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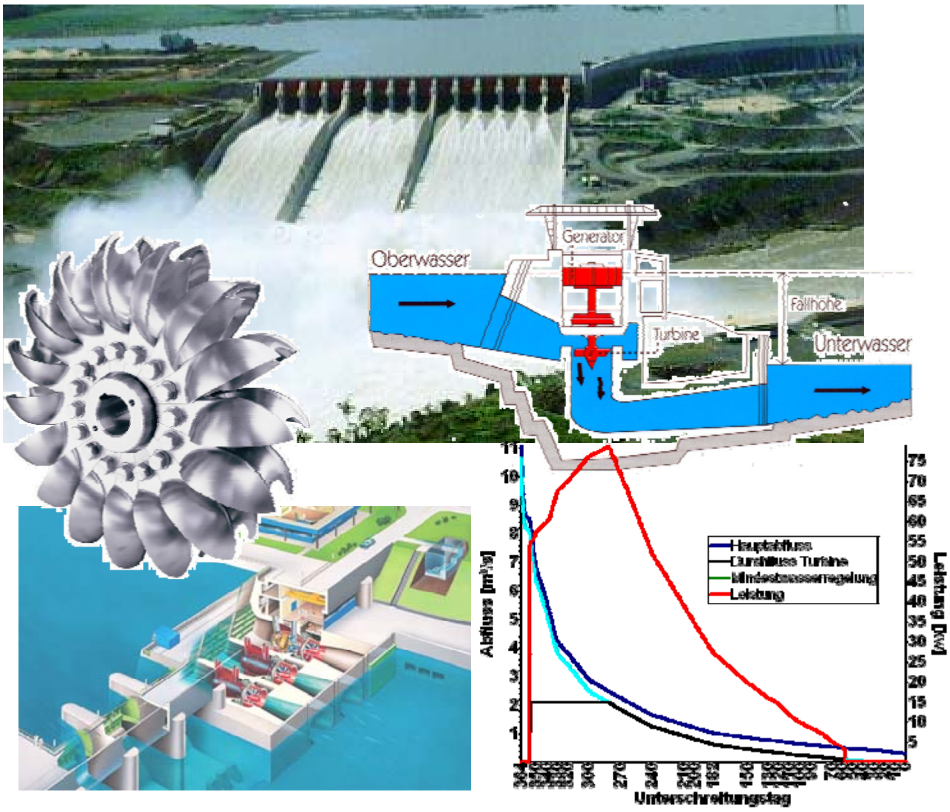
Handbook for the Habitat Simulation Model

CASiMiR

Module Hydropower
Base Version



Last Revision: January 2011

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1 Introduction

1.1 Energy and Economic Assessment of Hydropower Plants

Energy production of hydropower plants depends in the first instance on available discharge Q (volumetric flow rate) and hydraulic head. Accounting for the plant's specific coefficient of efficiency the simple formula for approximating electric power capacity of a hydroelectric plant is given by the equation:

$$P = \eta_{tot} \cdot \frac{\rho_w \cdot g}{10^3} \cdot Q \cdot h \qquad [kW]$$

where

P	=	*power [kW]*
η_{tot}	=	*total plant's coefficient of efficiency [-]*
ρ_w	=	*water density [kg/m³]*
g	=	*acceleration due to gravity = 9,81 [m/s²]*
Q	=	*volumetric flow rate [m³/s]*
h	=	*hydraulic head [m]*

Energy production E_a is equal to the integral of the generated power over a period of time:

$$E_a = \int_0^t P(t)\,dt = \eta_{tot} \cdot 9{,}81 \cdot \int_0^t Q(t) \cdot h(t)\,dt \qquad [kWh]$$

where

E_a	=	*energy production [kWh]*
t	=	*time period of production [h]*
Q(t)	=	*volumetric flow rate changing with time [m³/s]*
$h_f(t)$	=	*hydraulic head changing with time [m]*

Using these two equations the effect of time-dependent discharge, hydraulic head and technical characteristics of plants on the energy output can be evaluated.

1.2 Development of Hydropower

The first version of Hydropower application has been developed at the Institute for Hydraulic Engineering (IWS) of the University of Stuttgart. The original motivation was to study the economic effects for hydropower production as a result of ecologically adjusted discharges in minimum flow studies.

The current version of Hydropower as a part of the CASiMiR-Base software allows to calculate power and energy production for any combinations of hydrographs and flow duration curves for the main flow, mean flow regulation rules, discharge-dependent or constant fall heads and technical characteristics of a plant, such as discharge-dependent efficiency and operational switch points. Various scenarios of power plant operation can be easily simulated and compared using table and chart views of Hydropower.

2 Installation and Start

2.1 Installing Hydropower

☞ *Uninstall, if present, the previous version of Hydropower (see 2.4 Uninstalling the Program). If the link to the program is still present on the desktop, remove it manually.*

☞ *Download the current Hydropower setup file from the www.casimir-software.de website.*

☞ *Start the installation (for example through double clicking on the downloaded setup file) and follow the setup instructions.*

After successful installation, you will find a shortcut to **Hydropower** on your desktop.

2.2 Starting the Program

Starting the Hydropower application can be easily carried out by:

☞ *Double clicking on the* **Hydropower** *desktop icon.*

or

☞ *Going to "All Programs" from the Start menu, locating the group* **CASiMiR-Base**, *and choosing the module* **Hydropower**.

2.3 Closing the Program

☞ *From the main menu bar, go to* **File** *and choose the option* **Quit Hydropower**.

2.4 Uninstalling the Program

☞ *From the* **Start** *menu, go to* **Control Panel**. *Click the* **Add or Remove Programs** *icon. A list of the currently installed software is then populated. Select* **Hydropower** *and click on* **Remove** *to uninstall the program.*

3 Program Application

3.1 Creating New Project

Upon starting the Hydropower module the following menu bar appears on the screen:

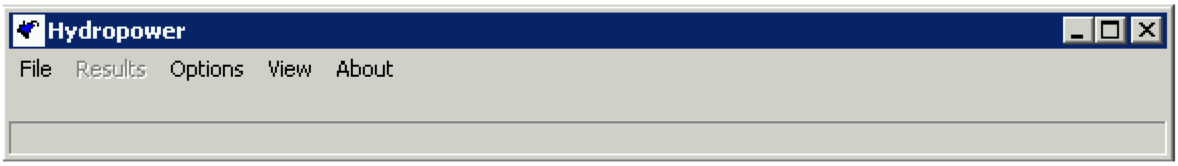

Figure 1. Hydropower main menu bar

The first step using the application is to create a new Hydropower project:

☞ *Select* **File → New** *from the main menu bar.*

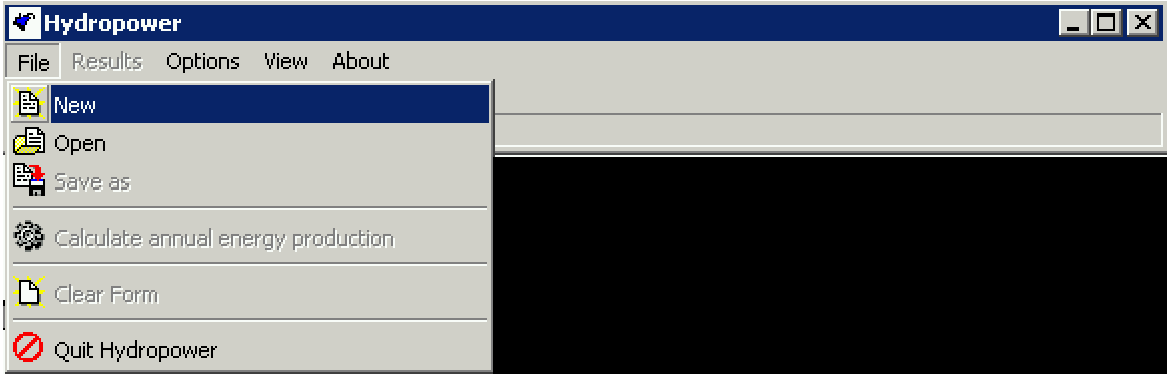

Figure 2. Creating a new Hydropower project

Figure 3 shows the user-interface of Hydropower for project data input. In the first column the discharge information for the main channel have to be specified. Depending on available data and required computation accuracy a user can select between a constant discharge, duration curve or a discharge (Q) time series. The second column gives a user an opportunity to include minimum flow regulation rules for residual water stretches, bypasses or fish ladders. Constant, discharge-dependent or ordered temporally minimum flow regulation rules can be specified here. The third column is used to define a head-discharge dependency for a given hydropower station (constant or discharge-dependent). In the fourth column the technical characteristics of a power plant are defined. Thus, the total plant efficiency dependent on the single efficiencies of a turbine, headrace pipeline, generator and a switchyard can be given either as a constant value or discharge-dependent function. In the lower part of the column 4 a user can define the discharge values for operational switch points such as the minimum required discharge (Q min), the maximum turbine capacity discharge (Q max) and the high water switch off discharge of a power plant.

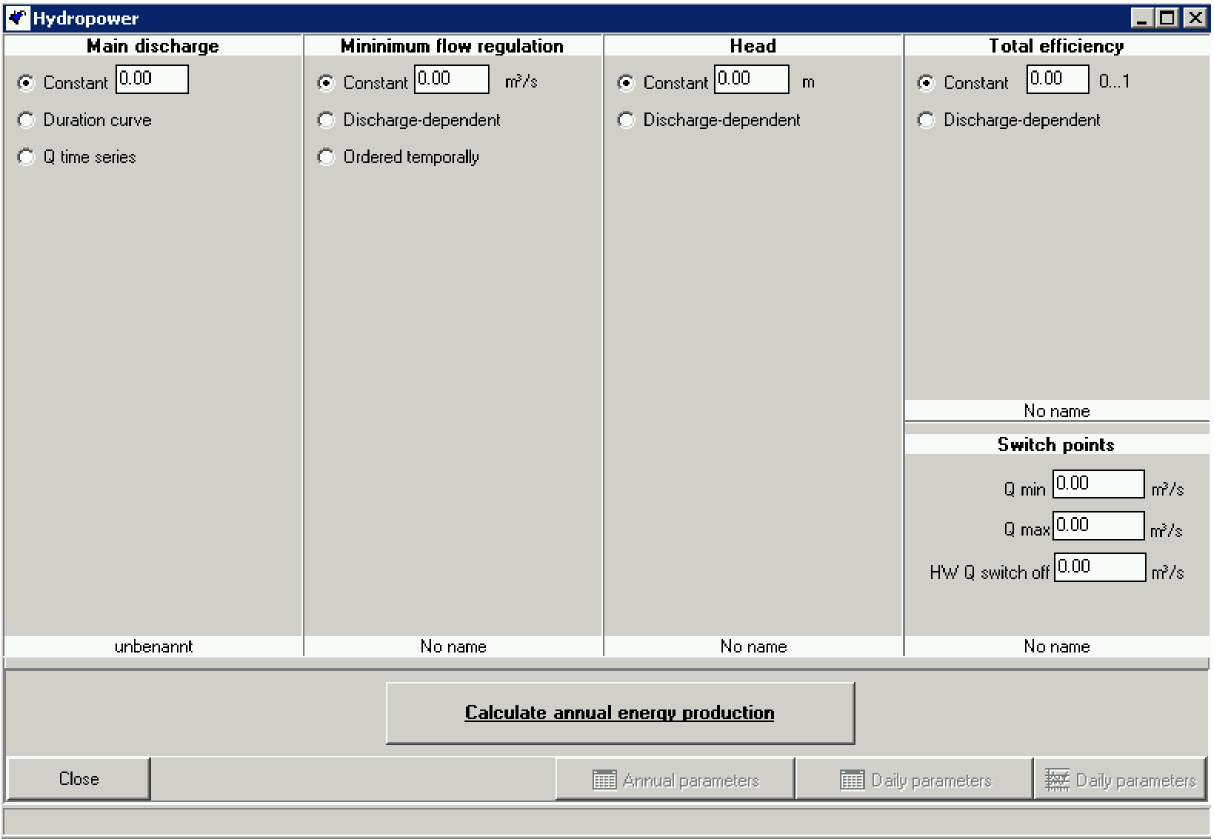

Figure 3. Start view of Hydropower for project data input

The version of Hydropower you are using comes with the set of example data files for energy and economic assessment of a small sawmill. These data files are automatically saved into the software installation directory and can be found under:

…CASIMIR-Base/Examples/Hydropower“.

In Chapter 4. Example of an Energy-Economical Assessment - we will examine this example of an energy and economic assessment step by step.

3.1.1 Defining Main Discharge Data

River discharge data is continuously recorded at official stream gauges. These data is usually available in form of:

- discharge (Q) time series (e.g. series of average daily discharges with date specification), or
- discharge duration curves (e.g. a dependency of an average year non-exceedance days for particular discharges).

Discharge information in Hydropower can be specified in three different ways:

- constant discharge,
- discharge duration curve,
- Q time series.

For the latter two options Hydropower allows to copy a discharge data directly from other programs such as Microsoft Excel®.

The units of discharge data is m³/s and the dot (".") is used as a decimal separator symbol (see: →*Start* →*Control Panel* →*Regional and Language Options* →*Number).*

Specified Q time series or discharge duration curve for the main discharge can be saved in a text file (file extension: „.wsabf") by clicking the right mouse button within the corresponding data column in the start view.

3.1.2 Defining Minimum Flow Regulation Rules

Minimum flow regulation rules for diversion hydropower plants belong, strictly speaking, also to the discharge information. The part of the total discharge needed to be left in the residual water river reach cannot be used for energy production. In Hydropower you can incorporate the minimum flow regulation rules in the following way:

- constant minimum flow discharge,
- dynamic minimum flow regulation
  (minor total discharge → minor minimum flow, high total discharge → high minimum flow) and
- seasonally adjusted minimum flow regulation
  (e.g. minimum flow regulation specifically defined for spawning season).

Specified dynamic and seasonally adjusted minimum flow regulation rules can be saved in a text file (file extension: „.wsmwr") by clicking the right mouse button within the corresponding data column in the start view.

3.1.3 Defining Hydraulic Head

Available hydraulic head that can be used for energy production is an important parameter in an energy and economical assessment of a power plant. The upstream water surface elevation can be often assumed constant for the plants with adjustable weir crests. On the other hand, the water surface elevation downstream of a plant is highly dependent on the available discharge and river geometry. Usually fluctuations of the downstream water surface level are much more significant than in the retention storage upstream of a plant. The lower the plant's hydraulic head is, the more important is to specify its precise value to obtain reliable results.

Hydropower allows for two input modes for a hydraulic head:

- constant head (average head) and
- discharge-dependent head

Discharge-dependant hydraulic head can be saved in a text file (file extension: „.wsfhd") by clicking the right mouse button within the corresponding data column in the start view.

3.1.4 Defining the Total Efficiency of a Plant

Total efficiency of a power plant depends in general on an available turbine discharge and on technical characteristics of a plant, such as a state of headrace pipeline, generator and switchyard efficiencies. For a particular turbine type the specific curves showing the dependency of the turbine's efficiency from the available discharge are usually available.

Hint: If the information about annual plant's energy production, as well as about operational time periods and discharge data for previous years is available, it is possible to assess average total plant efficiency for those time periods. By setting the constant efficiency of 1.0, the value of maximum theoretically possible annual energy production can be calculated. Comparing this value with an actual annual energy production, the value of total plant efficiency for the years considered can be derived.

In Hydropower the total plant's efficiency can be entered in two ways:

- constant efficiency (average efficiency) and
- discharge-dependent efficiency.

Specified discharge-dependent efficiency characteristics can be saved in a text file (file extension: „.wswgd “) by clicking the right mouse button within the corresponding data column in the start view.

3.1.5 Defining Operational Switch Points

In order to calculate the energy production of a plant the operational data (discharge switch points) have to be specified. These are:

- Q min - minimum turbine discharge required for the plant to start operating.
- Q max - capacity discharge of a plant.
- High water switch off discharge.

These discharge values should be given in m³/s and can be saved in a text file (file extension: „. wsspt “) by clicking the right mouse button within the corresponding data column in the start view.

3.1.6 Saving Hydropower Project File

Hydropower project file defines the combination of discharge input data and technical plant parameters for which an energy and economic assessment should be done. This feature allows to combine different discharge data (e.g. time series for wet, dry, mean flow years) and/or plant operating methods into scenarios and to analyze the consequences for energy production. To save a project file for the particular scenario:

☞ *Select from the menu* **File → Save as**

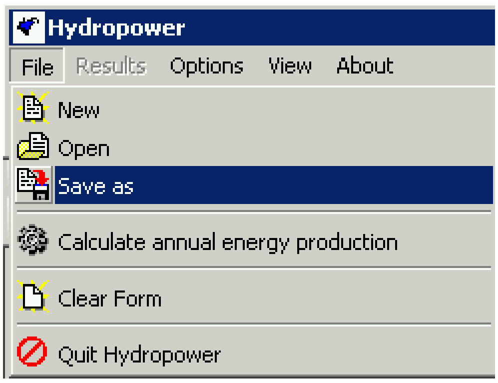

Figure 4. Saving a Hydropower project file

☞ *Navigate to the directory to save the project file (extension* ***„*.wsdat“****). Also select the input files which should be merged in a project file. They are listed in the area marked red in Figure 5.*

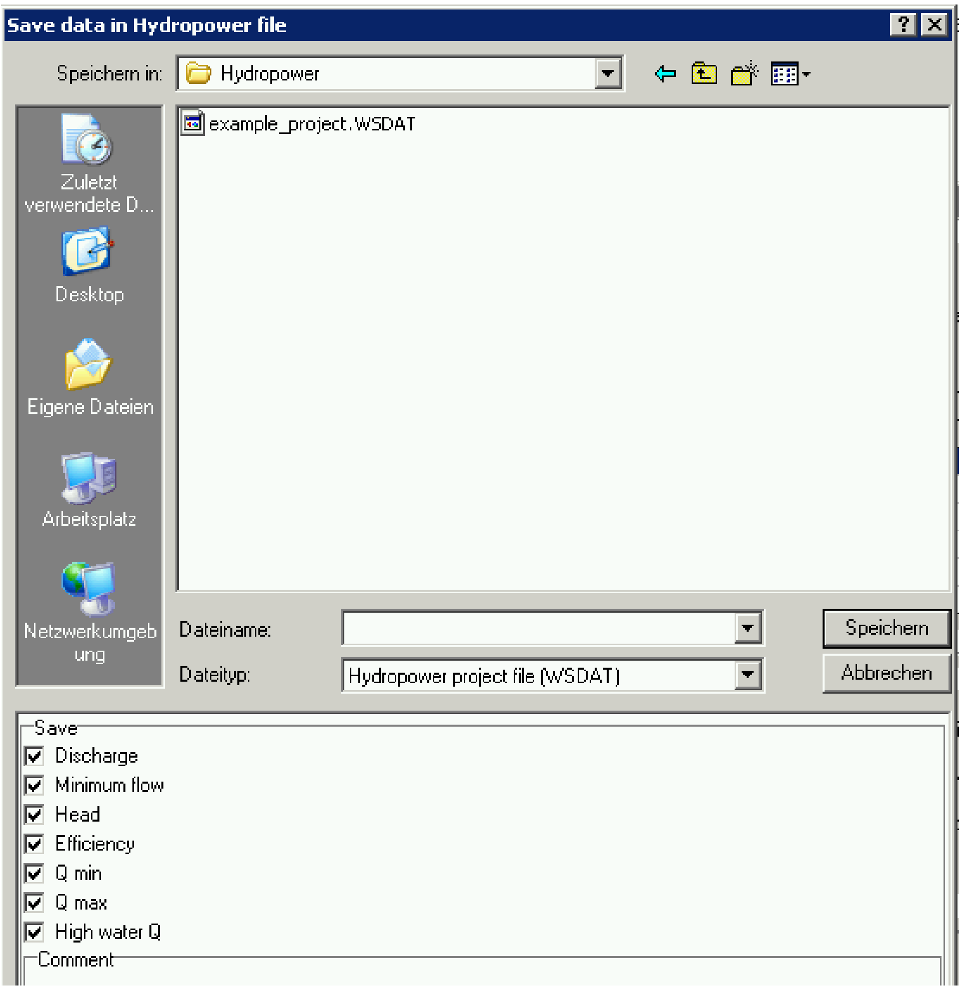

Figure 5. Save project dialog with the list of input files to merge

Upon opening a project file in Hydropower the corresponding input files will be loaded automatically.

3.2. Energy and Economical Assessment

After all required data is successfully defined an annual energy production and corresponding financial return can be calculated.

- *In the main project view press the button* **Calculate annual energy production**.

- *Alternatively select from the main menu bar* **File → Calculate annual energy production.**

The results of energy-economical assessment can be viewed in tables of annual or daily values or as charts of daily values. To view the results either:

- *In the main project view press one of the following buttons:* **Annual Parameters** *or* **Daily Parameters** *(with table or chart icon)*

- *Alternatively the views can be activated via main menu bar (see Figure 6).*

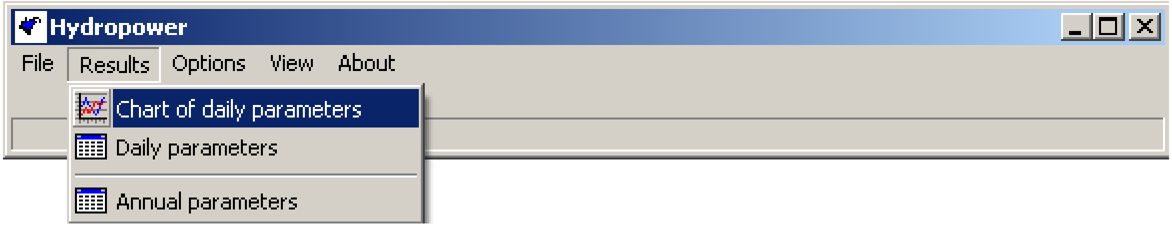

Figure 6. Accessing calculation results from the main menu bar

3.2.1 Calculation Results in Table Form

The values in tables of annual or daily parameters can be saved in a text file. Another alternative is to make a clipboard copy of a table and paste it into an external application (for example MS Excel).

Annual parameters:

Besides the values of annual energy production, annual financial return and total efficiency of a plant, the table „Annual parameters" also includes the following characteristics and their maximal, minimal and average values per year:

- *Power*
- *Efficiency*
- *Main discharge*
- *Usable discharge*
- *Head*
- *Daily energy production*
- *Turbine discharge*
- *Weir discharge*

In addition the total volumes of specific discharges are given:

- Annual discharge – main discharge volume summed up over one year
- Usable discharge – total volume of daily discharges which values exceed the Q min of turbines (see Chapter 0)
- Turbine discharge – total discharge volume used for energy production
- Weir discharge – total discharge volume that cannot be used for energy production and is spilled over a weir

Daily parameters:

The table „Daily parameters" includes the values of above mentioned parameters listed for each day of a year.

3.2.2 Calculation Results in Charts

The tabular results mentioned above can be visualized in charts. A user has the flexibility to examine the single charts of main parameters or combined charts produced by selecting the needed parameters using the corresponding buttons in a chart view. This helps to obtain a more clear inside into the energy production plan of a power plant.

3.2.3 Calculation of Financial Return

In order to calculate an annual financial return the proper feed-in tariff should be defined (in cent per kWh):

- *Select in main menu bar* **Options → Calculation of Return**

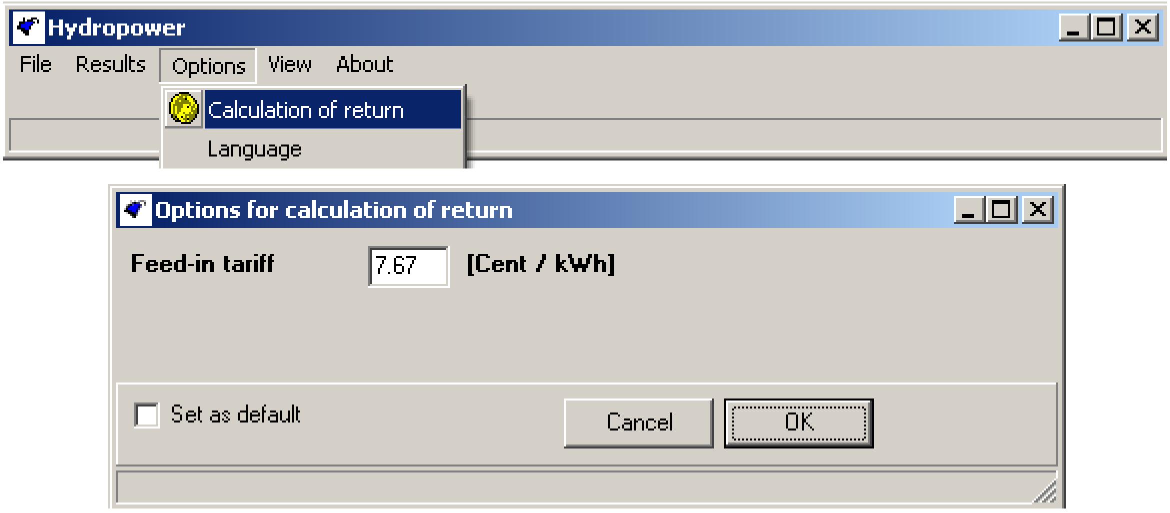

Figure 7. Defining a feed-in tariff for calculation of financial return

Results of the return calculation are presented as tables (annual or daily parameters) and can be visualized in charts.

4. Example of an Energy-Economical Assessment

The following example explains how to load the required input data in Hydropower, carry out an energy-economical assessment and visualize and interpret the results. All the input files are stored in the install directory of Hydropower under:

„… CASiMiR-Base\Examples\Hydropower“

First of all start the Hydropower application and create a new CASiMiR-Hydropower project:

☞ *Select* **File → New** *from the main menu bar.*

4.1 Loading Input Data

Discharge information:

This example contains three files containing main discharge information:

- **hydrograph_2001.WSABF**
  (time series of average daily discharges for the year 2001)
- **flow_durat_curve_2001.WSABF**
  (flow duration curve of average daily discharges for the year 2001)
- **flow_durat_curve_1989-2001.WSABF**
  (flow duration curve of average daily discharges for the period of 1989-2001)

Calculation can only be made for one file separately. To load the main discharge information into Hydropower:

☞ *Click the right mouse button within the column* **Main discharge** *and select from the appeared popup menu the option* **Load Q data from.** *In the* **open file dialog window** *select the file* **flow_durat_curve_2001.WSABF.**

The next figure shows the loaded discharge information from the flow duration curve file for the year 2001:

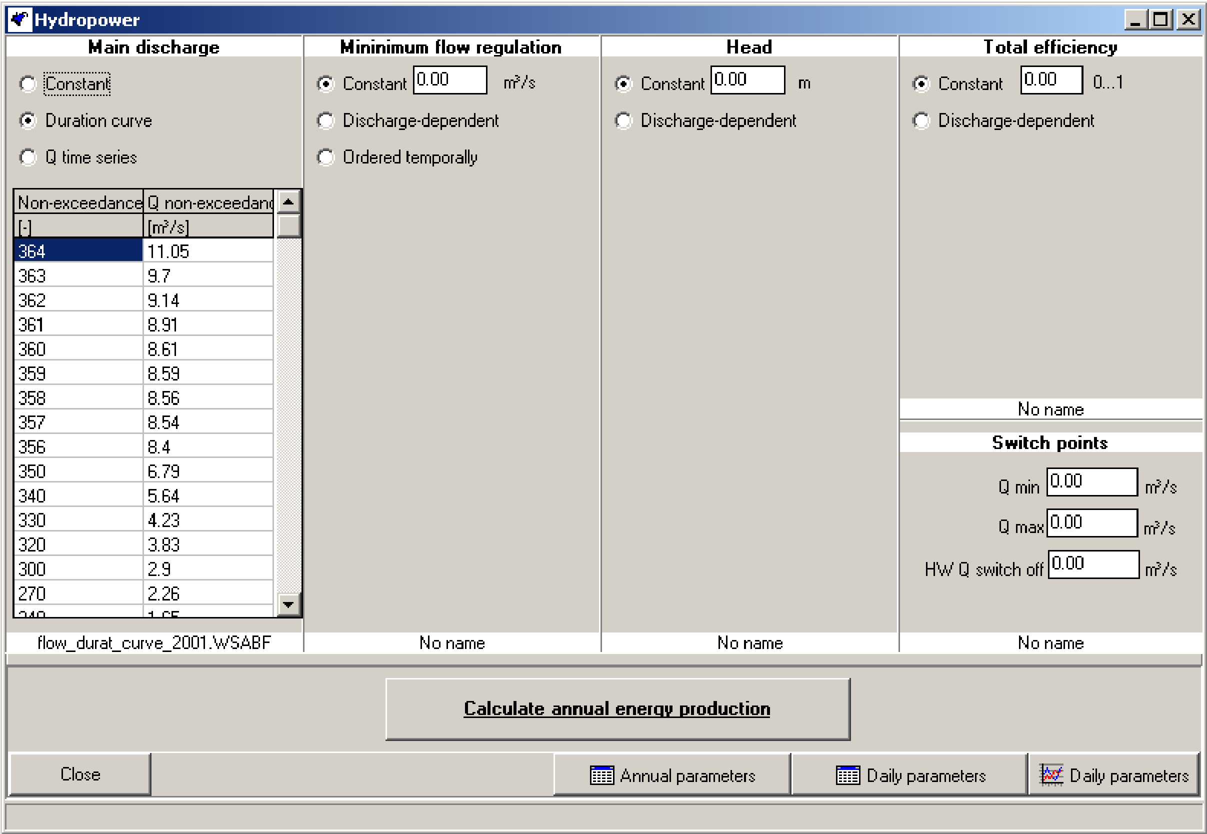

Figure 8: Loaded main discharge information

Minimum Flow Regulation:

There are two files for minimum flow regulations in the example folder:

- **min_flow_regulation_seasonal.WSMWR**
  (seasonal minimum flow regulation)
- **min_flow_regulation_Q_dependent.WSMWR**
  (discharge-dependent minimum flow regulation)

Load the discharge-dependent minimum flow regulation file into the program:

☞ *Click the right mouse button within the column* **Minimum flow regulation** *and select from the appeared popup menu the option* **Load minimum flow information.** *In the* **open file dialog window** *select the file* **min_flow_regulation_Q_dependent.WSMWR***.*

Figure 9 shows the loaded discharge-dependent minimum flow regulation rule:

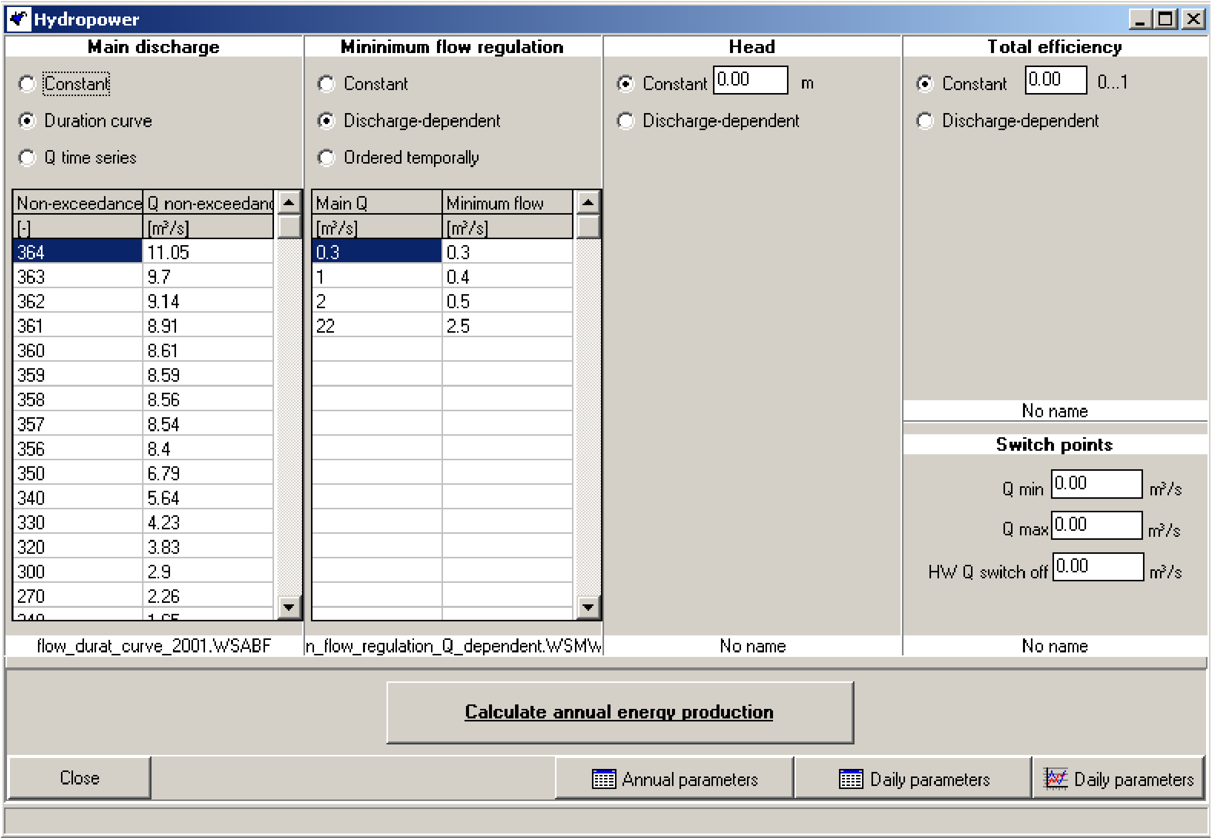

Figure 9: Loaded discharge-dependent minimum flow regulation

Fall head, total efficiency and switch points information:

Our example contains the following files for discharge-dependent fall head, efficiency and switch points which can be loaded in a way:

- *Click the right mouse button within the column* **Head** *and select from the appeared popup menu the option* **Load head data from.** *In the* **open file dialog window** *select the file* **head_Q_dependent.WSFHD.**

- *Click the right mouse button within the column* **Total efficiency** *and select from the appeared popup menu the option* **Load efficiency data from.** *In the* **open file dialog window** *select the file* **efficiency_Q_dependent.WSWGD.**

- *Click the right mouse button within the column* **Switch points** *and select from the appeared popup menu the option* **Load switch point information from.** *In the* **open file dialog window** *select the file* **switch_points.WSSPT.**

After all required data have been loaded the Hydropower project view should look like as shown in Figure 10.

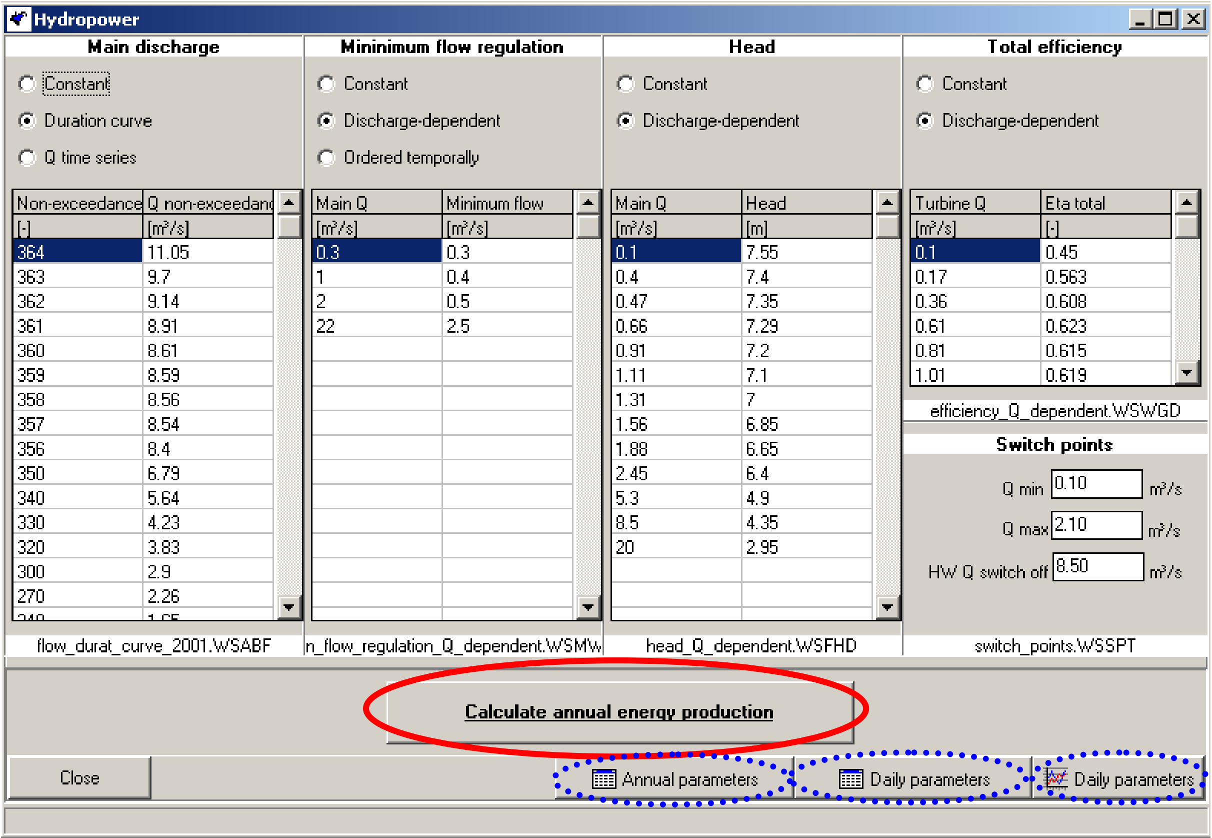

Figure 10: Project view after loading all the required input data files

4.2 Starting Calculation

To start an energy and economic assessment:

☞ *Press in the project view the button* **Calculate annual energy production** *(area marked red on Figure 10.*

4.3 Viewing Results

The results of the energy and economical calculation can be displayed in tables and charts. There are three buttons (marked with blue dot ellipses on Figure 10) for annual and daily parameters serving this purpose.

Table views of annual and daily parameters are shown in Figure 11 and Figure 12 respectively.

Using "copy and paste" a tabular data can be transferred into other extern programs, for example into MS Excel.

An interactive chart view of the calculation results allows obtaining a readily comprehensible plant operation plan by combining the input data with the result parameters as desired by the user (see Figure 13).

Discharge characteristics (main and turbine discharges, minimum flow regulation discharge) in the operation plan can be visualized together or separately using interactive parameter buttons. They can also be brought together with the values of power, efficiency, head, financial return or daily energy produced.

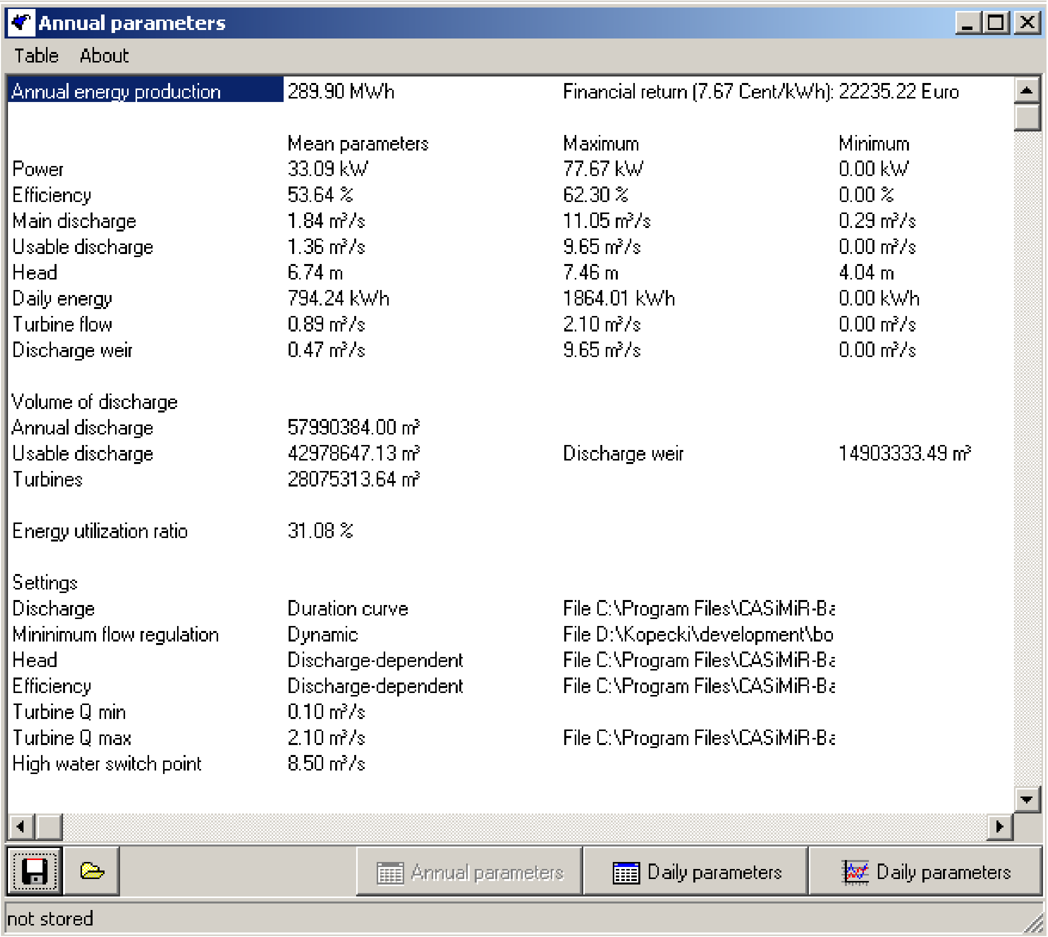

Figure 11. Table view of annual parameters

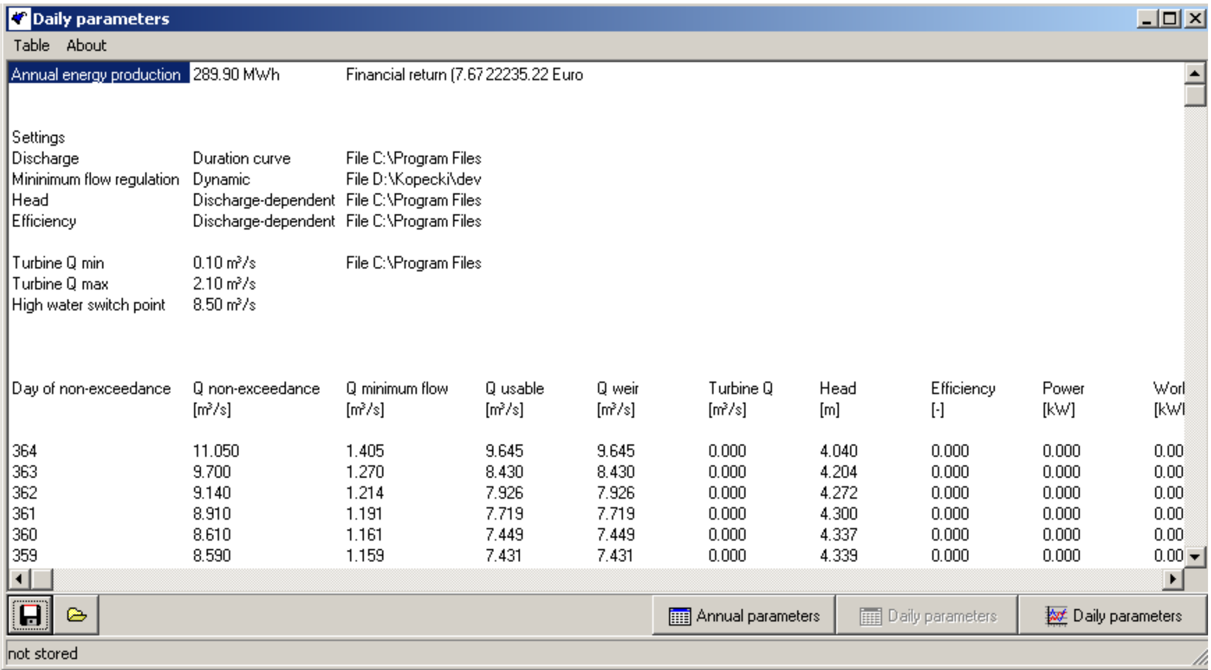

Figure 12. Table view of daily parameters

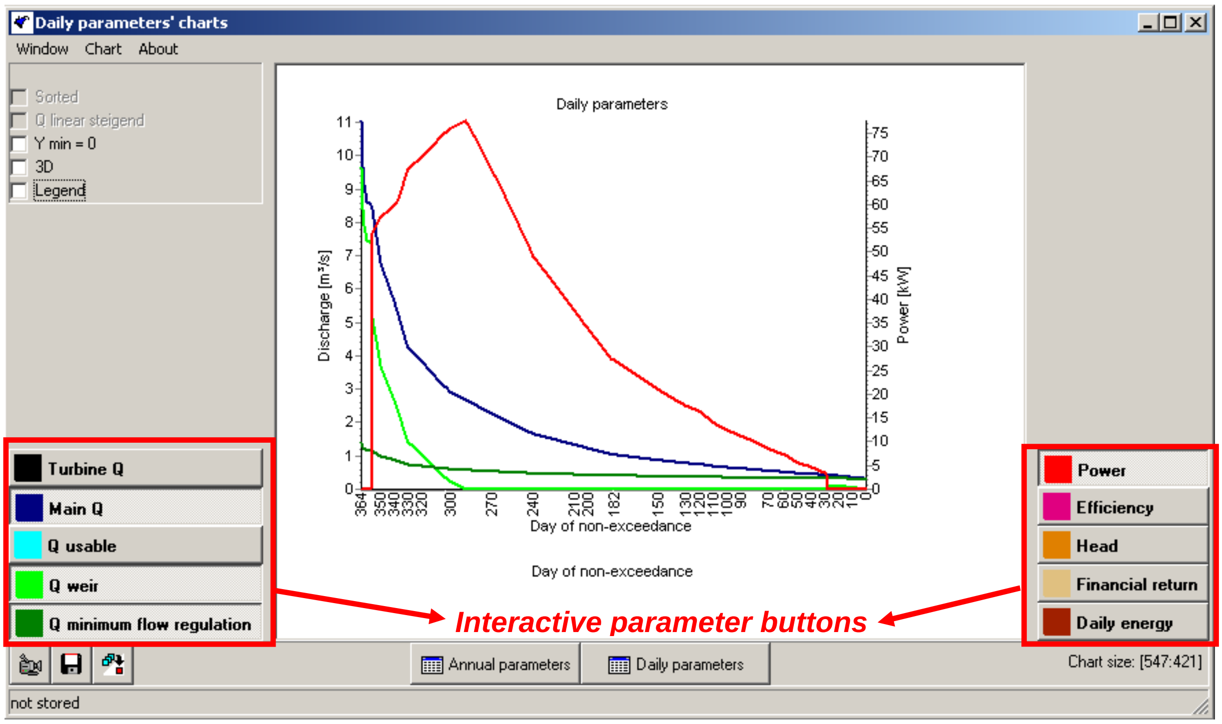

Figure 13: Chart view of daily parameters

Figure 14 shows an interactive chart of operation plan obtained for the case of time series of main discharge and seasonal minimum flow regulation. The input data files used in this case are:

- **hydrograph_2001.WSABF**
- **min_flow_regulation_seasonal.WSMWR**

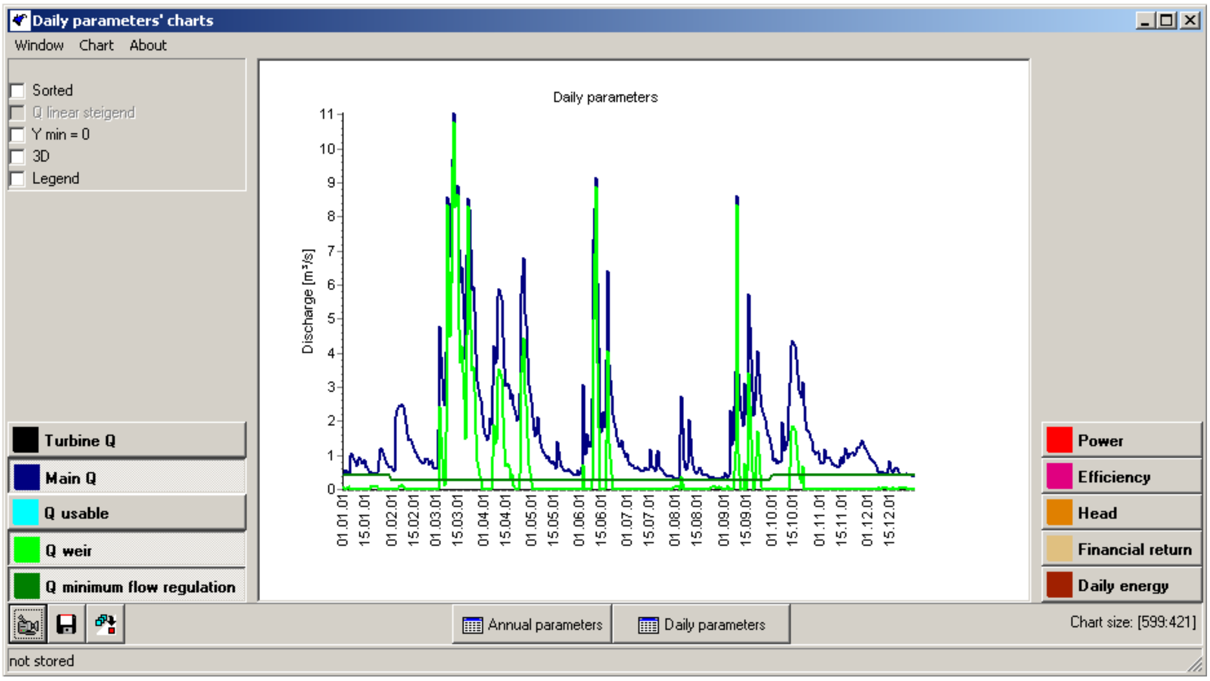

Figure 14. Chart of daily results for Q time series and seasonal minimum flow regulation

By analogy to the flow duration curve case (Figure 13) discharge characteristics can also be combined into one chart and compared with power plant specific values using the respective buttons.