The **Est. min diam. to limit the friction loss to 4%** (mm) value is provided as an initial estimate of the pipe diameter for this section of penstock, see the Glossary for more details. You can choose to adopt this value or specify an alternative.
- **Minor Losses** You can specify a wide selection of valves, bends, entrance and exit losses to apply to each section of pipe. The minor losses are calculated as the product of the loss coefficient (K) and the velocity head ($v^2/2g$) in the associated pipe section. You can edit the default coefficients used and specify the number of valves/bends etc. in the table and the individual headloss component is updated.
- **Summary of Penstock Losses** This panel summarises the dimensions and headlosses in each section of pipe you have defined and shows the **Total Penstock Head Loss (m)** which is the sum of all friction and minor losses.

Note You cannot edit the values shown in blue cells on this screen as these have been calculated and are non-editable. Once you have entered all the information you require, select **Save** to continue.

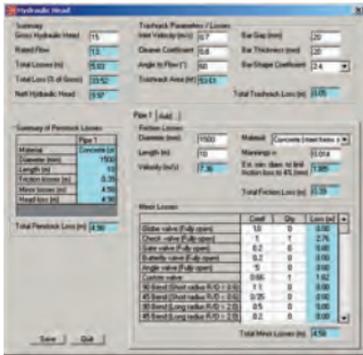


Figure 7.3 The Hydraulic Head screen for detailed headloss calculations

7.1 Changing default parameters

The [pstks.dat] data file included with the installation contains default headloss data for pipeline components (valves and bends) and pipe materials. You can edit this file to change the default minor losses parameters for pipe components and/or Mannings 'n' values for pipe materials.

This file is in a simple format with two sections [Components] and [Materials]. Items are listed as a data pair (text, value) separated by a comma under these sections, see Figure 7.4.



Figure 7.4 Example of defaults in [pstks.dat] file

You can add lines to this file (within the correct section) to enable a wider selection of options.

You can remove lines from this file, providing you always retain at least one data line in the [Components] section and one in the [Materials] section.

You can modify the existing lines in this file, changing the descriptive text and/or value. The maximum number of items in the [Component] or [Materials] list is 20. The maximum number of characters in the descriptive text item is 40.

8 Hydropower energy estimates

Once the river flow regime has been defined and the flow and head conditions have been set, the main screen displays results of the energy calculations, see Figure 8.1. The system nett head and rated flow are plotted on the turbine operating envelopes to identify which turbines are operable. You can view this by the **Plot Head/Flow** button. The annual energy produced by each operable turbine is then calculated as detailed below.

The potential energy lost by water flowing at rate Q (m^3/s) with a hydraulic head of H (m) can be converted to power by the following:

$$P = Q \times H \times \gamma$$

P is the power produced (kW)

Q is the available flow for power generation (m^3/s)

H is the head (m)

γ is the specific weight of water ($9.81\text{kN}/\text{m}^3$)

The portion of river flows throughout a year that can be used to generate power are defined by the usable flow envelop shown on the **Flow Duration** tab. This envelope is bounded by the Generating Flow line and the Minimum Flow line, see the Glossary for more details. The total annual energy is obtained by integrating the power equation across the usable flow envelope, accounting for turbine efficiencies at each flow.

$$E = \eta_{\text{gearbox}} \times \eta_{\text{generator}} \times \eta_{\text{transformer}} \times h \times \int (P \times \eta_{\text{turbine}})$$

E is the gross annual energy produced (kWh/yr)

η_{turbine} is the efficiency of the turbine, a $f(Q)$, derived from efficiency curves

η_{gearbox} is the gearbox efficiency (if relevant)

$\eta_{\text{generator}}$ is the generator efficiency

$\eta_{\text{transformer}}$ is the transformer efficiency

h is the number of hours the turbine operates per year

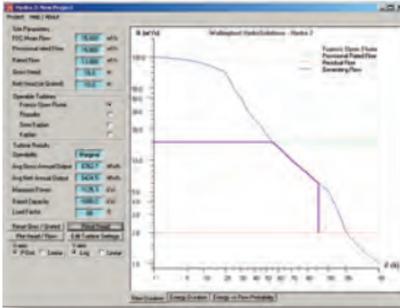


Figure 8.1 Main screen showing results (constant Residual Flow selected)

The **Site Parameters** panel displays a summary of the current river flow regime, head and flow conditions.

You can select to view results for different turbines using the buttons in the **Operable Turbines** panel. Clicking on the **Plot Head/Flow** button will show the current operating envelopes for the turbines. Results are only reported for turbines whose operating envelope encompasses the current system Head-Flow point. The **Operability** field is set to Marginal if the system Head-Flow point is on the boundary of the operating envelope.

The **Turbine Results** panel displays the energy calculation results for the selected turbine:

- **Average Gross Annual Output** This is the annual energy (MWh) generated considering the efficiencies of the turbine, gearbox (if relevant), generator and transformer.
- **Average Nett Annual Output** This is the Average Gross Annual Output adjusted for an annual downtime allowance for maintenance and repair.
- **Maximum Power** This is the maximum power (kW) generated by the system operating at nett head and Qrated flow, including the efficiency of the turbine at this point.
- **Rated Capacity** This is the Maximum Power (kW) reduced by considering the efficiency of the gearbox (if relevant) and generator.

- **Load Factor** Describes the proportion of the year that the system operates at full power. Economically viable mini-hydro schemes typically have Load Factors between 50% to 70% (BHA, 2005). The value is calculated as:

$$\text{Load Factor} = (\text{Ave Nett Ann Output} \times 1000) / (\text{Rated Capacity} \times 8760)$$

where Ave Nett Ann Output is in (MWh) and Rated Capacity is in (kW).

The higher the Qprovtrd value chosen, the smaller fraction of the year that the system will operate at maximum capacity. There is a trade-off between selecting a higher system flow (with an associated lower Load Factor but higher turbine costs) and a lower system flow which means that the (less expensive) turbines will work at maximum capacity for more of the year (a higher Load Factor).

You can choose to reset the Head or Flow conditions by selecting the **Reset Qres / Qrated** or **Reset Head** buttons.

The **Edit Turbine Settings** button enables you to edit the efficiency and downtime parameters used for each turbine. Your edits can be saved as defaults for use in subsequent projects.

Three plot windows display different information regarding the current scheme and the currently selected turbine.

- The **Flow Duration** plot shows the river regime FDC, the residual flow (Qres), the provisional rated flow (Qprovtrd), minimum flow (Qmin) and the generating flow. This plot window illustrates the usable flow envelope which generates energy against the river flow regime and flow conditions.
- The **Energy Duration** plot illustrates the distribution of gross energy generated within a year.
- The **Energy vs Flow Probability** plot illustrates how much energy (gross) is generated when the river regime is running at each flow percentile.

Note You can copy the image from each of the plot windows to the clipboard by a double L-click with the mouse. You can then paste them into documents etc.

8.1 Working with Hydra 2 project files

The **Save project** option under the **Project** menu enables you to save the current data as a project file. You can recall project files when starting up the software and switch from one project file to another using the **Switch project** option under the **Project** menu.

Note If you edit the project files manually 'outside' the software this may result in corruption of the files and instability in the power generation algorithms.

8.2 Exporting

The **Export** option under the **Project** menu on the Main screen enables up to three types of data to be copied to the clipboard and subsequently pasted into documents/spreadsheets etc.

- Choosing **Energy generation summary** will enable you to copy the data from the Turbine Results panel, for all operable turbines.
- The **Flow / energy-duration details for current turbine...** will copy the flow regime FDC, and flow condition lines from the **Flow Duration** plot window for the currently selected turbine.
- If detailed headloss calculations have been performed you will be able to choose the option **Head loss details** which will copy summary data relating to your definition of headlosses in system components.

The **Help / About** menu provides access to the software documentation.

8.3 Turbine data

The turbines included in the software are shown below, together with typical design head ranges.

Turbine	Type	Typical Design Head (m) (BHA, 2005)
Pelton	Impulse	>50m (High)
Turgo	Impulse	>10m (Medium to High)
Crossflow (or Banki)	Impulse	<50m (Low to Medium)
Kaplan	Reaction	<10m (Low)
Semi Kaplan	Reaction	<10m (Low)
Francis (Open flume)	Reaction	<10m (Low)
Francis (Spiral case)	Reaction	10–50m (Medium)
Propeller	Reaction	<10m (Low)
MPL Archimedean Screw	Reaction	<10m (Low)

The software utilises four sets of turbine data:

- **Operating envelopes** These describe the head and flow conditions under which the turbines will operate. These can be viewed via the Plot Head / Flow button, see Figure 8.2.

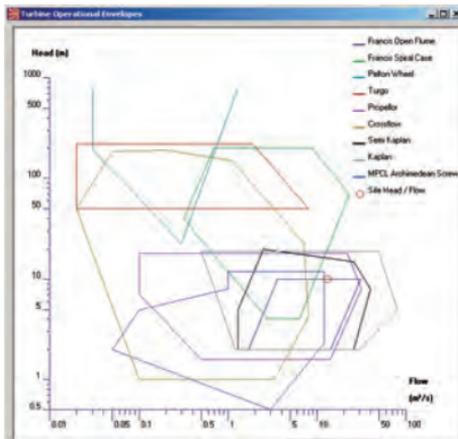


Figure 8.2 Turbine operational envelopes

- Efficiency curves** These describe how the turbine efficiency changes with changing flow. A set of typical curves are included in the software, see Figure 8.3. These were obtained from a variety of sources and may differ to specific values quoted by individual manufacturers.

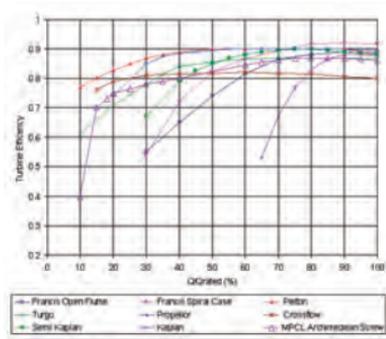


Figure 8.3 Efficiency Curves

- Minimum flow condition** (Q_{min}) This defines the lower limit of operability for a turbine, and is quoted as a fraction of Q_{rated} . The default values adopted in the software are shown on Table 8.1. These were obtained from a variety of sources and may differ to specific values quoted by individual manufacturers.

Table 8.1 Turbine Q_{min} values

Type	
Francis Open Flume	30%
Francis Spiral Case	30%
Pelton	10%
Turgo	10%
Propeller	65%
Crossflow	20%
Semi Kaplan	30%
Kaplan	20%
MPCL Archimedean Screw	10%

- **Component efficiencies** These describe the efficiencies associated with the scheme components and are accessed via the **Edit Turbine Settings** button. The downtime allowance is based on typical maintenance requirements. The typical values adopted as defaults for all turbines are shown on Table 8.2.

Table 8.2 Component efficiencies and downtime allowance

Component	Value
Gearbox efficiency (if relevant)	97.5%
Generator efficiency	96%
Transformer efficiency	98.5%
Downtime allowance (hrs/yr)	438

9 References

British Hydropower Association (BHA), 2005. *A guide to UK Mini-Hydro Developments*.

European Small Hydropower Association (ESHA) (2004). *Guide on how to develop a small hydropower plant*.

Environment Agency of England and Wales (EA) (2009). *Good practice guidelines annex to the Environment Agency Hydropower Handbook: The environmental assessment of proposed low head hydro power developments*.

10 Glossary

10.1 General concepts

Flow duration curves The flow duration curve (FDC) illustrates the percentage of time a particular river flow is equalled or exceeded. A popular design statistic is the **Q95** flow; this is the flow that is equalled or exceeded for 95% of the time. The flow duration curve is therefore an inverse cumulative frequency diagram of flow values.

A FDC is commonly plotted with the x-axis expressed as a probability axis and the logarithm of flow shown on the y-axis. It is also common practice, when comparing the flow duration curves for two or more catchments, to express the individual catchment daily flows on the FDC as a percentage of the long-term mean flow for the catchment (%MF). This removes the majority of the influence of hydrological scale (how large and how wet the catchment is).

Flow-duration statistics are commonly used to describe the dependability of flows for hydropower development. FDCs can be derived from observed data for gauged catchments, using software such as HydroTools. Where no gauged data is available, FDCs may be estimated by a variety of techniques including the regional hydrological model deployed within the LowFlows software suite.

10.2 Flow definitions

Mean flow The annual mean flow (MF) of a catchment is the average flow generated from a catchment over a year. For gauged catchments, this could be calculated from observed daily flow records. It could also be estimated from hydrological models such as those included in the LowFlows software suite.

Provisional rated flow (Q_{provrted}) is the initial estimate of the maximum flow available to generate power. Typically this is set to the catchment annual mean flow but this may vary with regulatory requirements.

Residual flow (Q_{res}) defines the flows which cannot be used to generate power and must be left in the river to support downstream

requirements. Within Hydra 2, Qres can be set as constant across the flow regime or can be set to vary at specific flow percentiles.

Rated flow (Qrated) This is the difference between Qprovrtd and Qres and hence defines the design flow for the hydropower scheme. All components of the scheme (intake, penstock, turbine etc.) will be designed to operate optimally at this flow rate.

Minimum flow (Qmin) This is the minimum flow at which a turbine can operate. Qmin is defined as a fraction of the Qrated, typically 20% to 30% depending on the turbine. The Qmin line on the Flow Duration plot window defines the lower boundary of the flow envelope used to generate power for the current system.

Generating flow The generating flow shown on the Flow Duration plot window defines the upper boundary of the flow envelope used to generate power for the current system.

10.3 Headloss calculations

Trashrack calculations A trashrack is used to screen for debris at the intake structure to protect the turbines. The headloss through a trashrack is calculated as described in ESHA (2004) using the Kirschmer equation which assumes the trashrack is perpendicular to the flow direction. The cleaner coefficient defaults to 0.8 which is appropriate if the trashrack has automatic cleaners. The inlet velocity to the trashrack should typically be in the range of 0.25m/s to 1.0m/s and may be dependent on requirements of the fish species occurring in the river, see EA (2009). The bar shape coefficient describes the shape of the trash rack bars (in cross section) and range from 2.4 for a rectangular shape (high resistance to flow) to 0.8 for a rounded leading edge and tapered trailing edge (low resistance to flow), see ESHA (2004) for more details.

Estimate of minimum pipe diameter An estimate of the minimum pipe diameter for a penstock section is made assuming that it is desirable to limit the friction losses in that pipe section to 4% of the gross head. This is a typical first-pass assumption for small hydropower schemes (ESHA, 2004).

Friction losses Headlosses due to friction (laminar flow) are calculated using Mannings equation, consistent with ESHA (2004).

Mannings 'n' values The default Mannings 'n' roughness coefficient deployed with the software are consistent with ESHA (2004) and are shown below. These values are stored in the [pstks.dat] file and can be edited as described in Section 7.1.

Material	Mannings n
Steel (welded)	0.012
Polyethylene	0.009
PVC	0.009
Cement (asbestos)	0.011
Iron (ductile)	0.015
Iron (cast)	0.014
Wood-Stave (new)	0.012
Concrete (steel forms smooth finish)	0.014

10.4 Allied software

CatchmentsUK™ A WHS software product which enables boundaries to be generated automatically for catchments in Great Britain. A catchment boundary defines the area of land draining to the catchment outlet and is required as an input file for LowFlows, to enable the flow regime of the catchment to be estimated using best practice hydrological models.

LowFlows 2™ Part of the WHS LowFlows software suite and enables flow-duration statistics to be estimated for ungauged catchments. The software uses a digital catchment boundary file (*.csv or ESRI® Shapefile format) to define catchment characteristics for the target catchment. This boundary can be defined automatically using the CatchmentsUK software. A series of hydrological models then estimate the monthly and annual flow duration statistics for the catchment. The estimation procedures are consistent with those used by UK environmental

regulators. The flow estimate file produced by LowFlows 2 can be directly imported into Hydra 2 to define the river flow regime for hydropower analysis.

HydroTools™ A WHS software product which provides a comprehensive suite of tools for analysing river flow data to support both water resource, hydropower and flood management design. Flow-duration statistics, flow frequency (low and high flows) analysis and base flow separation can be performed on data sets of gauged flows. The software includes a convenient database for archiving hydrometric data.



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