MODULE – 6: Hydropower Analysis

The generation of hydroelectric power is one of the main purposes of a water resources development project. With respect to types of site development, there are three major classifications of hydroelectric projects: storage, run-of-river, and pumped storage. Storage plants are projects that usually have heads in the medium to high range (greater than 25 m) and that have provisions for storing relatively large volumes of water during periods of high streamflow to provide water for power generation during periods of deficient streamflow. The volume of storage capacity required is determined based on the period of deficient flows.

6.1. Firm Power Determination

Traditionally, hydropower potential is determined on the basis of the critical hydro-period as indicated by the historical record (the period when the limitations of hydroelectric power supply due to hydrologic conditions are most critical with respect to power demands). The critical period is a function of the power demand, the streamflow, and the available storage. Firm power is the maximum quantity of power that can be guaranteed to be delivered each year 100% of the time according to some prescribed distribution. Critical period hydrology is used as the inflow sequence for the determination of the firm power output.

6.1.1. Assumptions

Some of the assumptions while using the ***Firm Power Determination*** module are as follows:

a) Starting value of inflow and demand sequence correspond to the beginning of a water year.

b) Metric system of units has been adopted and the desirable units of data have been specified at relevant places.

c) The inflow series needs to be specified for complete water years. Otherwise, the program aborts and prompts for entry of inflow series at daily/10-daily/monthly time step for complete water years.

6.1.2. Data Checks

Some of the checks performed by the module include:

a) Elevation-Area-Capacity (EAC) table of reservoir is checked. If the area (or capacity) at any reservoir level decreases with rising elevation, the program aborts and flags the line number in the EAC table for correction.

b) The capacity at each level of EAC table above the lowest level is checked by using the prismoidal formula. If the difference in the computed and specified capacity is

greater than 10%, a message is flagged at the screen and in the result file after the presentation of Elevation-Area-Capacity table in the Input Data section. The program does not abort in this case.

6.1.3. Input Data Description

The file extensions for input file, output file, and graphical files are ***.hfi, .hfo,*** and ***.hfg*** respectively. Various items input to program are described below:

Title of the analysis

Specify the title of the data file containing general details of the analysis for remembrance at a later date (not more than 100 characters).

Starting year of inflow series

Specify the starting year of the inflow time series. The same will be specified in the working table in output file.

Starting month of water year

Specify the starting month (numeric) of the water year. The first value of inflow sequence corresponds to the starting month of a water year.

Time step size (1-D/2-TD/3-M)

Three time steps are possible: daily, 10-daily, and monthly. Choose the option based on the availability of time step of inflow series.

Number of values in inflow series

Specify the number of values of inflow sequence at specified time step. Using this number, the form for entry of inflow time series will automatically generate the specified number of empty cell rows for input of inflow sequence.

Installed capacity of power plant (MW)

This refers to the maximum capacity of the power plant (MW). This will restrict the maximum power that can be generated at a time.

Minimum level for power generation (m)

Specify the minimum reservoir level for power generation (m). If the reservoir goes below this level, hydropower cannot be generated.

Efficiency of power plant (%)

Every power plant has its own efficiency (say, 85% or 90%). It is used to compute the hydropower production from net effective head and turbine discharge.

Maximum discharge capacity through power plant (cumec)

Specify the maximum discharge capacity (cumec) through the power plant. This restricts the maximum release through the power plant.

Number of values in EAC table

Specify the number of elevations for which corresponding water spread areas (sq. km) and cumulative storage capacity (MCM) are available in the EAC table. Based on the entered value, the EAC table will automatically generate the specified number of empty cell rows for input of elevation, area, and storage capacity.

Dead storage level (m)

Specify the dead storage level of the reservoir (m). As and when the reservoir level reduces below this value, no demand is met from the reservoir. However, evaporation losses are computed as long as there is water in the reservoir.

Full reservoir level (m)

Specify the full reservoir level of the reservoir (m). This is the maximum level of conservation zone beyond which water is spilled from the reservoir.

Number of levels in tail rating table

Specify the number of discharge values from the power plant for which corresponding tail water levels (m) are available in the tail rating table. Based on this value, the form for entry of tail rating table will automatically generate the specified number of empty cell rows for the input of discharge (cumec) and tail water level (m).

Minimum tail water level (m)

Specify the minimum tail water elevation (m) in the tail rating table. For discharges lower than the discharge corresponding to minimum tail water elevation, this value is used to compute the effective head for hydropower generation.

Maximum tail water level (m)

Specify the maximum tail water elevation (m) in the tail rating table. For discharges higher than the discharge corresponding to maximum tail water elevation, this value is used to compute the effective head for hydropower generation.

Number of levels in head-loss rating table

Specify the number of discharge values from the power plant for which corresponding head-loss in the conveyance system are available in the head-loss rating table. Based on this value, the form for entry of head-loss rating table will automatically generate the specified number of empty cell rows for the input of discharge (cumec) and head-loss (m).

Minimum head loss (m)

Specify the minimum head loss (m) in the head-loss rating table. For discharges lower than the discharge corresponding to minimum head-loss, this value is used to compute the net effective head for hydropower generation.

Maximum head loss (m)

Specify the maximum head loss (m) in the head-loss rating table. For discharges higher than the discharge corresponding to maximum head loss, this value is used to compute the net effective head for hydropower generation.

E-A-C table

Clicking on the ***E-A-C Table*** button opens a table for entry of elevation, area, and capacity of the reservoir. The number of cells depends on the data specified in the cell corresponding to number of data points in E-A-C table.

Evaporation depths (mm)

Clicking on the ***Evaporation Depths*** button opens a table for entry of normal evaporation depths in different months of a water year.

Demands thru power plant (MCM)

Clicking on the ***Demands thru PP*** button opens a table for entry of monthly demands through the power plant for various purposes, say domestic supply, irrigation etc. Release for such demands incidentally generate the hydropower.

Demands by-passing the power plant (MCM)

Clicking on the ***Demands by-passing PP*** button opens a table for entry of monthly demands for various purposes that by-pass the power plant, say for environmental flows, irrigation, domestic supply etc. Such demands are accorded highest priority in the operation analysis.

Inflow Time Series (MCM)

Clicking on the ***Inflow Time Series*** button opens a table for entry of inflow values in various time steps of analysis period. Number of cells in the table depends on the data specified in cell corresponding to number of values in flow series.

Tail-water rating table

Clicking on the ***Tail-water rating table*** button opens a table for entry of discharge (cumec) through the power plant and the corresponding tail water elevation (m). The number of cells depends on the data specified in the cell corresponding to number of levels in tail water rating table.

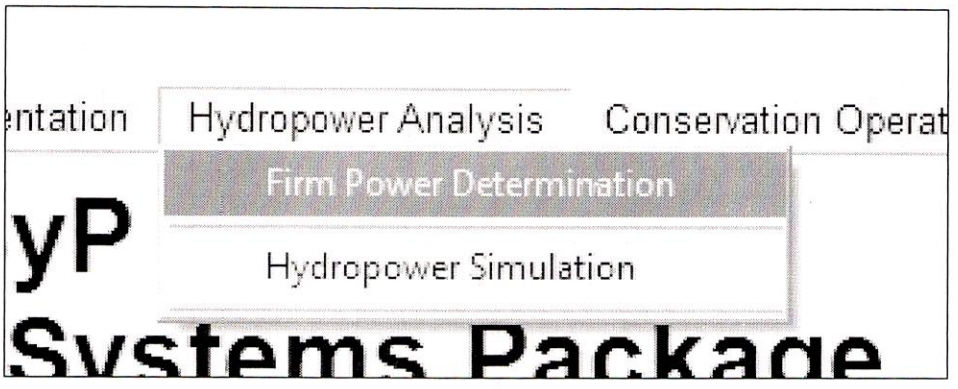
Head-loss rating table

Clicking on the ***head-loss rating table*** button opens a table for entry of discharge (cumec) through the power plant and the corresponding head-loss (m) through the conveyance system of hydropower plant.

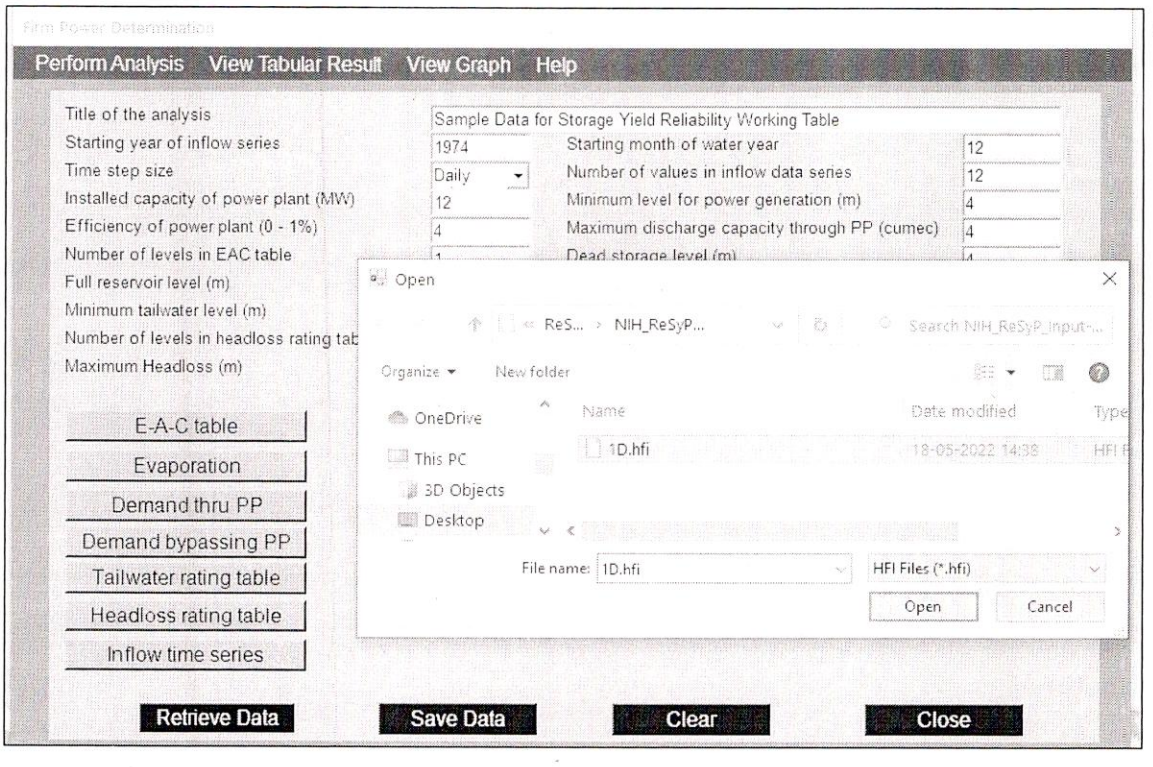
6.1.4. Steps of Analysis

The following are the steps for using the ***Firm Power Determination*** module:

a) Invoke the ***Firm Power Determination*** module. The data form will be displayed for entry of general details and tabular data.



b) Either retrieve an already existing data file by clicking on the ***Retrieve Data*** button or generate a new file by clearing the default data (by clicking on the ***Clear*** button) in the opening data form and fill all the data cells.



c) After entry of all data cells in the general data section, a blank **E-A-C Table** form appears in the lower part of the form for input of elevation, area, and storage capacity values. Click on the ***E-A-C Table*** button and fill all the values in the table **in specified units**.

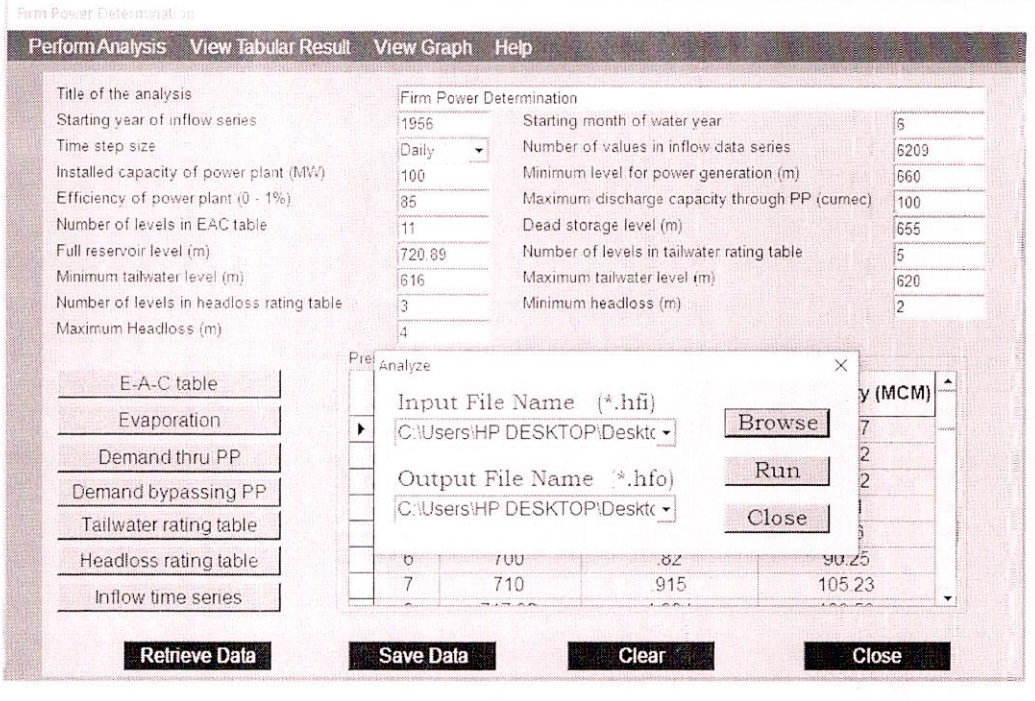
d) Similarly, click on other tabular data buttons (***Evaporation Depth, Demand thru PP, Demand by-passing PP, Inflow Time Series, Tail-water Rating table, and Head-loss Rating table***) and fill all the values in the tables **in specified**

units.

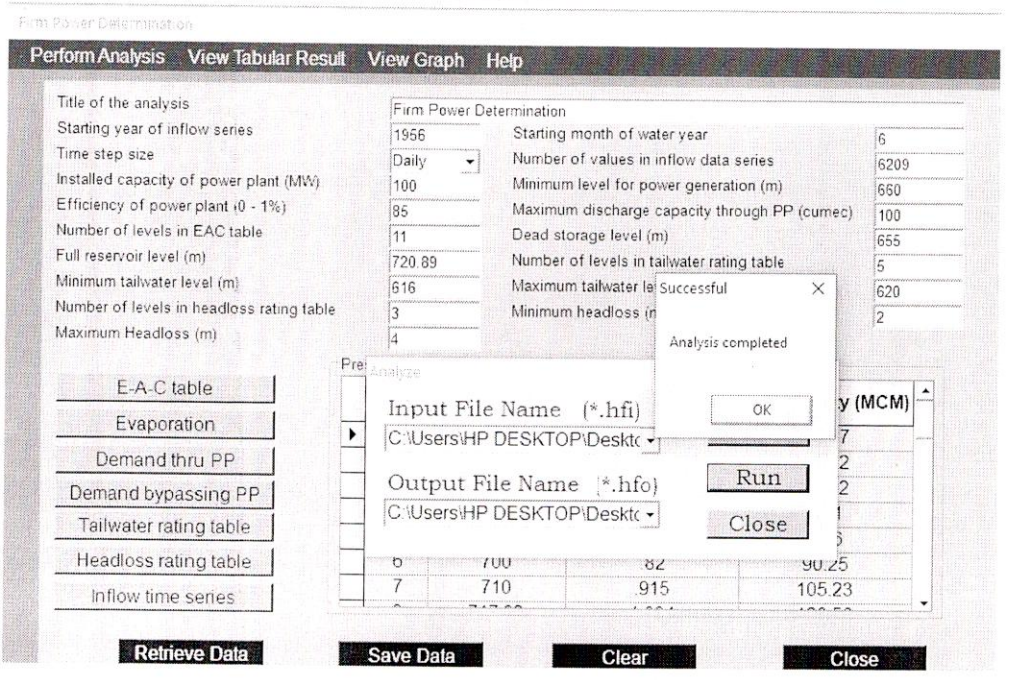
In the tabular data, it is also possible to ***Copy-Paste*** the data of all columns from MS-Excel. In that case, copy the data of all columns together from MS-Excel and bring the cursor to the first row in the table and press F1 (function key). Data will get pasted in all columns in the table. Check that data are present in all cells of the table **in specified units**.

e) After entry of all data cells in the form, click on the ***Save Data*** button. A separate window for saving the data file will appear. First select the desired directory and then specify the desired filename for the data file. The file will be saved as ***.hfi*** file. The extension will be automatically attached with the filename.

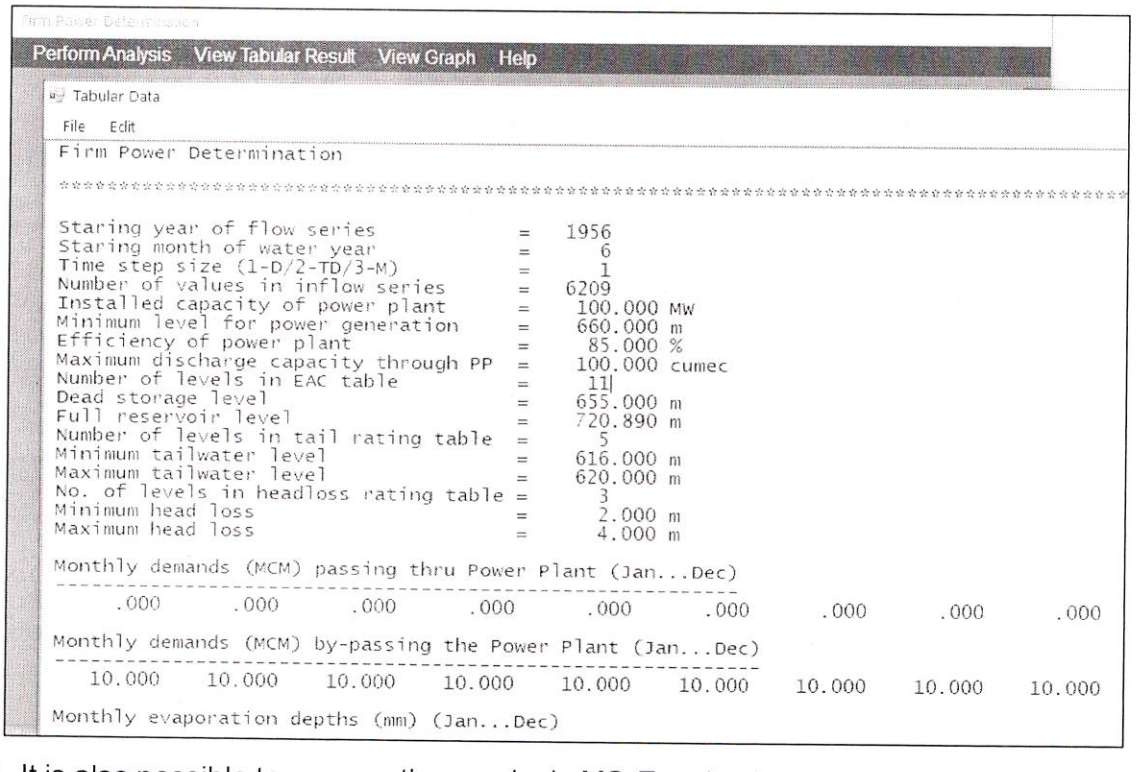
f) Click on the ***Perform Analysis*** button which will open-up a form for the specification of input and output files before the execution of the related program. First click on the ***Input File Name*** cell and then click on the ***Browse*** button. This will open a window for selecting the input file. Go to the desired directory and select the requisite data file. Click on the ***Open*** button to select the file. The file along with the path will appear in the ***Input File Name*** cell. Next, click on the ***Output File Name*** cell and repeat above steps. The filename along with the path will appear in the ***Output File Name*** cell.



g) After specifying the input and output filenames along with their location, the ***Run*** button gets **activated**. Click on the ***Run*** button to execute the related program with the specified input and output filenames. The program runs (in a window which closes automatically after the program execution is complete).



h) Click on the ***View Tabular Results*** button. To view data/results in tabular form, click on the ***Tabular*** button which will invoke the ***Notepad***. Click on the ***File*** and then ***Open*** and a window for file selection will appear. Go to the desired directory and select the requisite Input/Output filenames to see Input/Output files. It needs to be mentioned here that in this window, only files with extension ***.hfi*** or ***.hfo*** will be displayed. Select the desired filename and click on the ***Open*** button. The file will be displayed in the **Notepad**.



i) It is also possible to prepare the graphs in MS-Excel only with specific requirements.

For this purpose, ready-made graphs have been prepared in MS-Excel which can be modified. Open the graphical file (*.hfg) in MS-Excel as ***"Delimited"*** file with ***"Space"*** delimiters and with column data format as ***"General"***. The file will open in a separate MS-Excel sheet. Select and copy the whole worksheet and paste it in ***"Input"*** worksheet of ***"HP-Firm _Graph.xlsx"*** file of MS-Excel which is already built in. The graphs can be copied and pasted anywhere in a document. The graph for the sample analysis are shown in Figures below.

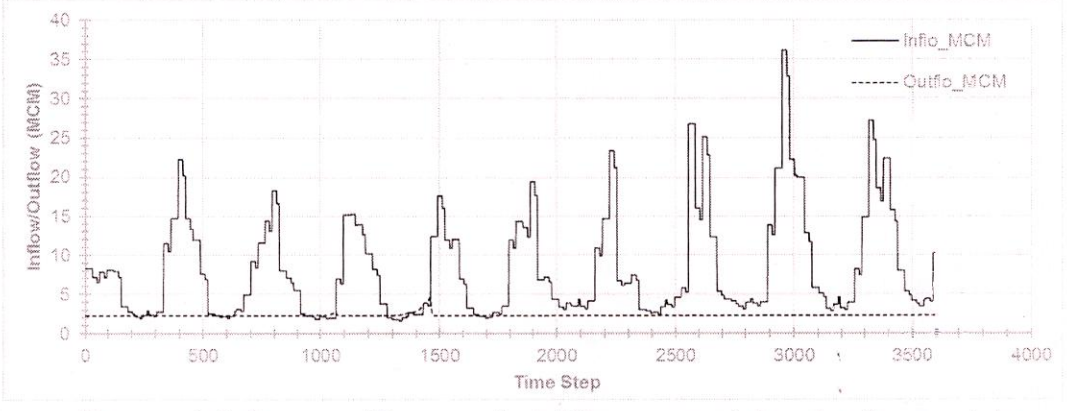


Figure: Reservoir inflow – outflow graphs of firm power determination module

Figure: Variation of reservoir storage graph of firm power determination module

j) Close the ***Firm Power Determination*** module by clicking on the ***Close*** button.

6.2. Hydropower Simulation

For hydropower simulation, no optimization is carried out and the efforts are made to meet the power demands to the extent possible within the system and water availability constraints. The operation of reservoir is simulated using the streamflow data. At each time interval, attempt is made to generate the power equal to the specified power demand, if possible. If the available water in reservoir is less than Smin, no release is made and the storage is depleted by evaporation only. If during any period, Si + Ii > Smax, the extra water over the storage capacity after meeting the

hydropower demand is spilled. If there is not enough water in the reservoir to generate the required power, the power is generated to the extent possible. In this way, the reservoir operation is simulated for the entire period of record

6.2.1. Assumptions

In addition to the operation procedure mentioned above, some of the assumptions while using the ***Hydropower Simulation*** module are:

a) Starting value of inflow and demand sequence correspond to the beginning of a water year.

b) Metric system of units has been adopted and the desirable units of data have been specified at relevant places.

c) The inflow series needs to be specified for complete water years. Otherwise, the program aborts and prompts for entry of inflow series at daily/10-daily/monthly time step for complete water years.

6.2.2. Data Checks

Some of the checks performed by the module include:

a) Elevation-Area-Capacity (EAC) table of reservoir is checked. If the area (or capacity) at any reservoir level decreases with rising elevation, the program aborts and flags the line number in the EAC table for correction.

b) The capacity at each level of EAC table above the lowest level is checked by using the prismoidal formula. If the difference in the computed and specified capacity is greater than 10%, a message is flagged at the screen and in the result file after the presentation of Elevation-Area-Capacity table in the Input Data section. The program does not abort in this case.

6.2.3. Input Data Description

The file extensions for input file, output file, and graphical files are ***.hsi, .hso,*** and ***.hsg*** respectively. Various items input to program are described below:

Title of the problem

Specify the title of the data file containing general details of the analysis for remembrance at a later date (not more than 100 characters).

Starting year of flow series

Specify the starting year of the inflow time series. The same will be specified in the working table in output file.

Starting month of water year

Specify the starting month (numeric) of the water year. The first value of inflow sequence corresponds to the starting month of a water year.

Time step (1-D/2-TD/3-M)

Three time steps are possible: daily, 10-daily, and monthly. Choose the option based on the availability of time step of inflow series.

Number of values in flow series

Specify the number of values of inflow sequence at specified time step. Using this number, the form for entry of inflow time series will automatically generate the specified number of empty cell rows for input of inflow sequence.

Maximum possible power generation

This refers to the installed capacity of the power plant (MW). This will restrict the maximum energy that can be generated at a time.

Minimum level for power generation

Specify the minimum reservoir level for power generation (m). If the reservoir goes below this level, hydropower cannot be generated.

Efficiency of power plant

Every power plant has its own efficiency (say, 85% or 90%). It is used to compute the hydropower production from net effective head and turbine discharge.

Maximum discharge capacity through power plant

Specify the maximum discharge capacity (cumec) through the power plant. This restricts the maximum release through the power plant.

Power requirement

Specify the hydropower requirement (MW) which is to be used as one of the demands in the simulation of the reservoir. Water requirement for this demand is worked out after accounting for the incidental hydropower that gets generated from the release of water for demands through the power plant.

Number of levels in EAC table

Specify the number of elevations for which corresponding water spread areas (sq. km) and cumulative storage capacity (MCM) are available in the EAC table. Based on the entered value, the EAC table will automatically generate the specified number of empty cell rows for input of elevation, area, and storage capacity.

Dead storage level

Specify the dead storage level of the reservoir (m). As and when the reservoir level reduces below this value, no demand is met from the reservoir. However, evaporation losses are computed as long as there is water in the reservoir.

Full reservoir level

Specify the full reservoir level of the reservoir (m). This is the maximum level of conservation zone beyond which water is spilled from the reservoir.

Number of levels in tail rating table

Specify the number of discharge values from the power plant for which corresponding tail water levels (m) are available in the tail rating table. Based on this value, the form for entry of tail rating table will automatically generate the specified number of empty cell rows for the input of discharge (cumec) and tail water level (m).

Minimum tail water level

Specify the minimum tail water elevation (m) in the tail rating table. For discharges lower than the discharge corresponding to minimum tail water elevation, this value is used to compute the effective head for hydropower generation.

Maximum tail water level

Specify the maximum tail water elevation (m) in the tail rating table. For discharges higher than the discharge corresponding to maximum tail water elevation, this value is used to compute the effective head for hydropower generation.

Number of levels in head-loss rating table

Specify the number of discharge values from the power plant for which corresponding head-loss in the conveyance system are available in the head-loss rating table. Based on this value, the form for entry of head-loss rating table will automatically generate the specified number of empty cell rows for the input of discharge (cumec) and head-loss (m).

Minimum head loss

Specify the minimum head loss (m) in the head-loss rating table. For discharges lower than the discharge corresponding to minimum head-loss, this value is used to compute the net effective head for hydropower generation.

Maximum head loss

Specify the maximum head loss (m) in the head-loss rating table. For discharges higher than the discharge corresponding to maximum head loss, this value is used to compute the net effective head for hydropower generation.

E-A-C table

Clicking on the ***E-A-C Table*** button opens a table for entry of elevation, area, and capacity of the reservoir. The number of cells depends on the data specified in the cell corresponding to number of data points in E-A-C table.

Evaporation depths (mm)

Clicking on the ***Evaporation Depths*** button opens a table for entry of normal evaporation depths in different months of a water year.

Demands thru power plant

Clicking on the ***Demands thru PP*** button opens a table for entry of monthly demands through the power plant for various purposes, say domestic supply, irrigation etc. Release for such demands incidentally generate the hydropower.

Demands by-passing the power plant

Clicking on the ***Demands by-passing PP*** button opens a table for entry of monthly demands for various purposes that by-pass the power plant, say for environmental flows, irrigation, domestic supply etc. Such demands are accorded highest priority in the operation analysis.

Inflow Time Series

Clicking on the ***Inflow Time Series*** button opens a table for entry of inflow values in various time steps of analysis period. Number of cells in the table depends on the data specified in cell corresponding to number of values in flow series.

Tail-water rating table

Clicking on the ***Tail-water rating table*** button opens a table for entry of discharge (cumec) through the power plant and the corresponding tail water elevation (m). The number of cells depends on the data specified in the cell corresponding to number of levels in tail water rating table.

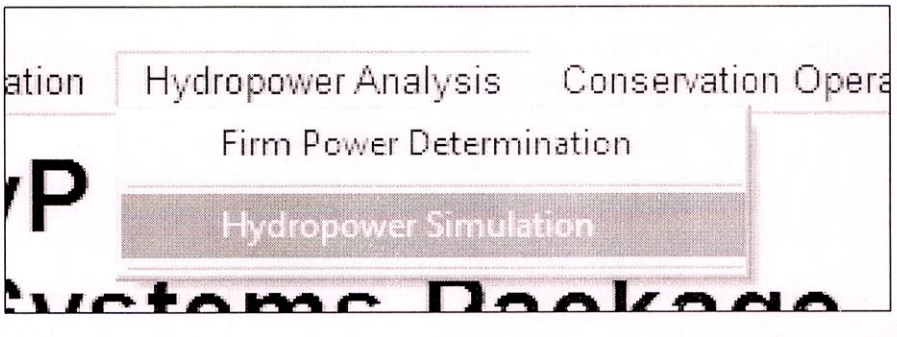
Head-loss rating table

Clicking on the ***head-loss rating table*** button opens a table for entry of discharge (cumec) through the power plant and the corresponding head-loss (m) through the conveyance system of hydropower plant.

6.2.4. Steps of Analysis

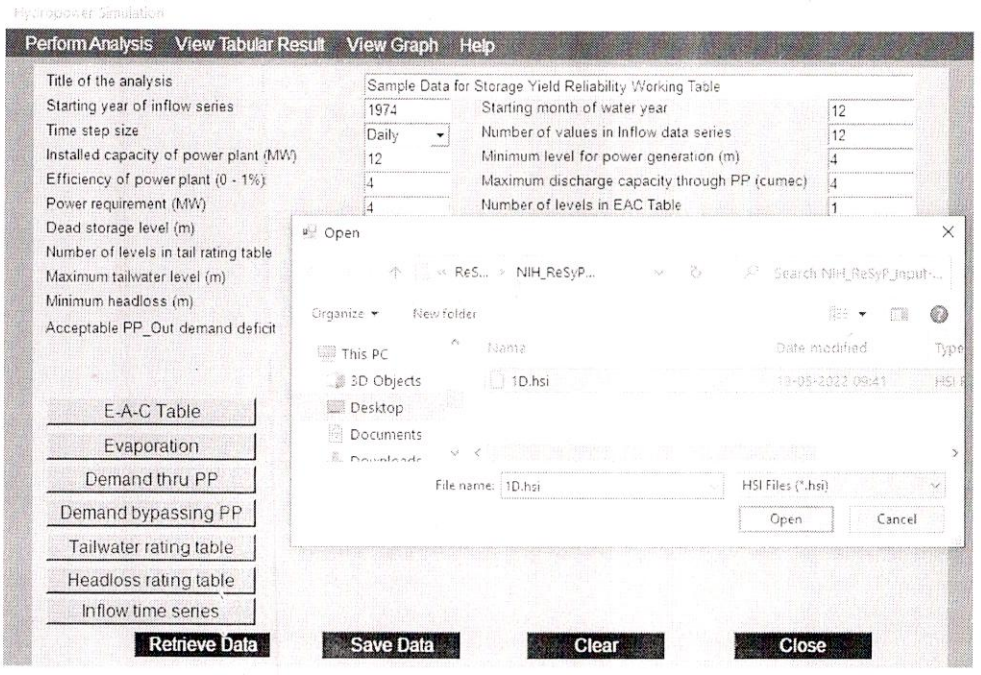
The following are the steps for using the ***Hydropower Simulation*** module:

a) Invoke the ***Hydropower Simulation*** module. The data form will be displayed for entry of general details and tabular data.



b) Either retrieve an already existing data file by clicking on the ***Retrieve Data*** button or generate a new file by clearing the default data (by clicking on the

Clear button) in the opening data form and fill all the data cells.



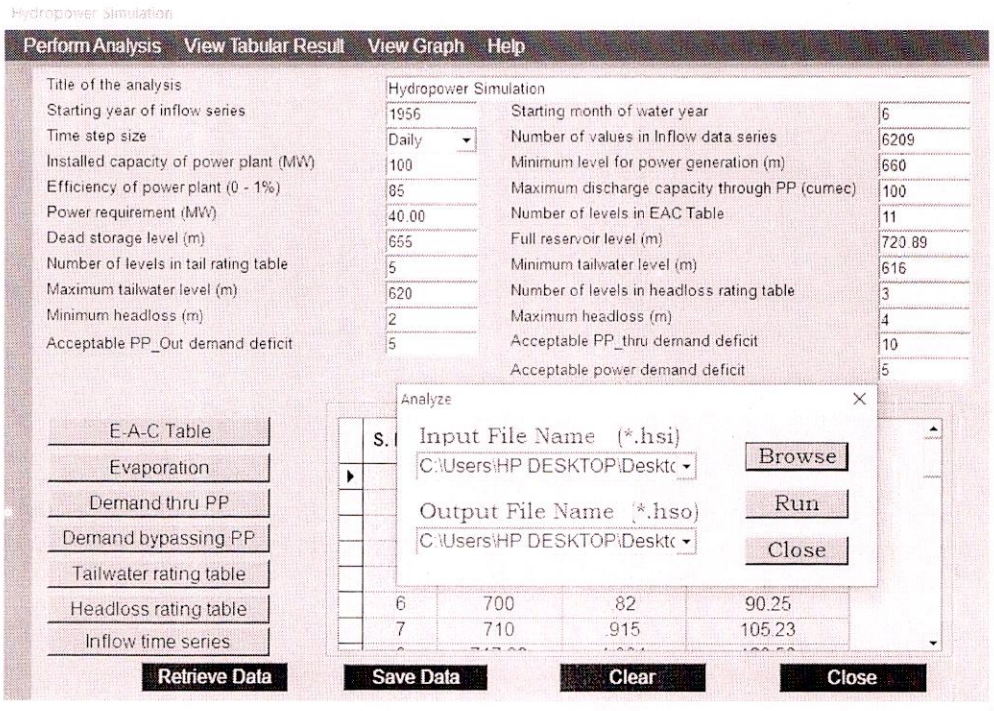
c) After entry of all data cells in the general data section, a blank **E-A-C Table** form appears in the lower part of the form for input of elevation, area, and storage capacity values. Click on the ***E-A-C Table*** button and fill all the values in the table **in specified units**.

d) Similarly, click on other tabular data buttons (***Evaporation Depth, Demand thru PP, Demand by-passing PP, Inflow Time Series, Tail-water Rating table, and Head-loss Rating table***) and fill all values **in specified units.**

In the tabular data, it is also possible to ***Copy-Paste*** the data of all columns from MS-Excel. In that case, copy the data of all columns together from MS-Excel and bring the cursor to the first row in the table and press F1 (function key). Data will get pasted in all columns in the table. Check that data are present in all cells of the table **in specified units**.

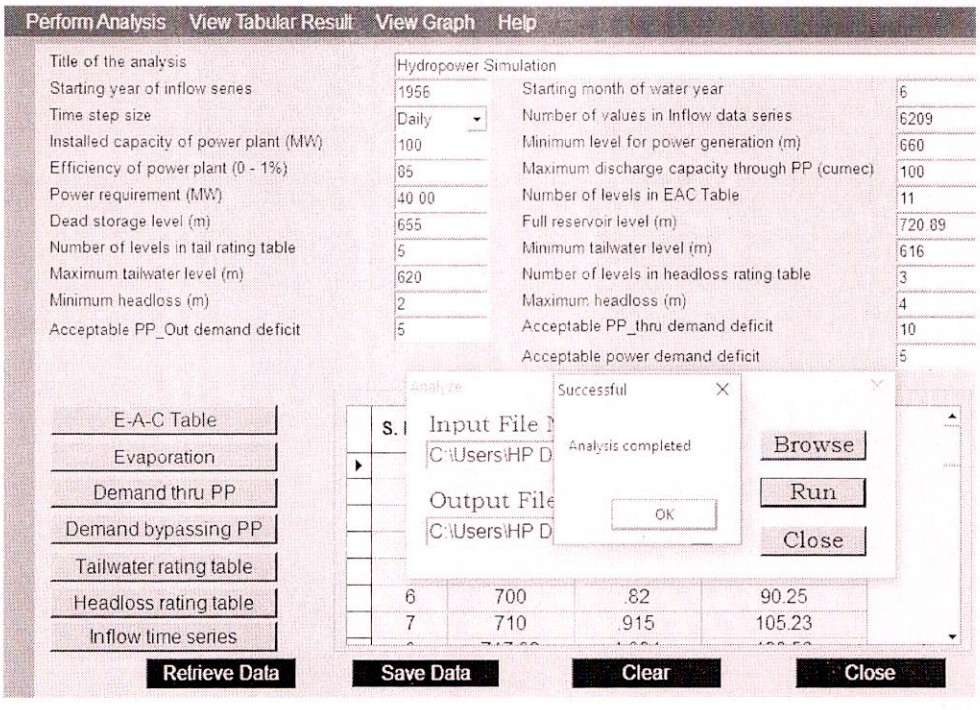
e) After entry of all data cells in the form, click on the ***Save Data*** button. A separate window for saving the data file will appear. First select the desired directory and then specify the desired filename for the data file. The file will be saved as ***.hsi*** file. The extension will be automatically attached with the filename.

f) Click on the ***Perform Analysis*** button which will open-up a form for the specification of input and output files before the execution of the related program. First click on the ***Input File Name*** cell and then click on the ***Browse*** button. This will open a window for selecting the input file. Go to the desired

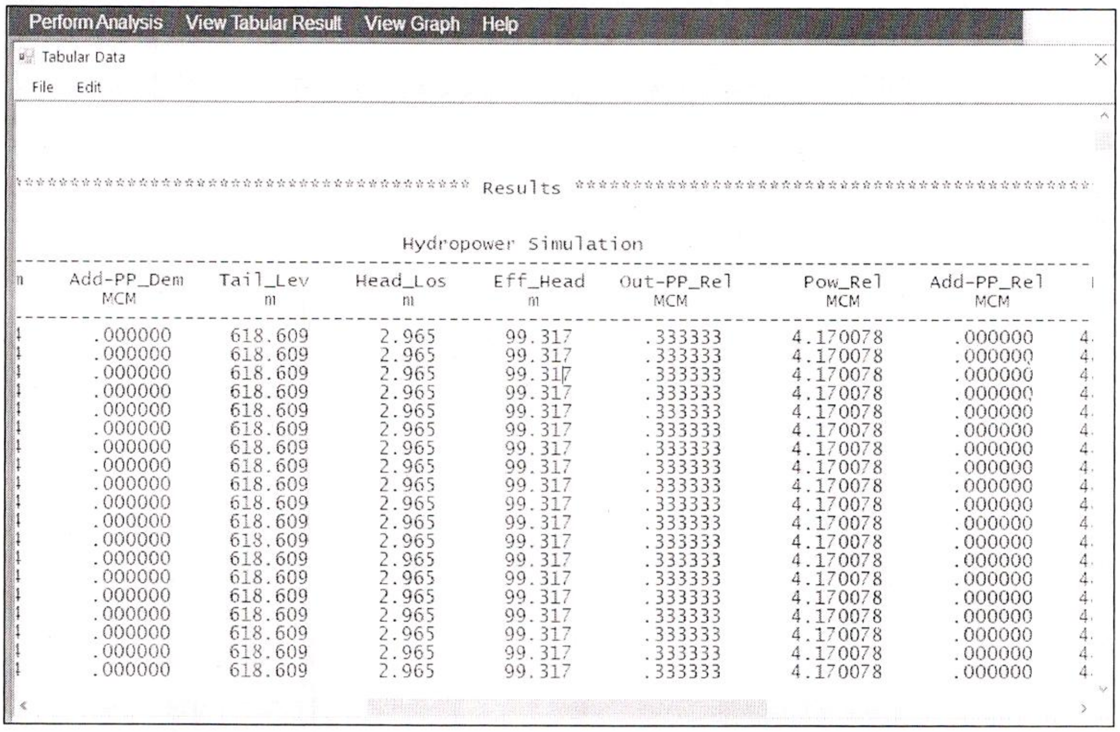


directory and select the requisite data file. Click on the ***Open*** button to select the file. The file along with the path will appear in the ***Input File Name*** cell. Next, click on the ***Output File Name*** cell and repeat above steps. The filename along with the path will appear in the ***Output File Name*** cell.

g) After specifying the input and output filenames along with their location, the ***Run*** button gets **activated**. Click on the ***Run*** button to execute the related program with the specified input and output filenames. The program runs (in a window which closes automatically after the program execution is complete).



h) Click on the ***View Tabular Results*** button. To view data/results in tabular form, click on the ***Tabular*** button which will invoke the ***Notepad***. Click on the ***File*** and then ***Open*** and a window for file selection will appear. Go to the desired directory and select the requisite Input/Output filenames to see Input/Output files. It needs to be mentioned here that in this window, only files with extension ***.hsi*** or ***.hso*** will be displayed. Select the desired filename and click on the ***Open*** button. The file will be displayed in the **Notepad**.



** Results **

Hydropower Simulation

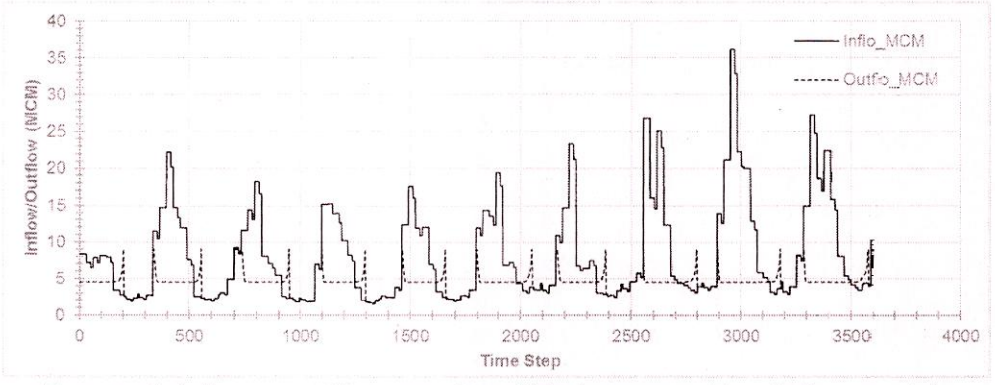
Add-PP_Dem MCM	Tail_Lev m	Head_Los m	Eff_Head m	Out-PP_Rel MCM	Pow_Rel MCM	Add-PP_Rel MCM	
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.
.000000	618.609	2.965	99.317	.333333	4.170078	.000000	4.

i) To view the results in graphical form, click on the ***View Graphs*** button. A window with following graphical option will invoke:

- Inflow – Outflow graphs, and
- Variation of Reservoir Level.

Select the option and then click on the ***View Graph*** button.

j) It is also possible to prepare the graphs in MS-Excel only with specific requirements. For this purpose, ready-made graphs have been prepared in MS-Excel which can be modified. Open the graphical file (*.hsg) in MS-Excel as ***"Delimited"*** file with ***"Space"*** delimiters and with column data format as ***"General"***. The file will open in a separate MS-Excel sheet. Select and copy the whole worksheet and paste it in ***"Input"*** worksheet of ***"HP-Sim _Graph.xlsx"*** file of MS-Excel which is already built in. The graphs can be copied and pasted anywhere in a document. The graph for the sample analysis are shown in following Figures.



Reservoir inflow – outflow graphs of Hydropower Simulation module

Variation of reservoir storage graph of Hydropower Simulation module

k) Close the ***Hydropower Simulation*** module by clicking on the ***Close*** button.