The Hydraulic Economic River System Simulator (HERSS)

User manual version 0.2, 20241014

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Content

Introduction

Welcome to the user manual for the Hydraulic Economic River System Simulator (HERSS). This document is intended to provide you with enough information to get you started with and use the HERSS software effectively. It is beneficial if you have some knowledge within hydrology, river hydraulics and hydropower. Some basic skills of opening and typing in commands in a terminal window running on an Ubuntu/Linux system, or in a Windows Subsystem Linux (WSL), is also helpful. Regardless of your level of competence the intention of this document is to help you to get up to speed on simulating the dynamics of regulated river systems using the HERSS model.

Please note that the HERSS software and this document is WORK IN PROGRESS. It is not perfect, nor finished, and if you investigate the code, the datasets or this document more deeply you may find errors or have ideas on how to improve things. Please note that not all the details of the current HERSS version are fully documented. To code is under constant development and it requires resources to update the user manual to all new features. Only the source code provides full details of how all the calculations are done. You are welcome to contribute to this project. We invite people to collaborate, share ideas, and further develop the HERSS model as an open-source project. The long-term goal of the HERSS project is to develop a lightweight, fast and flexible simulation tool that can be used in various types of analysis of regulated river systems.

Main releases

The first official release (main) on GitHub was in April 2024.

Release history of this user manual:

Version 0.1:	April 2024
Version 0.2:	October 2024
	Main changes in the project: Fixed problems with initialization of the model. Added compilation of shared object file (.so) in the Makefile. Tested usage of CPPYY (calling herss from python). Example of python code can be seen in the file pyherss.py. Made a mini riversystem of TAHPS, using only one reservoir and one powerstation.

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https://en.wikipedia.org/wiki/MIT_License

https://opensource.org/license/mit

Contributors

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Testdata uTAHPS:	Bernt Viggo Matheussen, Kim Ly
Funding:	Å Energi, www.ae.no

System Requirements

The HERSS models is written in C++. It has been developed and tested using *G++* and *Make*, running on a Ubuntu operating system (20.04). It has also been tested on Ubuntu installed under the Windows Subsystem for Linux (WSL) and on standalone servers.

The HERSS have successfully been compiled and run using G++ version 9.3.0 and 9.4.0, and the GNU Make 4.2.1 program. The software has also been tested on Ubuntu 22.04 using g++ 11.4.0. It compiled and ran without errors.

The HERSS uses only standard C++ libraries and has no other dependencies. It should compile and run on most computers having a C++ compiler.

The hardware requirements for the HERSS depend on how you intend to use the model. The test dataset that is part of the code has very low memory and CPU requirements and should run on almost any computer.

Installation Instructions

Download files from GitHub and unpack in a project directory. You should have a directory structure as shown in the figure below:

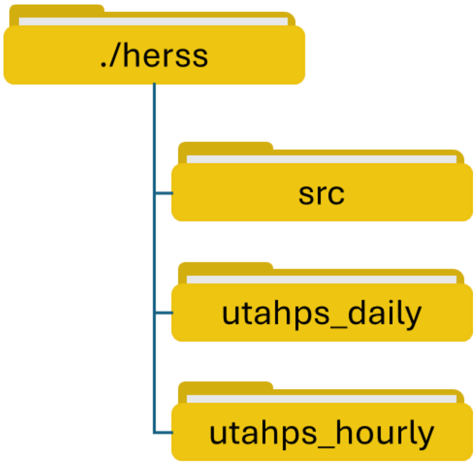

Figure 1 Directory structure of HERSS with source code and two test datasets.

Open a console window or terminal window on the machine you are using.

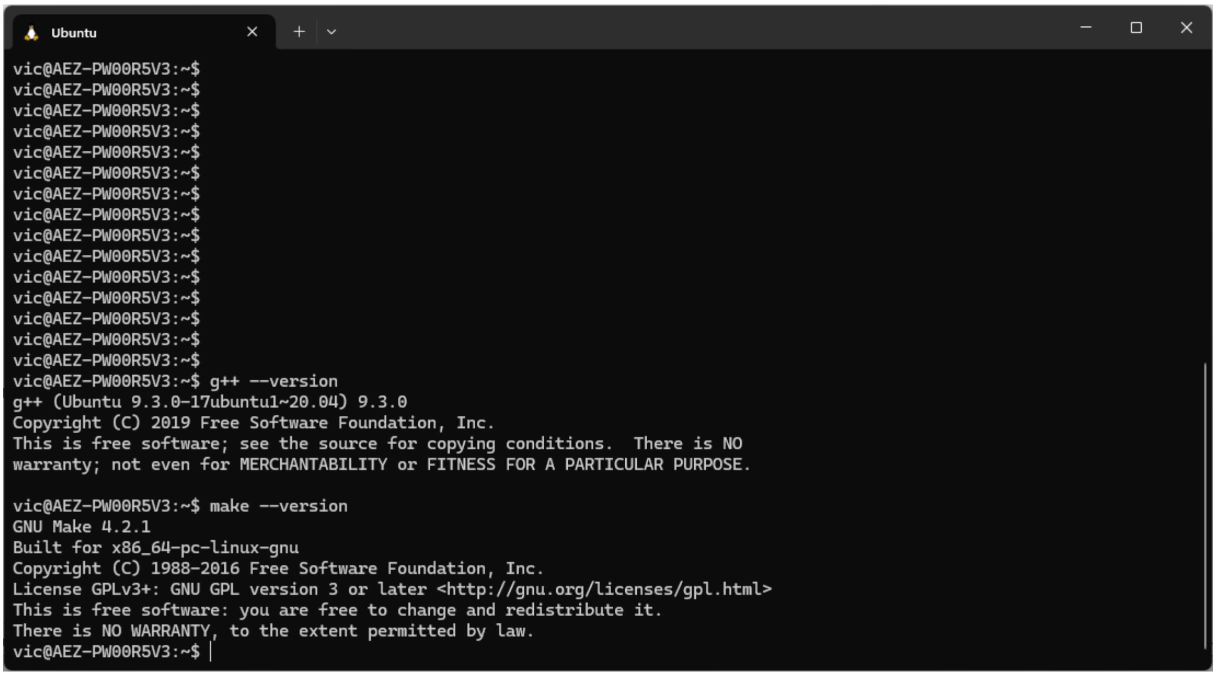

Figure 2Console/command window on Windows Subsystem for Linux (WSL)

Type in: `g++ --version` and check to see that you have g++ installed.

If you don't have g++ installed, you can install it using commands:

```
sudo apt-get update

sudo apt-get install g++
```

Now type in:

```
make --version
```

Check if you have GNU Make installed on your system, if not then install it.

```
sudo apt install make
```

If you have installed *g++* and *make* you are now ready to compile the source code. Jump into the src/ directory typing: `cd src`

Now type: `make`

The code should compile without warnings or errors. The executable file, herss.exe is produced in the *./herss* folder.

You are now ready to start using the HERSS model.

HERSS model structure

HERSS is a software model that can be used to simulate water flow, power production and economy in hydro power river systems. It is written in C++ and can be run on most computers. HERSS models a regulated river as a network of connected nodes. Each node can represent a Reservoir, Powerstation or open Channel. The water flows between nodes in a specified direction starting from the most upstream node. The network must be a directed acyclic graph (DAG). This means that water cannot flow in circles, or that water can never return to a node it has previously been in. HERSS aims to model a river system with moderate complexity, keeping computational requirements low. A simple example of a river network is shown in Figure 3.

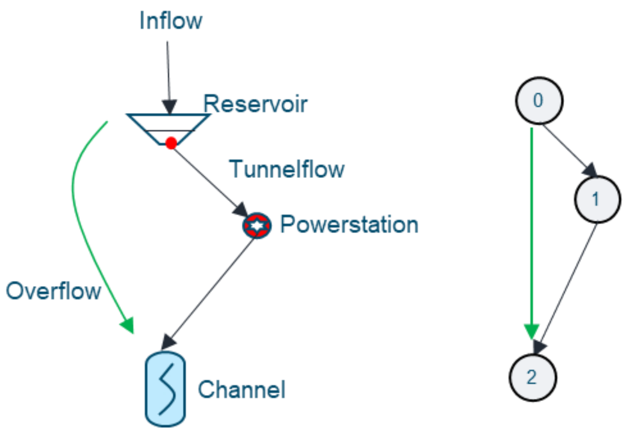

Figure 3 Example of a node-link network. A regulated river system is modelled as a network consisting of Reservoirs, Powerstations and Channels.

Nodetype Reservoir

The node *Reservoir* models a hydropower reservoir. The user needs to specify the reservoir curve together with the Highest Regulated Water level (HRW) and the Lowest Regulated Water level (LRW). A Reservoir can have up to four outlets that can release water to downstream nodes. These are overflow, Q_{min} hatch, tunnel outflow or a regular release hatch. The release policy (action) must be specified to the hatch and tunnel outflows. See more details in the example dataset (uTAHPS).

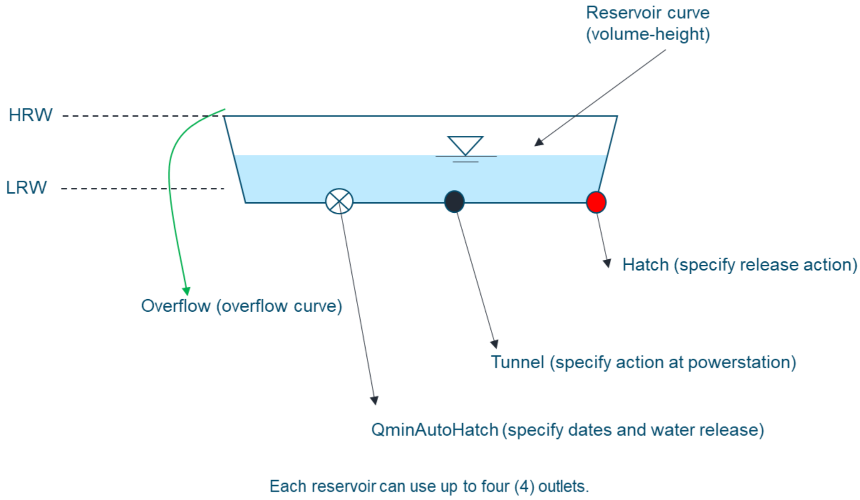

Figure 4 Node type Reservoir

For each reservoir, it is essential to establish a relationship between the water fill levels, measured in meters above sea level (masl), and the volume of water, quantified in million cubic meters (Mm3). This is known as a reservoir curve. Additionally, it is necessary to supply a curve representing overflow, which is defined as the overflow [m^3/s] as a function of the water height above the dam's crest, this could be HRW, or top of the dam. Please refer to the provided test dataset for examples of these specifications.

Nodetype Powerstation

The node type Powerstation models a power station and the tunnel that connects to the reservoir (see Figure 5). Several parameters and an efficiency curve must be specified. See the example dataset for details. In the current version of HERSS, each powerstation can only have one generator.

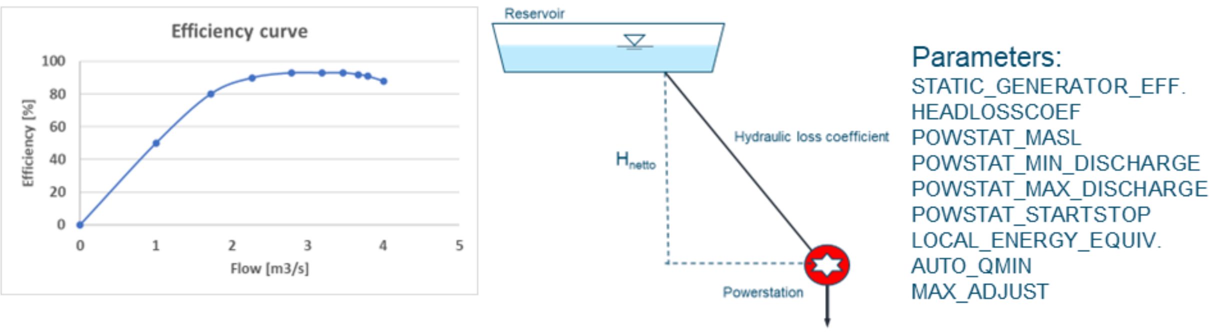

Figure 5 Schematics of a Powerstation and the tunnel connecting it to a Reservoir

Nodetype Channel

The node type Channel is used to model the water transport in open channels (see Figure 6). The traveling time in the channel is modelled as a series of linear reservoirs. If the traveling time is four hours in a channel, four reservoirs is used, and the water moves one linear reservoir pr timestep in the simulation.

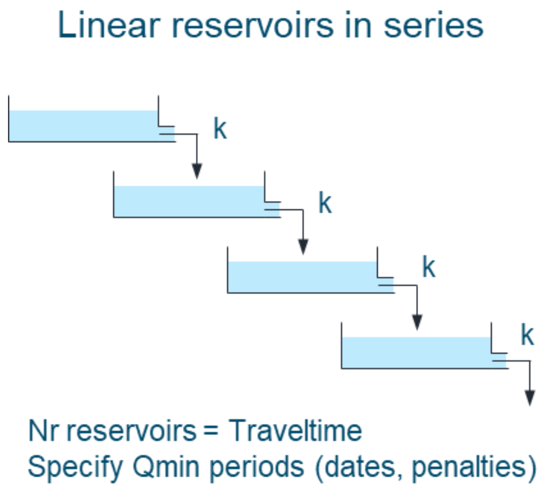

Figure 6 Schematics of the nodetype Channel. The waterflow is modelled as a cascade of linear reservoirs.

A coefficient on the outlet of the linear reservoir can be used to further delay the water. If minimum flow requirements need to be modelled, the nodetype Channel can be used for this. The dates for the Q_{min} period, and the economic penalty for breaking the requirements needs to be set. See test dataset and source code for more details.

Input

Several ascii text files are needed to run the HERSS model. A short description of each file is given below.

Global configuration file

The global configuration file specifies the system name, input/output directories, name of other input files (topology, inflow, etc) and output files. See the file *global_utahps.txt* for more details. The global configuration file is sent as input to HERSS on the command line when the model is run.

Topology file

The topology file is used to specify all the nodes that the riversystem consists of. Each node needs an identification number (idnr). The first node needs the idnr to be zero (0), and the following nodes increasing. Upstream and downstream nodes also needs to be specified. The lowest outlet node (ocean or most downstream part of riversystem is identifies if the downstream node is set to -9). See more details in the file topology_utahps.txt. The topology file is typically made by looking at maps/GIS description of your system. In Norway nve-atlas is a good start for this.

Price file

The HERSS model needs a timeseries of powerprice as input to the simulations. This is specified in the pricefile. It is assumed that the whole riversystem is located within the same price region. Each powerstation and/or penalty is calculated with the same price. In addition to the timeseries and end of planning horizon restprice (water value) is also needed. This is used to estimate the remaing value of the water in the reservoirs. The HERSS model is currency agnostic, meaning that it can use any currency as input. The testdata uses Euro/MWh.

Inflow file

The inflow file specifies the local water inflow to the reservoirs. Note that the idnr in the first row needs to be consistent with the node idnr specified in the topology file.

Date_NodeID	0	3	5	9
2022090100	0.36	0.23	0.31	0.67
2022090101	0.36	0.23	0.30	0.67
2022090102	0.36	0.23	0.30	0.67
2022090103	0.36	0.23	0.30	0.66
2022090104	0.36	0.22	0.30	0.66
2022090105	0.36	0.22	0.30	0.66
2022090106	0.35	0.22	0.30	0.66
2022090107	0.35	0.22	0.30	0.65

Figure 7 Example of an inflowfile.

In Figure 7 the first row of data specifies the idnr of each coloumn. This number corresponds to the idnr of each reservoir in the model. These are 0, 3, 5, and 9. This means the following reservoirs that can be found in the topology file:

NODE RESERVOIR 0 HJELLE

NODE RESERVOIR 3 GRESSE

NODE RESERVOIR 5 TOPPSY

NODE RESERVOIR 9 KROKNESVATN

Note that if you have mixed up the idnr in your system, the model will not work or give weird results. It is a good idea to build one node in your model, test it, and then add a new node.

Actions file

Figure 8 shows an example of a timeseries of actions specified for each of the nodes provided in the first row. The actions file contains information about how each powerstation, hatch or decision node/point will be operated in each timestep. All actions are set as floating numbers in the range [0.0 – 1.0]. For Powerstations the water release calculation uses the action to find the flow level based on the minimum and maximum flow through the generator. For each hatch in a reservoir the water release is also specified with the action. The actual flow is found by the min,max outflow specifications of the hatch description.

Date_NodeID	1	6	7	10
2022090100	0.80	0.00	0.00	0.00
2022090101	0.80	0.00	0.00	0.00
2022090102	0.80	0.00	0.00	0.00
2022090103	0.80	0.00	0.00	0.00
2022090104	0.80	0.00	0.00	0.00

Figure 8 Example of an actions file. In this example there are four nodes (powerstations) where the actions are specified for each timestep in the simulation period.

Start state file

The start state file specifies the starting reservoir filling, current production state of the powerstations, and initial water stored in the open channels. Figure 9 illustrates an example of a start state file for the uTAHPS system. The initial reservoir filling is specified as a fraction [0.0 – 1.0]. This number is used together with LRW and HRW to calculate the filling in Mm^3 and masl. The initial power of the powerstation is specified as MWh and amount of water in each linear reservoir is given as m^3.

```
# STATEFILE UTAHPS
# BVM 04 Mar, 2024

# NODE RESERVOIR IDNR NAME INIT_RES_FR
NODE RESERVOIR 0 HJELLE 0.9
NODE RESERVOIR 3 GRESSE 0.82
NODE RESERVOIR 5 TOPPSY 0.9
NODE RESERVOIR 9 KROKNESVATN 0.99

# NODE PSTATION IDNR NAME MWh
NODE PSTATION 1 SVOLETJONN 0.0
NODE PSTATION 6 SVEIGSHYL_I 0.0
NODE PSTATION 7 SVEIGSHYL_II 0.0
NODE PSTATION 10 EASTER 0.0

# NODE CHANNEL IDNR NAME, water volume stored in each segment
NODE CHANNEL 2 VANAROSEN
25.0 25.0  25.0 25.0 25.0
NODE CHANNEL 4 GRONANI
50.0 50.0 50.0 50.0 50.0
NODE CHANNEL 8 DALSANA
50.0 50.0 50.0 50.0 50.0 100.0
NODE CHANNEL 11 HYNNEKLEIV
100.0
## END
```

Figure 9 Example of a start state file. Starting reservoir levels, current production level at powerstations, and water travelling in channels are specified.

Output

The HERSS model writes several ascii text output files after the simulation is finished. These files are written to the output directory specified in the global configuration file. The first ones are node files providing timeseries of all the fluxes and states in each node. Secondly, the end state of the riversystem is written. This file is the same as the input state file and can be used as input to new simulations. The third file is a timeseries of all the reservoir levels. The last file is the riversystem summary file. A short description of each file is provided in the section below.

Node output files

A separate file for each node in the riversystem is generated. Each node type (Reservoir, Powerstation, Channel) has a unique file type and format. The file name consists of the node idnr and the node name. If you run the example located in the utahps_hourly folder you will find files with the following names in the output folder:

node0_HJELLE.txt, node1_SVOLETJONN.txt, node2_VANAROSEN.txt, node3_GRESSE.txt, node4_GRONANI.txt, node5_TOPPSY.txt, node6_SVEIGSHYL_I.txt, node7_SVEIGSHYL_II.txt, node8_DALSANA.txt, node9_KROKNESVATN.txt, node10_EASTER.txt, node11_HYNNEKLEIV.txt

Please run the example and open the output files for inspection. Each of the files should be self-explanatory.

Output state file

At the end of the simulation horizon the end state of all reservoirs, powerstations and channels are saved. The state of each node is written to the output state file. An example of such file is shown in Figure 10. We see that the node type, idnr, node name and the state data is written for each node.

```
NODE RESERVOIR 0 HJELLE 0.25570
NODE PSTATION 1 SVOLETJONN 1.59691
NODE CHANNEL 2 VANAROSEN
11520.00017 11520.00017 11520.00017 11520.00017 11520.00017
NODE RESERVOIR 3 GRESSE 0.23921
NODE CHANNEL 4 GRONANI
0.00000 0.00000 0.00000
NODE RESERVOIR 5 TOPPSY 1.00856
NODE PSTATION 6 SVEIGSHYL_I 2.67354
NODE PSTATION 7 SVEIGSHYL_II 6.59378
NODE CHANNEL 8 DALSANA
36499.40980 36505.18685 36510.91383 36516.65029 36522.33663 36528.03238
NODE RESERVOIR 9 KROKNESVATN 1.14438
NODE PSTATION 10 EASTER 14.19484
NODE CHANNEL 11 HYNNEKLEIV
53684.52604
```

Figure 10 Example of an output state file (ascii text).

Reservoir file

The reservoir file contains timeseries of the reservoir levels in all the reservoirs. The reason for writing this file is to make the reservoir levels easily accessible. It can also be extracted from the node files (Reservoirs).

Riversystem summary file

The riversystem summary file contains three sections of output data. The first one is a listing of all the nodes in the river system and their end state (remaining Mm^3). The second section contains a global water balance for the system (Mm^3). The water balance of the riversystem is calculated as the sum of initial water plus inflow minus all outgoing water over the simulation period minus the end state. The water balance should be zero down to decimal place 5 or 6, otherwise there is something wrong.

The last section in the riversystem summary file contains information about the economy and energy in the system. The table below lists the output variables and a description of what they mean.

Table 1 Example summary data written in the riversystem summary output file

Parameter	Description
Average_price_Euro	Average energy price calculated from the input timeseries
RestPrice_Euro	The end of planning horizon water value (user specified).
tot_remaining_available_Mm3	Total water value remaining in system
tot_remaining_available_MWh	Total energy remaining in system calculated with energy equivalent.
tot_remaining_available_Euro	Value of remaining energy
Sum_Production_MWh	Sum of the energy production in the simulation period
tot_income_Euro	Total income from actual production in the simulation period
Avg_achieved_price_E_MWh	Average achieved energy price in the simulation period
sum_qmin_cost_Euro	Sum of penalties for breaking minimum flow restrictions
sum_lrw_cost_Euro	Sum of penalties for breaking LRW
sum_startstopcost_Euro	Sum of start/stop costs on machinery
sum_max_adjustment_cost	Sum of adjustment costs for machinery
tot_cost_Euro	Total of all costs
tot_profit_Euro	Total profit (income minus penalties)
valuefunction_Euro	Value function means total value of actions, penalties and remaining value.

Using HERSS

Running herss on the commandline

After you have installed and compiled the HERSS model you are now ready to use it. The HERSS model has no graphical user interface. It is run in a terminal/command window. We will now try to run the hourly test dataset for the Upper Tovdalen Artificial Hydropower Systems (uTAHPS).

Navigate to the folder: *./utahps_hourly/*

You should see the following files in this folder:

global_utahps_hourly.txt, topology_utahps.txt, inflowseries_utahps.txt, actions_utahps.txt, pricefile_utahps.txt start_state_utahps.txt

Now we can run the HERSS model.

Make sure you have the herss.exe file located in the folder above.

Run the following command: **../herss.exe**

You should now see a printout of the HERSS model to the screen.

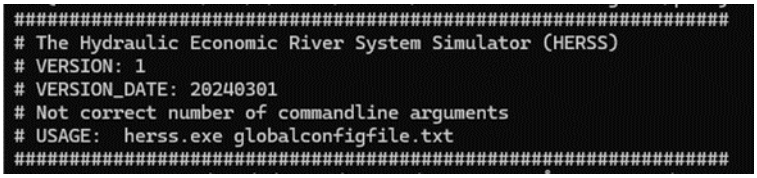

Figure 11Screen after running herss.exe without global config file

Run the following command: **../herss.exe global_utahps_hourly.txt**

If everything went well you should see some printing to the screen.

```
ACTIONFILE          actions_utahps.txt
INFLOWFILE          inflowseries_utahps.txt
PRICEFILE           pricefile_utahps.txt
TOPOLOGYFILE        topology_utahps.txt
OUTPUTFILE          output_utahps.txt
SYSTEMNAME          uTAHPS
STARTSTATEFILE      start_state_utahps.txt
OUTSTATEFILE        outstate_utahps.txt
NR_NODES            12
NR_RESERVOIRS       4
NR_CHANNELS         4
NR_PSTATIONS        4
DT                  3600
STPS                8760
WRITE_NODEFILES     1
OUTPUTDIR           ./output/
THE-END
```

Figure 12 Screen after runninf the herss.exe with the global config file

Congratulations, you have now successfully run the HERSS model for the test dataset (uTAHPS).

Youi can now open the results files located in the ./output/ directory. If you have changed the output directory to something else, please look there.

The figures below illustrate the reservoir fillings and the total outflow at the Hynnekleiv channel.

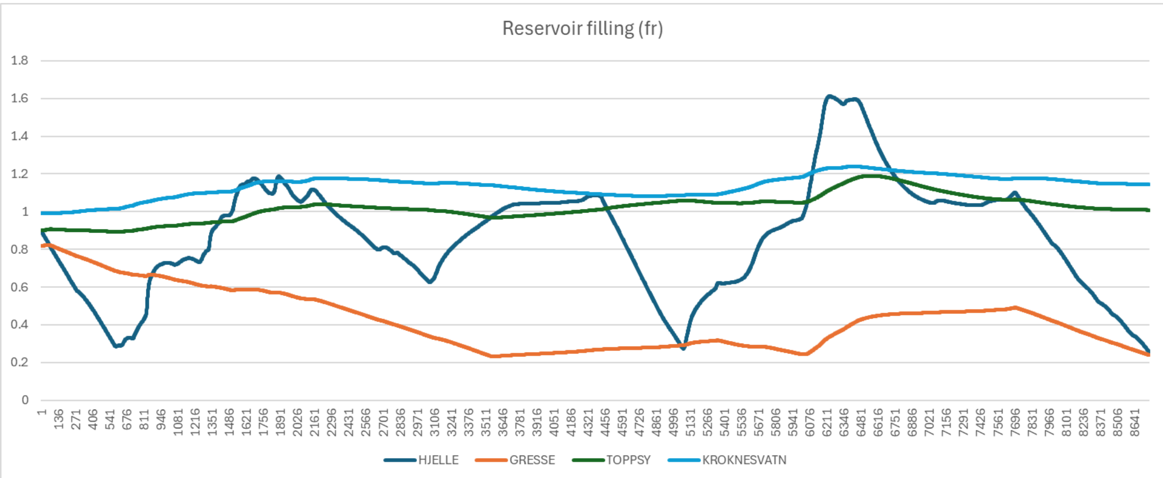

Figure 13 Simulated reservoir filling in uTAHPS using hourly data

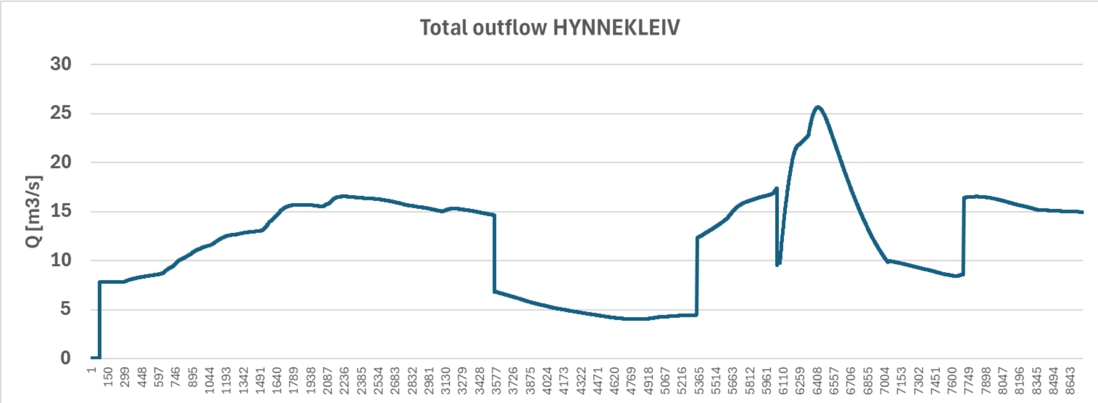

Figure 14 Total outflow at Channel Hynnekleiv (hourly data).

Now we will try to run the same system using daily timesteps.

Change directory to ./utahps_daily

You should see a list of files there. Note that in the daily node-network one of the channels have been removed.

Run the command: **../herss.exe global_utahps_daily.txt**

Now go to the ./output/ folder.

Open the file reservoirs_uTAHPS_out.*txt*

If you plot the data you will see a similar plot as shown in the figure below. Note the similarity in Figure 13, and Figure 15.

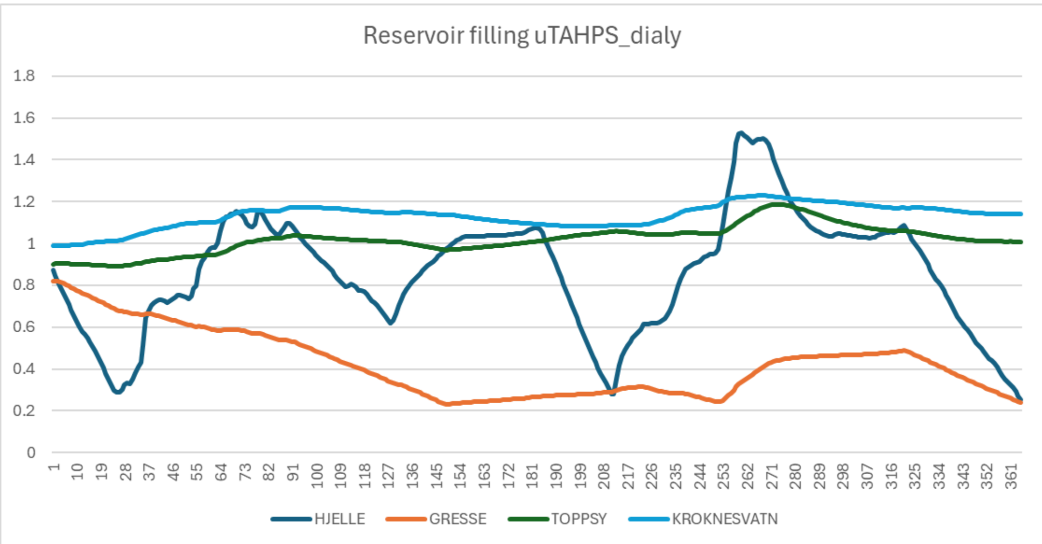

Figure 15 Simulated reservoir fillings in the uTAHPS system. Data is generated with daily input.

Using herss in python code

When compiling the herss model the makefile makes an executable (herss.exe) and a library file (herss.so). The file herss.so can be used within Python. The way to do this is to install the cppyy module in python.

The file pyherss.py demonstrates how to run the herss model from within python code. It also shows how to get data out of the herss model, setting new data and run simulations.

Upper Tovdalen Artificial Hydropower System (uTAHPS)

Riversystem

In this open source project, we have defined an artificial hydropower system that doesn't exist in the real world. We have synthetically placed a hydropower system in the upper part of the Tovdalen river system, located in southern Norway. We define this system as the Upper Tovdalen Artificial Hydropower Systems (uTAHPS). The system consists of four reservoirs and four powerstations. A schematic of the system is illustrated in Figure 16. Red dots are powerstations, the blue regions are illustrations of the synthetic reservoirs. The drainage area for each reservoir is also noted in the figure. The technical details of the system is provided in the topology files under the *./utahps_hourly/* folder.

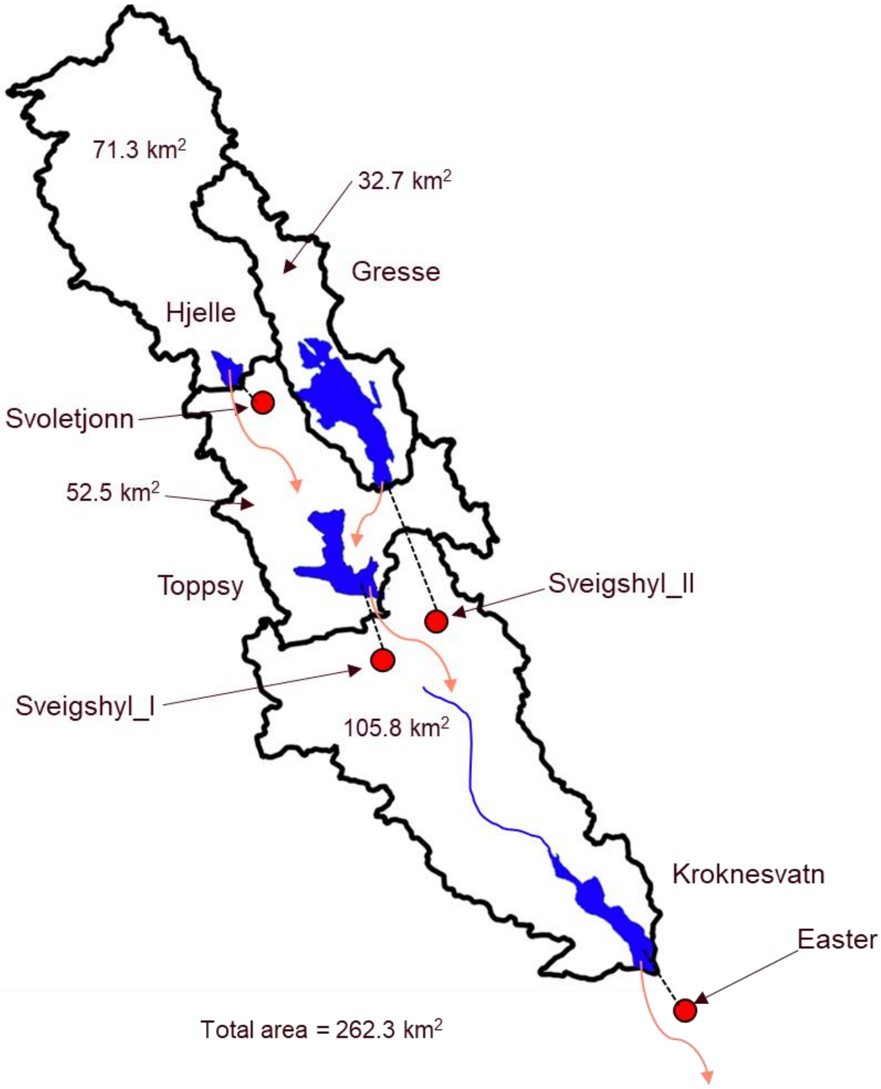

Figure 16 Schematics of the Upper Tovdalen Artificial Hydro Power System (uTAHPS)

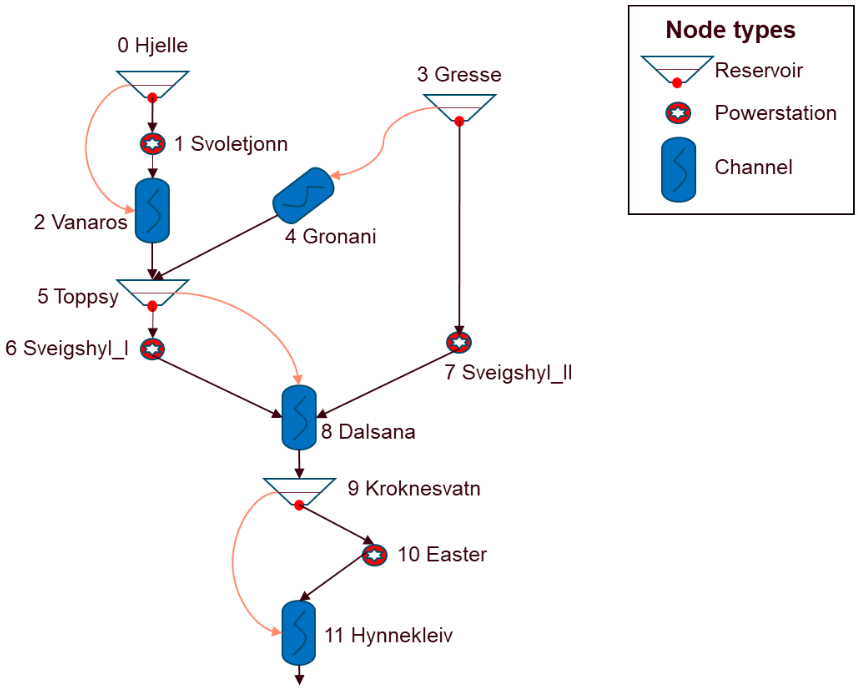

Figure 17 Riversystem network defined by nodes and their connections.

Figure 17 presents a node-network of the uTAHPS system. This node-network is defined in the topology files that the HERSS model reads. Note that the uTAHPS can be modelled with fewer nodes depending on the users preferences.

Timeseries data

In addition to riversystem description for the uTAHPS a set of timeseries are also provided. Hourly and daily data of inflow and price are provided in the dataset. The selected time period goes from 1 Sep,2022 until 31 Aug, 2023.

Inflow

In the uTAHPS system it is assumed that the four reservoirs receive local inflow. The timeseries for these reservoirs are generated from observed streamflow data extracted from the Sildre open database available from The Norwegian Water Resources and Energy Directorate (www.nve.no, https://sildre.nve.no/). The hydrological stations Austenå and Songedalsåi were used to estimate the inflow to the four reservoirs (Hjelle, Gresse, Toppsy and Kroknesvatn). A simple scaling by area in combination with manual scaling weights were used to generate the inflow data for each reservoir. Figure 18 shows the timeseries of inflow to each of the four reservoirs in uTAHPS.

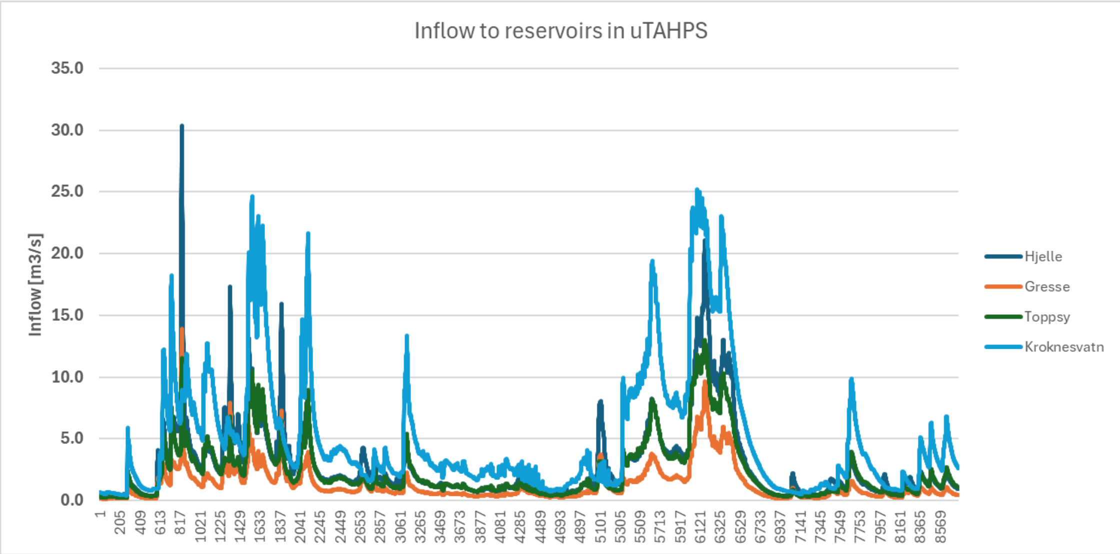

Figure 18 Inflow to reservoirs in uTAHPS. The data were generated from two nearby gauging stations with observed streamflow.

Energyprice

The uTAHPS system is located in the NO2 price region in Norway. Historical data for this region is available through Forbrukerrådet (https://www.forbrukerradet.no/). These data were converted to Euro/MWh assuming 1 Euro = 10 NOK and Value Added Tax of 25 %. The data can be downloaded from: https://www.forbrukerradet.no/strompris/spotpriser/

Actions

The timeseries of actions (production) for each powerstation were manually set in each timestep.

Mini-uTAHPS

A new testsystem of the Tovdalen riversystem has been developed. It uses only one reservoir and one powerstation. See the folder "**./mini_tahps/**" for an example of the inputfiles.