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Modernised GUI and Automated optimizing of hydropower schemes for nMag

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Hydropower Development

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Abstract

Tools to simulate hydropower systems have existed for decades. One of these programs, nMag, has been used by both students and researches. It started as a single reservoir simulator in the 1980's and later evolved to be able to run complex systems. The uses range from prefeasibility studies to environmental analyses. Today however, the existing user interface has become outdated. This thesis tackles the development of a new user interface that will keep using the original simulator. Besides an upgraded environment, some additional features have been added. Including a method of visualising a system in real time. This makes the water system overview clearer and provides direct feedback to the user.

Some systems can be too complex to optimise manually, finding a way to do this automatically will extend the potential uses of this program even more. A genetic algorithm is used to find the optimal configuration of a given system. The first results showed potential, especially for complex systems that lack a lot of data.

Keywords: Hydropower operation, water system simulation, nMag, reservoir balancing, genetic algorithm, flow diagram visualisation

Summary

During the last decades of the twentieth century various tools to simulate water systems have been developed. One of these tools is ENMag, a simulator that models a single reservoir. Later, in the 1990's as a continuation of its predecessor, nMag was created. This newer version allows multiple reservoirs to be simulated. As data had to be written in text files which were read by nMag, setting up a simulation could be tedious. To improve this, a user interface had been developed. It acts as a data editor and presenter.

nMag is used mostly for prefeasibility studies, environmental effect analyses and educational purposes. All of these uses become more important in the future as the energy market in Norway is changing. Old hydropower schemes must be upgraded and new ones must be build. A lot of studies use or could use a general purpose, easy-to-use simulator.

The current user interface of nMag has become outdated and is not user friendly. This can be problematic, especially for educational purposes. Combined with the fact that nMag is not capable of running automatic optimisations, there is a demand for an upgrade.

The objective of this thesis is to develop a new UI for the nMag simulator. This UI must also include an optimiser and a method of visualising the water system. During design and development, intuitive and convenient user interaction should be the main focus.

The software has been designed with extension in mind for future features and changes. Python was selected as the programming language because of its low learning curve and usage within NTNU. As the nMag program has become quite large and complex, C# has replaced Python to ensure that the code stays structured and maintainable.

To visualise the water system an algorithm has been developed that places the components in a grid creating connections between them. This visual interface of the system is the main mechanism to switch between the components.

For systems with multiple reservoirs and complex connections there are a lot of parameters that have to be set to the right value to find the optimal use. Optimisation of the water system is done by using a genetic algorithm. A set of potential solutions is modified and evaluated. From each set, the best solution is chosen and used to create the next set. When a certain criteria is met the iteration stops and the best solution is reported.

Testing the optimisation on a single reservoir hasn't shown any promising results. When using it on a more complex system, the algorithm was able to find a better operation strategy than the standard balancing function of nMag. Improving the algorithm and tuning the evolution parameters will increase the effectiveness of this new feature.

This new UI already demonstrated the new possibilities. It should, however, be continuously tested and improved to reach its full potential.

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Abbreviations

C	Gene complexity
C#	Programming language
Δt	Time step
η	Efficiency
E	Electric energy
ENMag	Precursor of nMag
EP	Electric power
Fortran	Programming language
FP	Firm power
FPL	Firm power level
FPP	Firm power price
g	Gravitational acceleration
G	Generation count
GA	Genetic algorithm
GUI	Graphical user interface
HGR	Gross head
HL	Head loss
IDE	Integrated development environment
JSON	JavaScript object notation
N	Population size
NB	Net benefit
.NET	Software framework developed by Microsoft
nMag	Water scheme simulation program
NMag	The new GUI of nMag
NTNU	Norwegian University for Science and Technology
P	Mutation probability
ρ	Density
Q	Discharge
R	Mutation range
RC	Rationing/surplus costs
S	Mutation speed
UI	User interface
XAML	Extensible application markup language

1 Introduction

1.1 Background

During the 1980's ENMAG was developed at the Norwegian Hydrotechnical Laboratory as a hydropower simulation model. In the 1990's nMag followed as an improved version, where more than just a single reservoir could be simulated. A separate user interface was created to enable data editing for the nMag simulator. The last version dates to 2004 and has been used since, in various studies and courses. While the user interface has enabled a less complicated interaction with the simulator, it has become outdated and user unfriendly for today's standards. It also lacks the possibility to optimise the operation of a system automatically.

Computer tools become increasingly more important for both academic as well as research purposes. Using better and faster software can help increase the quality and quantity of data analysed. It also improves the user experience, which helps the user to become more familiar with the software in a shorter amount of time.

With a changing energy market and aging hydropower systems, analyses have to be carried out to study the effects of implementing new systems and renovating old ones. These analyses can become quite complex and the right tools are necessary to perform them. There is a range of software commercially available, but these can be too advanced for general use.

Since the nMag simulator can still handle large water systems, updating the user interface and including an optimisation tool will modernise nMag and prepare it for future simulations.

1.2 Objectives and scope

The purpose of this thesis is to develop a new GUI for the nMag simulator. Because the program is used in a number of courses, a focus on a user friendly design is important. Data manipulation should be as intuitive and convenient as possible.

Modification of the simulator is not possible and the creation of a new simulator would be out of scope of this thesis. Therefore, a method of optimising a water system must be found that can be used in this outside of the simulator.

Testing both the UI as well as the optimiser is crucial in ensuring that simulations are carried out without any errors.

2 Theory

2.1 nMag model

The GUI application will be referred to as NMag and the simulator as nMag.

The nMag model contains data in the form of modules, hydrology and an energy market. These data types will be briefly discussed in this chapter. Both nMag and its predecessor ENMag can be used, the latter is only capable of running single reservoir systems.

2.2 Modules

A water system is represented by individual modules containing general information like routing and name, but also module specific data. The following module types are defined in (Killingtveit, nMag - A Computer Program for Hydropower and Reservoir Operation Simulation, 1999).

2.2.1 Reservoir

Reservoirs are the main modules as they are capable of storing water when the inflow is higher than the required amount and releasing it when the demand must be met. nMag is able to control the reservoirs using release, guide and rule curves and other strategies.

2.2.2 Power plant

A power plant module represents a hydro-electric power plant, but can also be used for pump-storage and other water needs like irrigation or water supply. Energy produced is calculated using Equation 2-1 and Equation 2-2 Electric energy

(Killingtveit & Sælthun, Hydropower Development Volume 7: Hydrology, 1995)

Equation 2-1 Electric power

$$N(t) = \frac{g \cdot \rho \cdot \eta \cdot Q(t) \cdot (H_{GR}(t) - H_L(t))}{1000 * 3600}$$

Equation 2-2 Electric energy

$$E(t) = N(t) \cdot \Delta t$$

Where

Δt	=	time step [h]
$N(t)$	=	electric power [kW]
$E(t)$	=	electric energy [kWh]
g	=	gravitational acceleration [9.81 m s ⁻¹]
ρ	=	density of water [1000 kg m ⁻³]
η	=	Total efficiency [-]
$Q(t)$	=	plant discharge [m ³ s ⁻¹]
$HGR(t)$	=	gross head [m]
$HL(t)$	=	head loss [m]

2.2.3 Interbasin transfer

Catchments and modules can be connected through a transfer that has a limited capacity. This module describes the capacity as fixed, discharge, or head depending.

2.2.4 Control point

Control points can be used as a module with no other use than to set restrictions at a point or to monitor the discharge.

2.2.5 Connections

Each module can specify to which other module the released water, bypass or spill flows. At least one module must have its downstream connections go out of the water system.

2.3 Hydrological data

Hydrological data is the driving force behind the simulation. All processes in the model are depending on the amount of water that flows through them. It is therefore important to be able to specify this data accurately.

Runoff series are the hydrological input for the simulator. Each module has a weight assigned to the runoff series to represent the inflow, using its mean annual runoff. The resolution of the data can be either monthly, weekly or daily, ignoring leap days.

2.4 Restrictions

Most water schemes have multiple users. Ranging from economic, social and environmental uses. To model these interactions restrictions can be set to each module. These have the highest priority and will be met before firm power is produced.

2.4.1 Minimum flow

Describes the minimum amount of water that is allowed to flow through the module.

2.4.2 Bypass release

Is used to simulate an environmental release, which ensures a certain water level in the downstream reach. This is an important tool for reducing damage to downstream flora and fauna.

2.4.3 Minimum / maximum reservoir level

When a reservoir has a multi-purpose use, it could be required to keep the water between certain limits. These curves tell the simulator which limits it must not pass.

2.5 Energy market

One of the main uses of nMag is to perform a prefeasibility study of a potential system in which financial viability plays a big role. To assess the benefits and costs of running a power plant scheme, some additional data needs to be provided.

2.5.1 Firm Power

Firm power is the guaranteed power provided by the power plants. The amount and distribution depends mostly on seasons and is described in a contract. nMag can either use a constant distribution, daily values, or seasonal variation.

2.5.2 Surplus power

When only producing firm power, the reservoirs can fill up and eventually spill water. When the inflow into the system is expected to be high, it can be worth to produce more than firm power and sell the surplus.

2.5.3 Power deficit

If the system cannot produce enough power to meet the firm power demand, it could result in economic losses. These losses would be problematical when the deficit exceeds 10-15%. (Killingtveit, nMag - A Computer Program for Hydropower and Reservoir Operation Simulation, 1999) Producing too little power has a negative financial effect for the power plant owner and has to be minimised. It can be noted that producing a few percent less can still be feasible if it is compensated by surplus power.

2.5.4 Preference curve

A preference curve describes the increased cost of a power deficit and also the additional income from surplus power. An example of this curve can be seen in **Error! Reference source not found.** On the left side of the y-axis it shows for how much the surplus power can be sold. In this case 13 øre/kWh for the first 15% surplus, 4 øre/kWh for the next 100% surplus, etc. On the right side a rapidly increasing rationing cost can be seen. The first 15% rationing cost 62 øre/kWh, while the last 72% of missing firm power production costs 350 øre/kWh. Multiple preference curves can be used to handle the seasonal distribution.

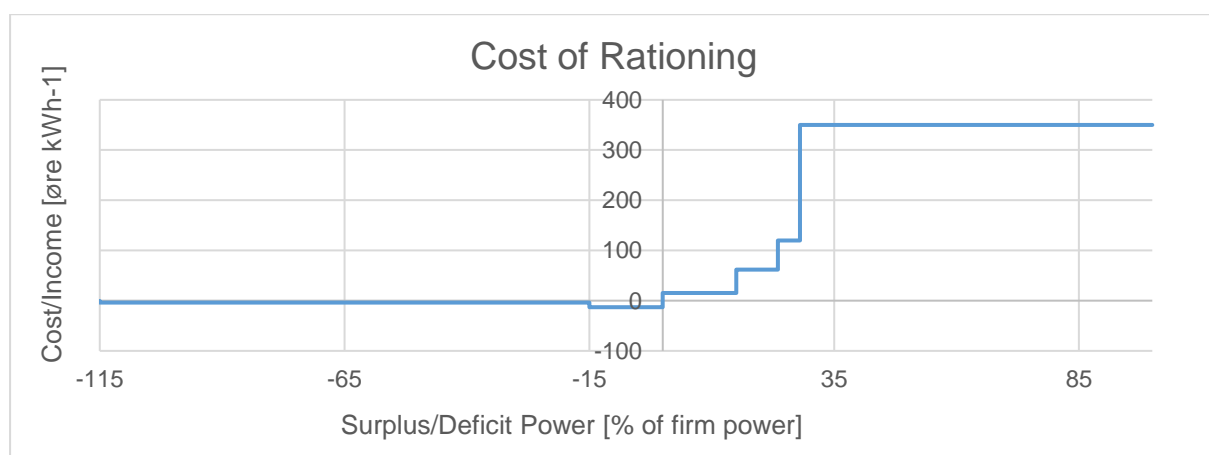


Figure 2-1 Preference curve

2.6 Operational strategy

These strategies control the system as they dictate how the modules must operate. There are three modes available for the nMag simulator.

2.6.1 Reservoir release specification

Using the average annual release of a reservoir, a release distribution in percent can be given. The simulator will follow this curve releasing the specified amount.

2.6.2 Reservoir guide curve

Hydrological data usually follows a seasonal distribution. (Killingtveit, nMag - A Computer Program for Hydropower and Reservoir Operation Simulation, 1999) A curve can be fitted to follow this trend and release water when inflow is expected to increase, while storing water before a dry period. Using this strategy, firm power is produced initially. Then the deviation from the curve is calculated, which will result in the production of surplus power if the reservoir level is above the curve. Rationing follows when the level is below the curve.

2.6.3 Automatic reservoir balancing

This mode can be used when guide curves or release curves are unknown. nMag will select a reservoir level to optimise the energy produced.

2.6.4 ENMag mode

When using ENMag mode it is possible to run two other modes next to using a reservoir guide curve: unconditional firm power production and a rationing/surplus curve.

2.7 Model data manipulation and reporting

All data transfer to and from the simulator makes use of the directory from where the executable is launched. The following files are used by nMag or are generated during a simulation.

Data set (*.set)

The data set file contains the data describing the system. It includes all module and energy market data. It also links to files that contain the runoff series. It ends with the job control, describing the initial reservoir levels, simulation period and what data to output.

Hydrological data (*.vsf)

A separate file for each runoff series must be added to the directory. A Fortran format is added at the start of these files so the simulator can interpret the data. The reader follows the specified time resolution and reads sets of the year and annual data.

Error (“nMAGerr.txt”)

When an error occurs during the simulation this file will contain the resulting message, if it is implemented.

Check (“nMAGchk.txt”)

To inspect if the simulator is reading the input data in the right way this file can be consulted as it lists an overview of all interpreted data.

Results (“nMAGres.txt”)

The results file contains all results from the simulation, it shows the states of the modules as well as total and average production and discharges of the system.

User specified data output

The user can select up to three system variables that will be written into files when only a small set of data is needed for further analysis.

2.8 Optimisation

Finding the optimal operation of a water system can involve manipulating a large number of parameters. Several methods could be used.

2.8.1 Monte Carlo Simulation

This method is based on random sampling of different sets of parameters. Statistical analyses are used to find an optimal value. (Whitlock & Kalos, 2008)

2.8.2 Genetic algorithm

This method is based on biological evolution. A set of potential solutions (population) is created using an initial guess or random input. Each solution contains a set of chromosomes that hold the parameter values. Using mutation and crossover the parameters are changed randomly. Each generation is evaluated and the best solutions are chosen as a start for the next generation. (Chandra & Omlin, 2007)

2.8.3 Gradient search

Similar to the genetic algorithm, a multi-dimensional parameter space is navigated. The gradient, comparing the evaluations of the sets, around a potential solution is used to find an optimum.

3 Methodology







3.1 Redefining the model

With the four module types described before it is possible to construct a subsystem that can still be handled by nMag. These subsystems include a combined reservoir and power plant; pump storage, which consists of two power plants running in parallel; and non-power production uses, for example irrigation and water supply. These subsystems do not require the same data and can make the system look less structured.

The solution used in this thesis is to redefine these four module types as units and combine them into modules. In this and later chapters the term “units” is used to describe the four base modules and “modules” is used to refer to a defined combination of these units and/or other modules. An overview of the different modules can be seen in Table 3-1. Each module has its own symbol and data interface. Data that is not relevant for the module will not be shown. In the case of pump storage, one of the power plants will automatically behave as a pump for the simulator.

The symbols can also be used to represent states of the modules, a reservoir can show its level relative to the total volume and a power plant the current production compared to its capacity. After a simulation has been done, the symbols in the system can be animated to visualise the changes over time.

Table 3-1 Overview of modules

Module name	Units	Modules	Symbol	Effect shows:
Reservoir	Reservoir	-		Reservoir level
Power plant	Power plant	-		Production
Transfer	Transfer	-		Transfer capacity
Control point	Control point	-		User specified
Combined	Reservoir, Power plant	-		Reservoir level/ Production
Pump storage	-	Power plant (2x)		Production/ Pumping

In the previous UI, restrictions data, operational strategies and module runoff were separated from the modules. To make the program more coherent this data is now directly linked to the modules, both in code as in the UI.

3.2 User interface design

NMag is used for both educational purposes and research. Each of these uses have their own set of requirements when it comes to simulating water systems. For students it is important to provide a clear overview of the data and apply intuitive feedback. Researchers often need to test specific cases and therefore require flexibility and high degree of customisation. Both groups are considered during the design of the new user interface.

3.3 Programming language and software

Selecting the right programming language is important as it affects almost all aspects of the program, including maintainability, compatibility and performance.

The languages that would be most feasible for creating this program are Python and C# as they are both suitable for building a UI application. Python is a relative simple language that has a large availability of third party libraries for additional functionalities, the UI is limited by the chosen library. C# has a more consistent and advanced structure. As it is part of the .NET Framework a lot of features, for example XAML, are included. It is however mostly limited to running on Windows.

Initially Python was chosen, due to the low difficulty and its use at NTNU. During the initial stages of development it was found that, because of the complexity and size of the program, maintainability, readability and ease of extension would be negatively affected over time. It was therefore decided to switch to C# for coding and using XAML to design the UI. Visual Studio is used as IDE as it has a large range of code editing tools and debug possibilities.

Rendering graphs is done by an external library Live Charts. A Newtonsoft JSON (de)serialiser is used to read and write project files.

3.4 Program structure

The program is split into three parts; a C# “core” library which has all computational and file handling procedures as well as the simulation and optimisation routines; the UI, designed in XAML which describes the properties of most visual elements; and the C# code behind the UI that uses the core library. The core could later be used as a standalone library for other applications, including Python scripts.

Object oriented design is used to improve the readability of complex algorithms and procedures. The MVVM architectural pattern is followed, which enforces a strict separation between data and the UI. While requiring a large amount of overhead code, it makes extending the program easier in the long term.

The program can be divided into four distinct parts, a simplified visualisation of which is shown in appendix A.

3.4.1 Application / user interaction

This is the main application that is running while the program is open. The application holds the data and uses procedures from the core. The flow diagram algorithm is part of the core, but rendering happens in the UI code.

3.4.2 Model Data

All model data is part of the project object. This makes it easier to access specific objects like modules and units. The project can be (de)serialised to load and save data.

3.4.3 Data input / output and manipulation

Part of the core library is dedicated to reading, interpreting and writing data. All two-dimensional data, for example curves and time series, can be loaded through these methods.

3.4.4 Simulation and optimisation

The simulator object is responsible for preparing the simulations and running the nMag simulator. It can be called directly by the application or be used in an optimising loop. Before running, a validation of the project is done to check if any problems could occur. The simulator uses the error file to inspect the simulation. When completed successfully, the binary output which contains all data, is read and the results are send back to the application.

3.5 Water system visualisation

For larger water systems it can be difficult to keep track of all the components. To improve this, a visualisation of the system is generated and shown to the user in real time. It also allows the user to select the modules more easily. It can later be extended to show more information, for example the reservoir levels and power plant utilisation.

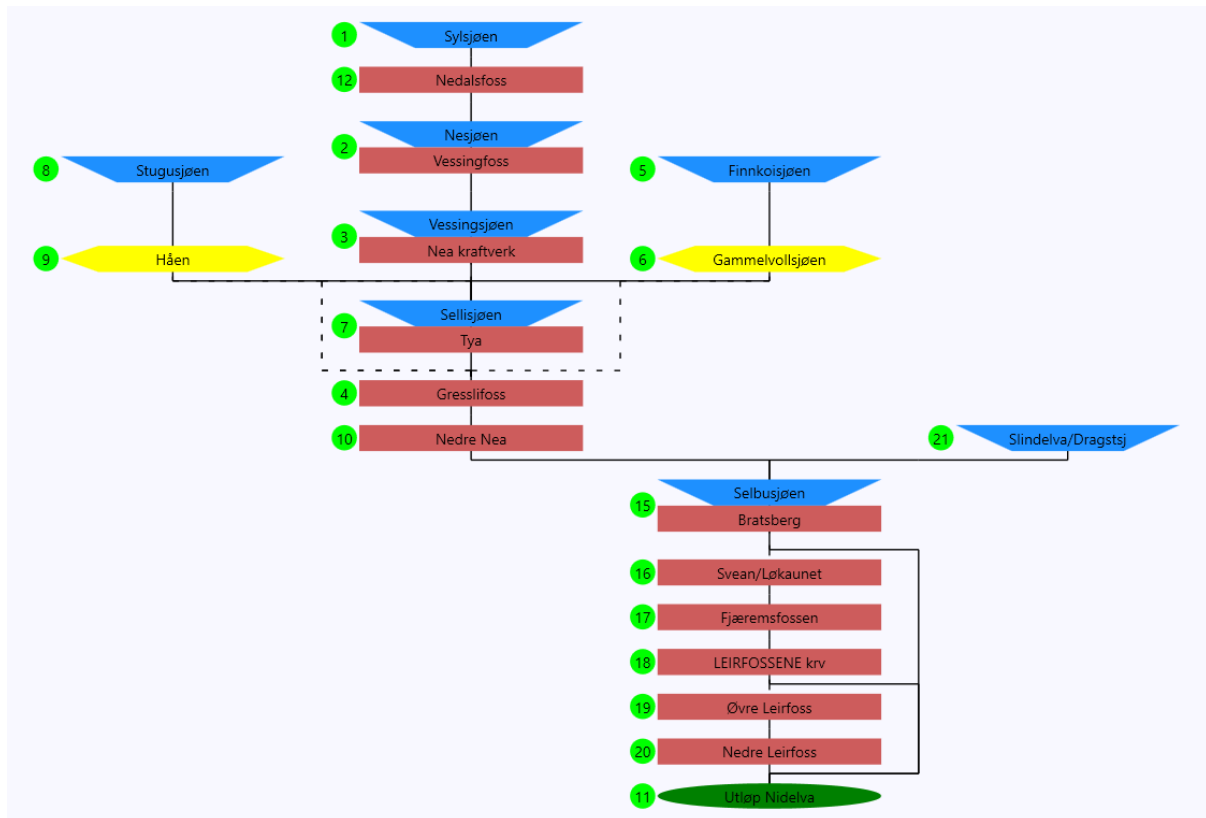


Figure 3-1 Nea Nidelva system

The connections between the modules are used to place them in a grid where water will flow from the top to the bottom. As an example the data set for the Nea Nidelva scheme will be used, it can be found in appendix D. The resulting visual representation is shown in Figure 2-1. A simplified description of the algorithm follows six steps. A more detailed overview of the algorithm can be found in appendix B.

1 Find module connections

Using the release, spill and bypass, the modules are connected and grouped by sources and sinks. Each module can have up to three sinks and an unlimited amount of sources.

2 Combine chains

To reduce computing time, modules are combined into chains where all the water that flows into the upstream module will exit the lowest module. Each module that only has one sink will be connected. The resulting chains can be seen in figure Figure 3-2.

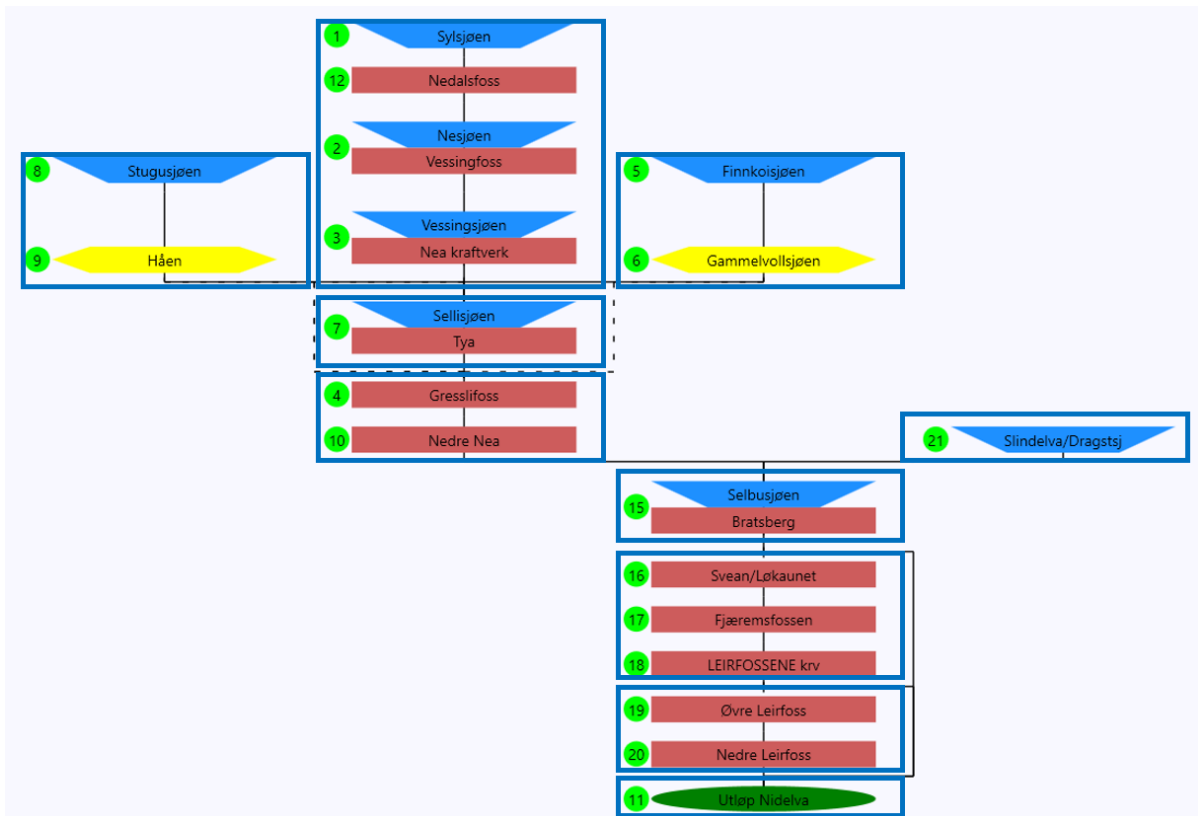


Figure 3-2 Nea Nidelva system with chains

3 Link chains

The connections found in the first step are now used to connect the module chains. Each chain source is linked with the respective chain sinks.

4 Set chain levels

Levels are created until each chain is assigned to one. For each new level all chains are selected that have no sinks without a level. This means the modules that flow out of the system are assigned to the first level.

5 Set chain columns

For each level the chains of the previous level are selected. The columns of these chains are used to set the columns of their sources. The chains on the first level are set at column 0. When multiple sources are connected to the same chain they are spread around the column of this chain. With even numbers, this centre column is not used, so a symmetric pattern can be seen.

6 Create module connections

To draw the release, bypass and spill connections between the modules, a direct path is created between each connected module. When the modules are in different columns, another set of points is added so the path follows the gaps between the modules. It can occur that two modules are blocked by one or more other. In that case, the path is moved with an offset as can be seen in **Error! Reference source not found.**

3.6 Optimisation

A direct control of the modules is not possible as the simulator runs independently from the UI. To overcome this obstacle it uses the operational strategies. When the optimiser is started, it runs one simulation with an unconditional production or automatic reservoir balancing strategy, depending on the amount of reservoirs. It then takes the storage curve from the results as initial reservoir guide curve. By manipulating this curve an optimal operation can be found.

The more points used to describe this curve, the closer the approximation is to the optimum. An increase in points also has a negative effect on the optimisation time. A Monte Carlo simulation will probably not be the best solution in this case. Instead, a genetic algorithm was chosen. Compared to a gradient search algorithm it is more complicated and requires tuning, but it is able to be customised and improved for specific cases. It is difficult to tell in advance which of the two will yield the best results. (Ahmad, Mat Isa, Osman, & Zakaria, 2010) (Salomon, 1998)

A set of solution candidates form a population and are part of a generation. Each candidate has a list of chromosomes, which contain base pairs. These base pairs are the X and Y coordinates of the guide curves. When simulating multiple reservoirs, each reservoir is represented by one of the chromosomes of a solution. The first generation will use the storage curves after the initial simulation as starting point. Next, some or all of the candidates will mutate; The X and Y coordinate of at least one base pair will move in a random direction by a random amount, thus transforming a section of the curve. When all of the candidates of the current generation have mutated, their chromosomes are used to simulate the model. Before a candidate is evaluated, its chromosomes are inspected to prevent invalid guide curves. When an invalid curve is detected, its candidate will not be evaluated. The net benefit is used as evaluation criteria and calculated using Equation 3-1. (Goldsmith, 1993)

Equation 3-1 Net benefit

$$NB = FPL * FPP - RC$$

Where

NB	=	Net Benefit [mill monetary units, NOK/\$]
FPL	=	Firm Power Level [GWh]
FPP	=	Firm Power Price [cents kWh -1]
RC	=	Rationing/Surplus Costs [mill monetary units]

After simulating the candidates, the one with the highest net benefit is selected and used to populate the next generation. The optimiser will continue until no valid candidate is left, or until the generation limit is reached. As the optimiser runs on a separate thread from the application, it can be aborted at any time.

As mentioned before, a genetic algorithm has to be tuned so the optimum can be found effectively. Tuning can be done by changing the population control parameters.

Generation count ($G > 0$)

Maximum amount of iterations. A high generation count will most likely increase the net benefit, but this yields diminishing results over time.

Population size ($N > 0$)

The amount of candidate solutions used within one generation. Higher numbers increase chances of approaching the optimum, but also increase time between iterations. A sufficient size is needed to ensure the survival of a generation.

Gene complexity ($C > 0$)

The amount of base pairs per chromosome. A low number will make it difficult to approximate the optimal curve, while a high number makes the iterations unnecessarily slow.

Mutation probability ($100 > P > 0$)

Chance that a chromosome mutates. Low values slow down the optimisation, while high values can cause a sudden drift away from the optimum or leaves no valid candidates for evaluation.

Mutation speed ($100 > S > 0$)

Describes the amount of mutations that occur on a chromosome relative to the number of base pairs on that chromosome.

Mutation range ($R > 0$)

The range of the possible changes made to a base pair. Measured in days and reservoir level (%).

3.7 Validation

To validate the simulation and optimisation results, a simulation with the old UI will be done. With identical data set and hydrological data, the results should be the same.

4 Analysis

4.1 Optimisation of Funna Power Plant

The Funna data set shown in appendix E consists of a single reservoir, power plant and control point as seen in Figure 4-1. The operational strategy in the provided data set is using rule curves. Hydrological data is used from Høggåsbru, the optimiser has a clear goal of approximating these curves.

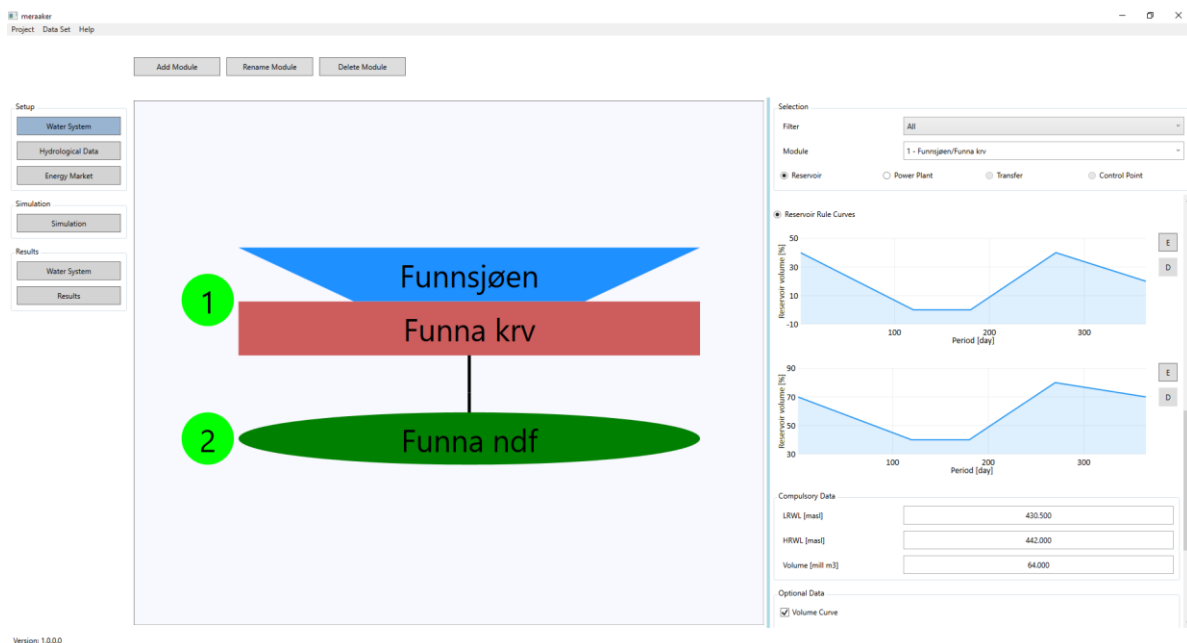


Figure 4-1 Funna power plant

The first simulation is run without changes to the data and returns a NB of 111.49 mill NOK. This corresponds with the results from the old UI.

To optimise this power plant, an unconditional firm power production simulation is run first. This results in NB of 108.98 mill NOK, slightly less than when using the rule curves.

Figure 4-2 shows the situation with default settings and fittest solution. It is clear that the optimal solution is not found as the NB for the best fit is -31.56 mill NOK. An evolution of the curve can be seen in Figure 4-3. This system was run with the parameters shown in Table 4-1. This system was run with the parameters shown in Table 4-1.

Table 4-1 Genetic algorithm parameters

Parameter	Value
Generations	50
Population Size	50
Gene Complexity	10
Mutation Probability	90
Mutation Speed	25
Mutation Range	5

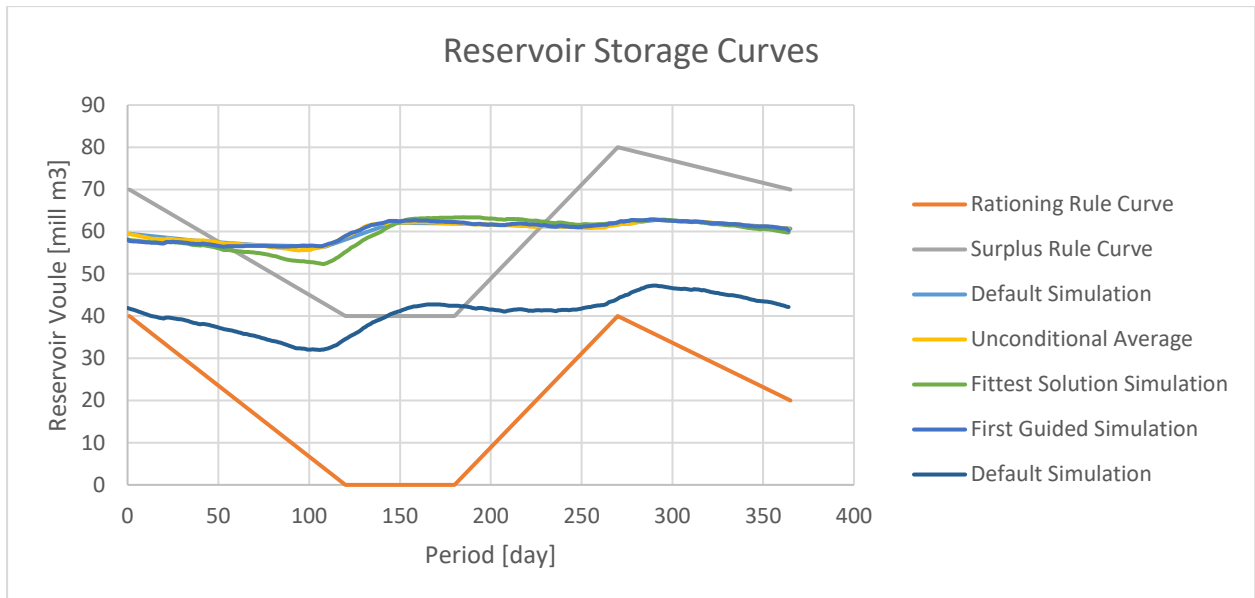


Figure 4-2 Optimisation results Meråker

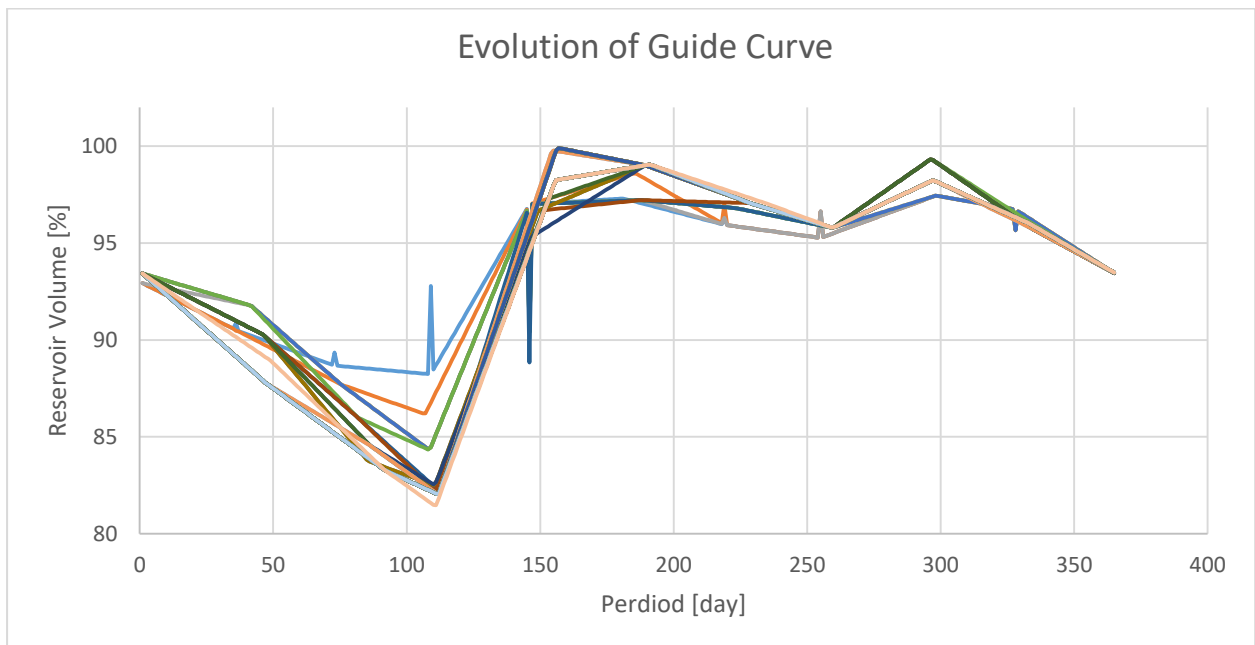


Figure 4-3 Evolution of Meråker guide curve

4.2 Optimisation of Orkla system

The Orkla system is more complicated with a large amount of interconnected modules. A representation can be seen in appendix C. This system uses two runoff series, Bjorset and Naverdal. As it contains multiple reservoirs, the automatic reservoir balancing must be used, which results in a NB of 8697 mill NOK. After running the optimisation, the best solution resulted in a NB of 8858 mill NOK. The different storage curves and runoff is shown in Figure 4-4. Two other optimisations have been carried out and a comparison can be seen in Figure 4-5.

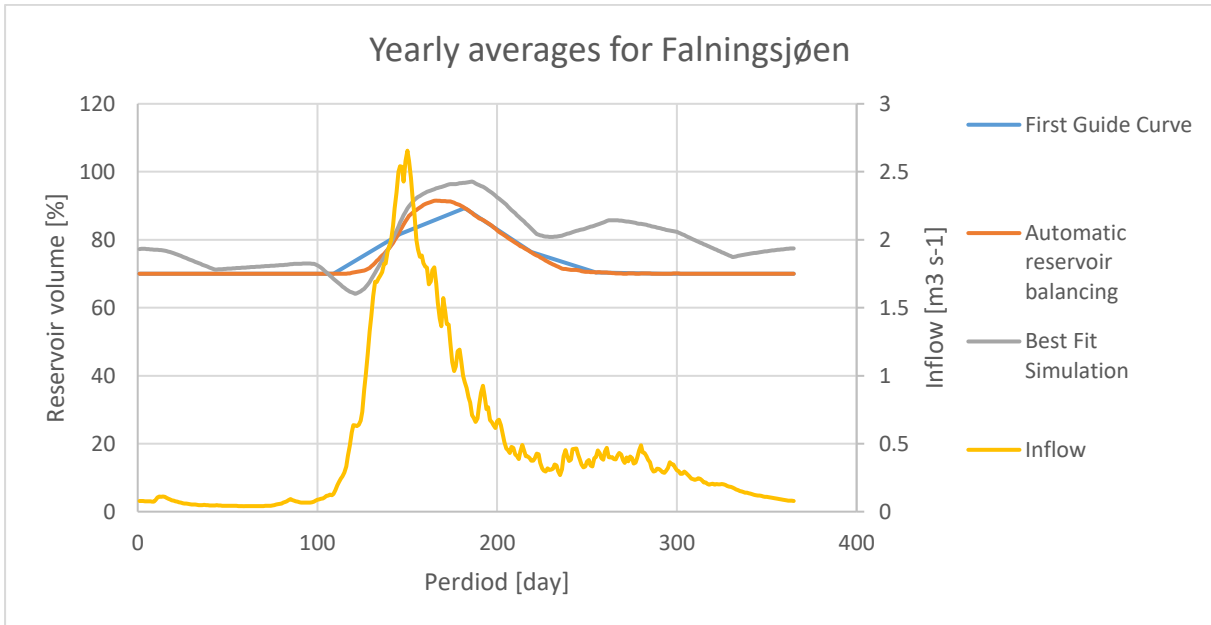


Figure 4-4 Yearly average storage and runoff for Falningsjøen

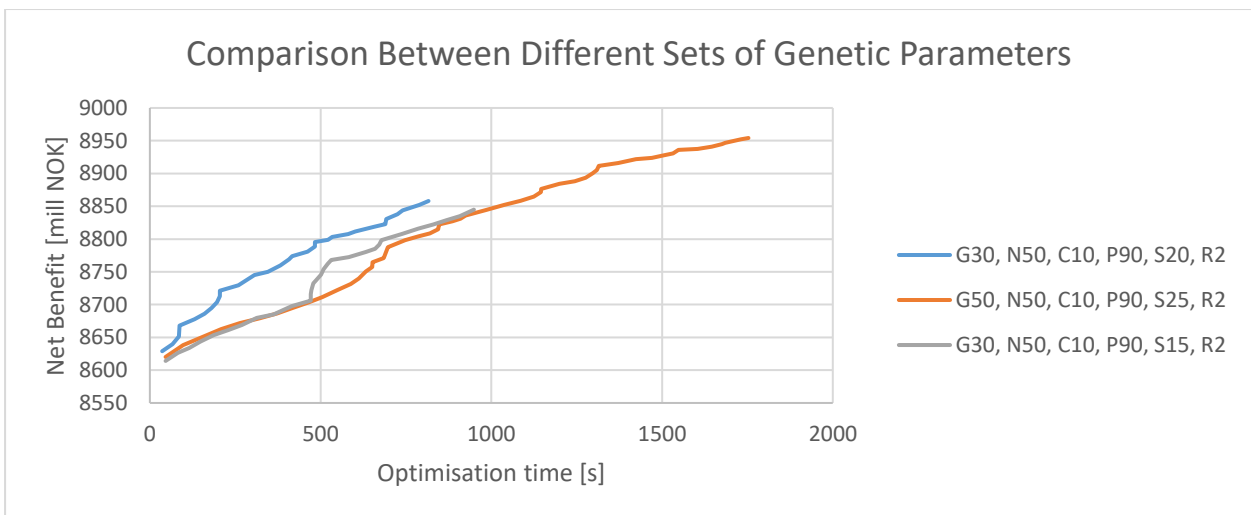


Figure 4-5 Comparison between optimisations

5 Discussion

An explanation for these positive results can be interpreted from Figure 4-4. The reservoir is initially operated by a constant value, which is based on the annual inflow. From this simulation the guide curve is created and used as the start of the evolution. The best fitting curve is seen to dip down when the wet season is about to start. It also takes longer to stabilise as it still uses the extra water in the reservoir.

It is still unclear why the Meråker system cannot be optimised, but it is most likely related to how nMag handles unconditional firm power production. There could also be a bug in the code causing the discrepancy. Optimising the Orkla system seems to prove more effective, mainly because of the semi-constant balancing level. Even though the increased net benefits are relatively low for the Orkla system, in the range of a few percent, other systems could yield even better results. These optimisations have also been aborted in under 30 minutes. Longer and more extensive optimisations will most likely improve the outcome.

Tuning the optimisation algorithm will be a manual task for the moment, but patterns could be found which allow easier and faster optimisation of new systems. The current GA only uses random mutation and single fittest selection. Crossover and heuristics can reduce the chance of finding a local minimum and improving the optimisation speed in general. The comparison in Figure 4-5 showed that the set with a mutation speed of 20 seemed to be the best configuration, this could be coincidence and a larger sample size must be generated.

The visualisation of the system seems to work to a certain degree. Complex systems with a large number of crossing connections will reduce the quality of this overview however. Just having the option to switch between modules with one click is already proving to be quite convenient. Both the quality of the visualisation as well as the extent should be improved. Animated modules can show the user in a more direct way how the system is working.

The data input and simulation starts to become relatively fast and easy, this will only be improved when more validations are built into the system to check user input. While optimising the water systems it would be convenient to have a set of analytical tools available, instead of relying on external tools like Excel.

6 Conclusion

Redefining and designing the model in detail has paid off as the improved use of nMag can already be seen. The first optimisation tests showed promising results. There is still a large number of features and problems to add and overcome, but the progress achieved in this paper is a step in the right direction.

7 Recommendations

In this thesis only two water systems have been simulated. It is difficult to handle all special cases with these data sets. More and varying systems should be simulated to find potential problems or opportunities.

Tuning the GA for specific systems could be the topic for further research. Describing new modules and sub systems can also be useful. Large water systems could be (partially) combined into single modules to increase optimisation speed and accuracy, but a method to do this correct has to be developed.

As the code has grown to over 17000 lines, there are bound to be errors. These must be found to prevent invalid results. Testing the program as well as refactoring the code should be common practice during the continued phases of development and initial stages of usage.

8 References

- Ahmad, F., Mat Isa, N., Osman, M., & Zakaria, H. (2010). Performance comparison of gradient descent and Genetic Algorithm based Artificial Neural Networks training. *Proceedings of the 2010 10th International Conference on Intelligent Systems Design and Applications*, (pp. 604-609).
- Chandra, R., & Omlin, C. (2007). The Comparison and Combination of Genetic and Gradient Descent Learning in Recurrent Neural Networks: An Application to Speech Phoneme Classification. *International Conference on Artificial Intelligence and Pattern Recognition*. Orlando, Florida.
- Goldsmith, K. (1993). *Hydropower Development Volume 6: Economic and Financial Analysis of Hydropower Projects*. Trondheim: Norwegian Institute of Technology.
- Killingtveit, Å. (1999). nMag - A Computer Program for Hydropower and Reservoir Operation Simulation.
- Killingtveit, Å. (sd). Test case for Funna power plant in Meråker.
- Killingtveit, Å., & Sælthun, N. R. (1995). *Hydropower Development Volume 7: Hydrology*. Trondheim: Norwegian Institute of Technology.
- Salomon, R. (1998). Evolutionary algorithms and gradient search: similarities and differences. *IEEE Transactions on Evolutionary Computation Volume 2 Issue 2*.
- Whitlock, P. A., & Kalos, M. H. (2008). *Monte Carlo Methods*. WILEY-VCH Verlag GmbH & Co. KGaA: Weinheim.

APPENDIX A – TASK DESCRIPTION

MASTER DEGREE THESIS

Spring 2018

for

Student: Menno Kemp

Modernised GUI and Automated optimizing of hydropower schemes for nMag

BACKGROUND

The Norwegian hydropower system is aging and built for another market than is expected to be dominant in the future. Modernising, reconstructing and renovation of the hydropower system is thus both necessary and a way to increase efficiency and adaptation to a new market situation. Hydropower systems are complex and complex simulation tools are necessary to embrace all effects of changes in a hydropower system. Such tools exist at different levels. nMag is one of these simplest models and is feasible for all, from small student projects to larger hydropower schemes in a prefeasibility study. nMag is also useful for different other analyses of a hydropower system. Tools that are more complex are available, but these are at an expert level and not feasible at a prefeasibility level of a project. The available version of nMag has an inefficient and "unmodern" user interface and nMag does not have any automated optimizing available. All optimization has to be carried out manually.

TASK

Develop a new GUI and an automated optimizing tool for nMag

Task description

1. Redo the existing GUI for nMag.
2. Develop an Optimizer for nMag
3. Test and validate GUI and Optimizer

Objective and purpose

The objective is to make nMag more user friendly and modern in the design. And to implement an optimizer to expand the use of the model.

Subtasks and research questions

1. Carry out a literature review giving an overview of system design and optimization
2. Redo the existing GUI for nMag.
 - a. Develop a new GUI written in Python that handles all user input to the model and prepare the input file for the simulator, runs the simulator, exports and presents the simulation results.



- b. Develop a visual interactive presentation of the setup of the simulated system based on user input and a translator that presents system setups based on nMag setup/simulation files ("two way translator")
 - c. Develop a translator from NVE Atlas to nMag (if time available)
 - d. Test and validate the GUI and the translator using existing setup
 3. Develop an optimizer for nMag
 - a. For optimizing system design and capacities
 - b. For testing and optimizing operation strategies for different markets, water users and different restrictions
 - c. Test and validate

The report shall be on an article format. Approximately 20 pages and structured as an article ready for publication.

General about content, work and presentation

The text for the master thesis is meant as a framework for the work of the candidate. Adjustments might be done as the work progresses. Tentative changes must be done in cooperation and agreement with the professor in charge at the Department.

In the evaluation thoroughness in the work will be emphasized, as will be documentation of independence in assessments and conclusions. Furthermore the presentation (report) should be well organized and edited; providing clear, precise and orderly descriptions without being unnecessary voluminous.

The report shall include:

- Standard report front page (from DAIM, <http://daim.idi.ntnu.no/>)
- Title page with abstract and keywords. (template on: [wiki page for students at CEE Departement](#))
- Preface
- Summary and acknowledgement. The summary shall include the objectives of the work, explain how the work has been conducted, present the main results achieved and give the main conclusions of the work.
- The main text.
- Text of the Thesis (these pages) signed by professor in charge as Attachment 1.

The thesis can as an alternative be made as a scientific article for international publication, when this is agreed upon by the Professor in charge. Such a report will include the same points as given above, but where the main text includes both the scientific article and a process report.

Advice and guidelines for writing of the report is given in "Writing Reports" by Øivind Arntsen, and in the departments "Råd og retningslinjer for rapportskrivning ved prosjekt og masteroppgave" (In Norwegian) located at [wiki page for students at CEE Departement](#)

Submission procedure

Procedures relating to the submission of the thesis are described in DAIM (<http://daim.idi.ntnu.no/>). Printing of the thesis is ordered through DAIM directly to Skipnes Printing delivering the printed paper to the department office 2-4 days later. The department will pay for 3 copies, of which the institute retains two copies. Additional copies must be paid for by the candidate / external partner.

The master thesis will not be registered as delivered until the student has delivered the submission form (from DAIM) where both the Ark-Bibl in SBI and Public Services (Building Safety) of SB II has signed the form. The submission form including the appropriate signatures must be signed by the department office before the form is delivered Faculty Office.

Documentation collected during the work, with support from the Department, shall be handed in to the Department together with the report.

According to the current laws and regulations at NTNU, the report is the property of NTNU. The report and associated results can only be used following approval from NTNU (and external cooperation partner if applicable). The Department has the right to make use of the results from the work as if conducted by a Department employee, as long as other arrangements are not agreed upon beforehand.



Faculty of Engineering Science and Technology
Institute of Civil and Environmental Engineering

Page 4 of 4 pages

Tentative agreement on external supervision, work outside NTNU, economic support etc.

Separate description is to be developed, if and when applicable. See [wiki page for students at CEE Department](#) for agreement forms.

Health, environment and safety (HSE) <http://www.ntnu.edu/hse>

NTNU emphasizes the safety for the individual employee and student. The individual safety shall be in the forefront and no one shall take unnecessary chances in carrying out the work. In particular, if the student is to participate in field work, visits, field courses, excursions etc. during the Master Thesis work, he/she shall make himself/herself familiar with "Fieldwork HSE Guidelines". NTNU student HSE policy is found here: <https://innsida.ntnu.no/hms-for-studenter>

If you are doing labwork for your project og master thesis, you have to take an online e-course in lab HSE. To get link, email kontakt@ibm.ntnu.no.

The students do not have a full insurance coverage as a student at NTNU. If you as a student want the same insurance coverage as the employees at the university, you must take out individual travel and personal injury insurance.

Start-up and submission deadlines

Start-up and submission deadlines are according to information found in DAIM.

Professor in charge: Oddbjørn Bruland

Other supervisors: Knut Alfredssen, Ånund Killingtveit

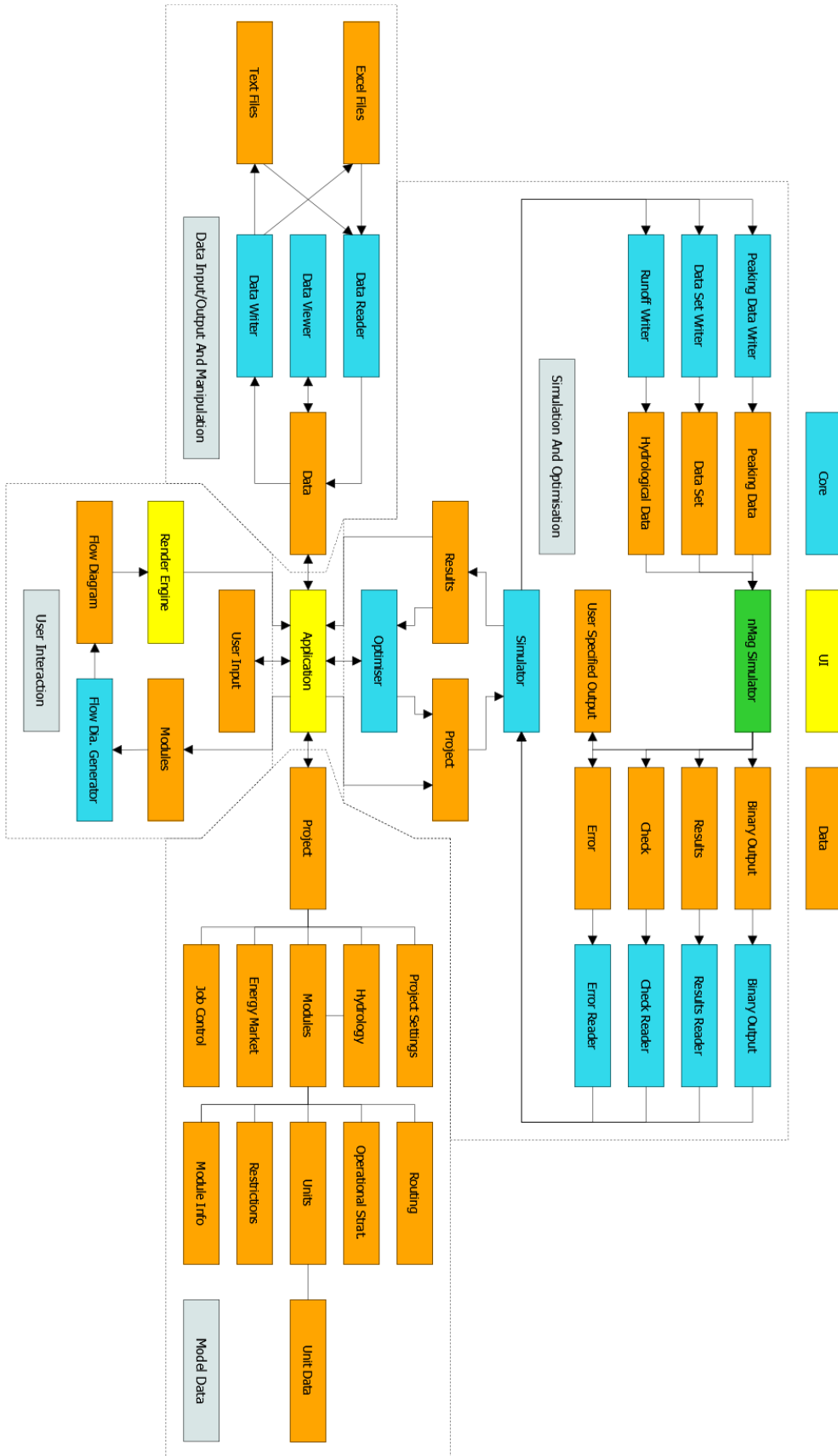
Department of Civil and Transport Engineering, NTNU

Date: 12.01.2018, (revised: dd.mm.yyyy)

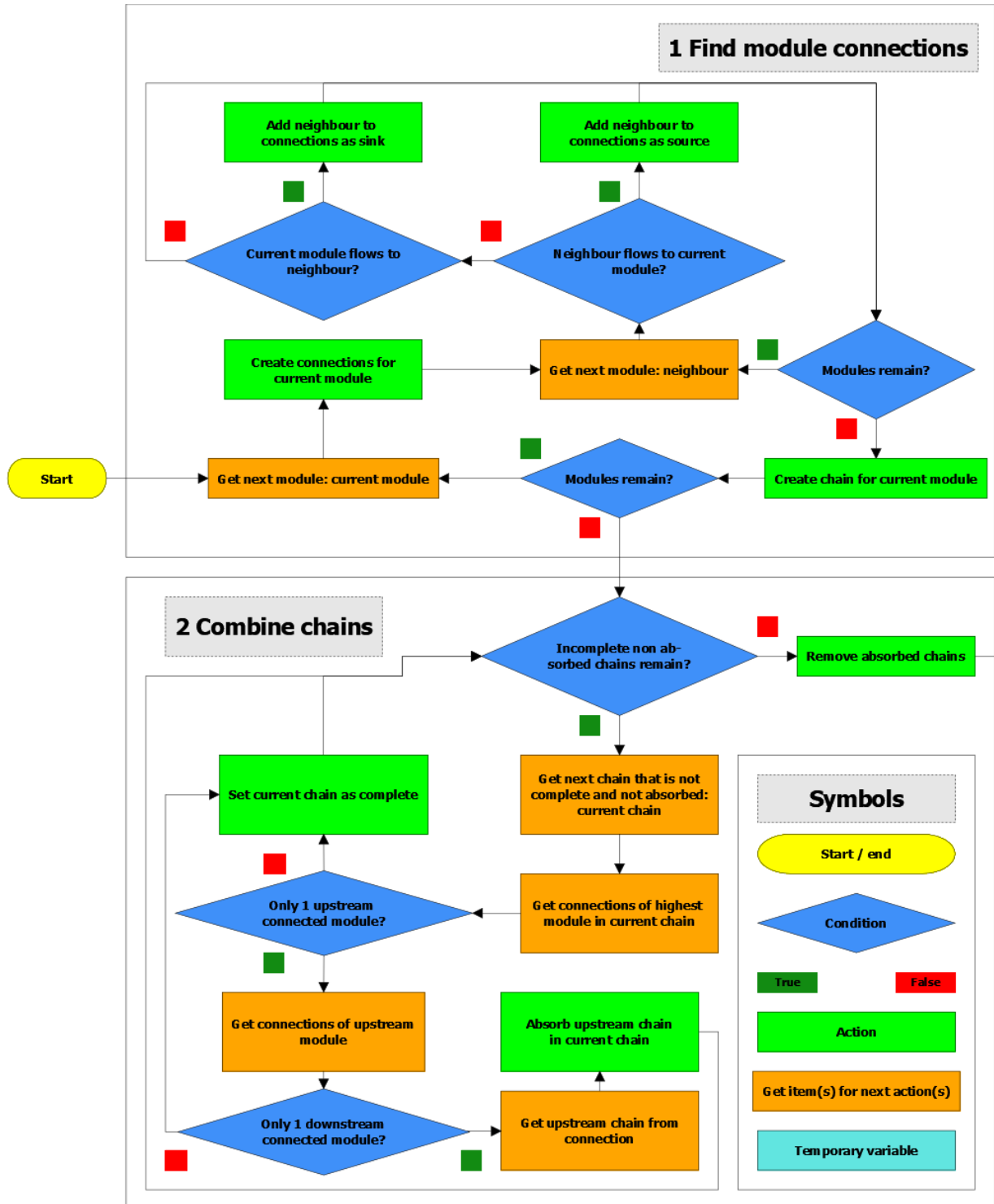
A handwritten signature in black ink, appearing to read 'Oddbjørn Bruland', written over a horizontal line.

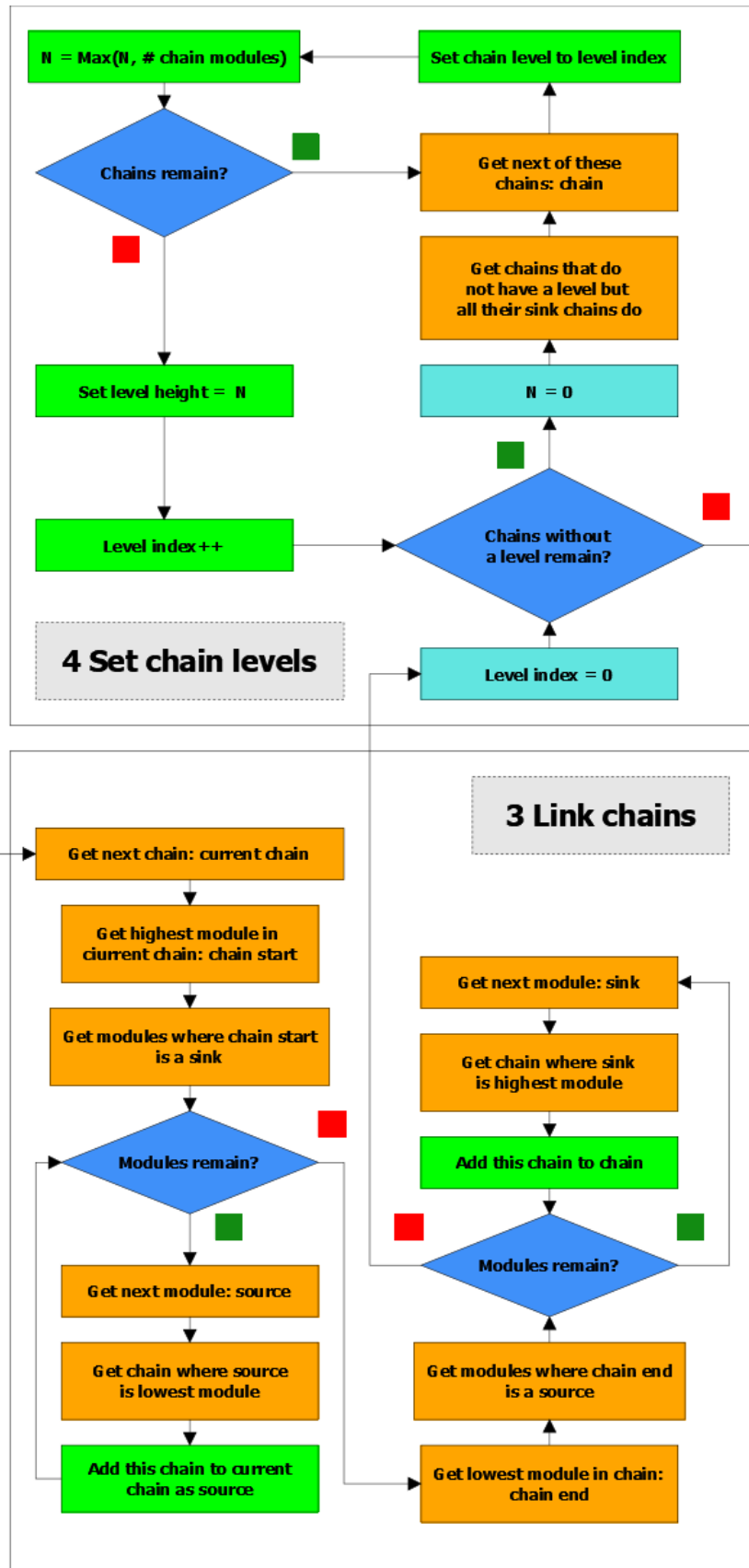
Professor in charge (signature)

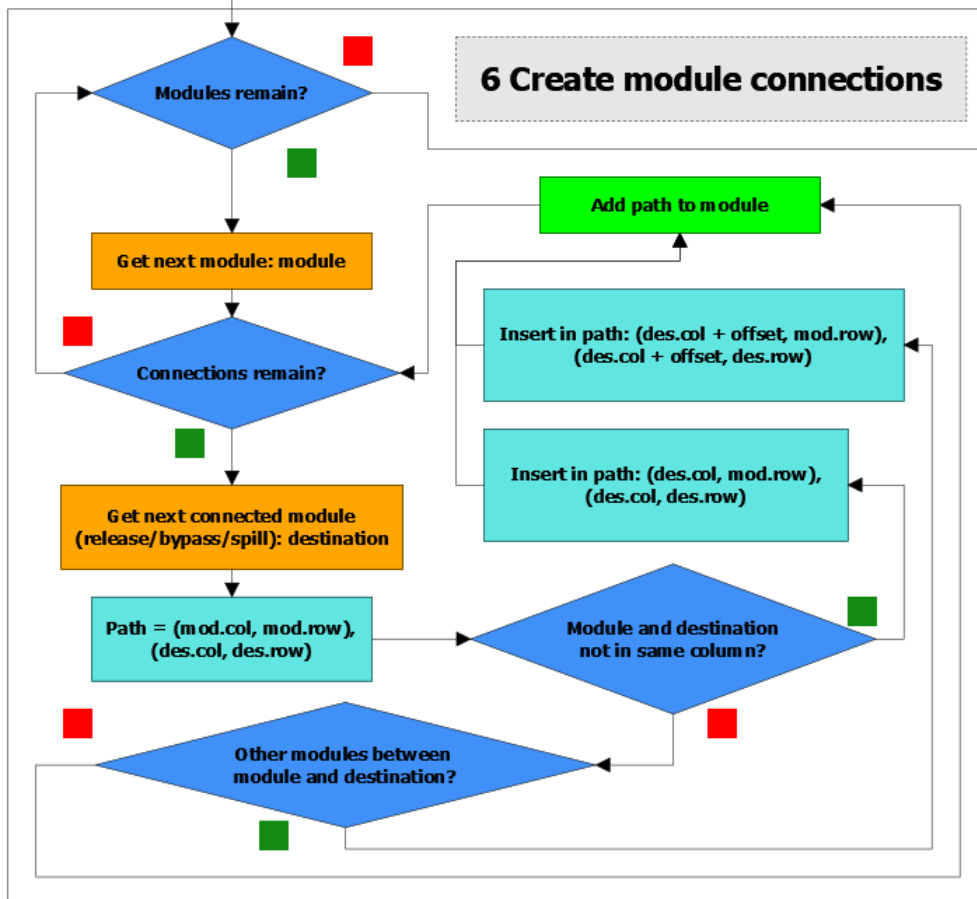
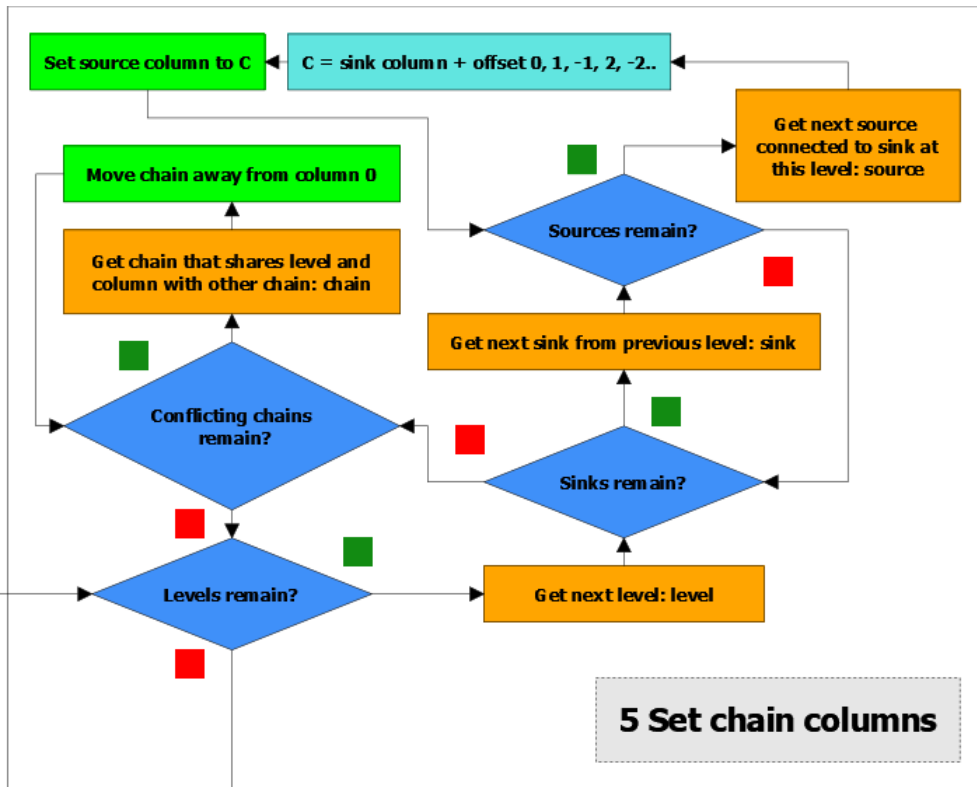
APPENDIX B – NMAG STRUCTURE



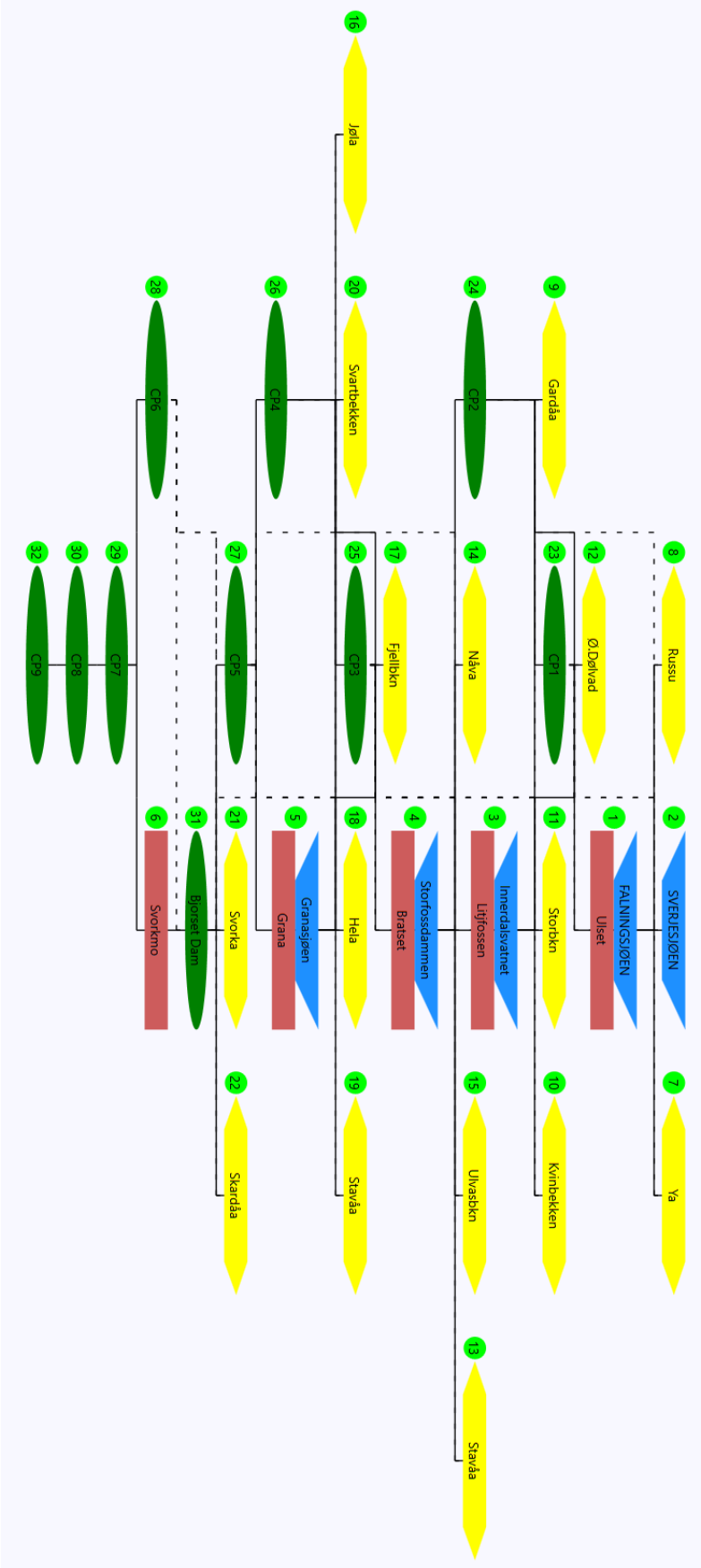
APPENDIX C– FLOW DIAGRAM ALGORITHM







APPENDIX D – ORKLA SYSTEM



APPENDIX E – NEA NIDELVA DATA SET

365, * # of time steps in a year
 19, * Total # of modules (*MA, *KR, *OF og *KO)
 8, * # of reservoirs
 12, * # of power plants
 2, * # of transfers (divertions)
 1, * # of control points
 12, * Max # of entries in a table
 *CO

Hydropower system: Nea-Nidelv

Ånund Killingtveit

This dataset contains the description of the current hydropower system. This will be used as a reference for later simulations for proposed new development in Nidelva.

*MA ***** MAGASINET *****

1, * Modul: 1 - Sylsjøen

Sylsjøen

828.0,

828.3,

187.0,

12,12,12,

200,

2,

850.0,0.0,

851.0,187.0,

2, * Modul: 2 - Nesjøen

Nesjøen

709.6,

732.6,

582.0,

3,3,3,

200,

5,

709.6,0.0,

717.6,54.0,

726.0,225.6,

729.6,397.0,

732.6,582.0,

500,

12,

1,0.0,

2,0.0,

3,0.0,

4,0.0,

5,0.0,

6,0.0,
7,0.0,
8,0.0,
9,0.0,
10,0.0,
11,0.0,
12,0.0,

3,
Vessingsjøen

* Modul: 3 - Vessingsjøen

661.9,
676.9,
37.3,
7,4,4,
200,
5,
661.9,0.0,
667.9,12.3,
670.9,19.8,
673.9,28.2,
676.9,37.3,

5,
Finnkoisjøen

* Modul: 5 - Finnkoisjøen

758.0,
769.0,
41.7,
6,6,6,
200,
5,
758.0,0.0,
761.0,5.4,
765.0,20.2,
768.0,36.0,
769.0,41.7,

7,
Sellisjøen

* Modul: 7 - Sellisjøen

500.15,
500.2,
1.1,
4,4,4,

8,
Stugusjøen

* Modul: 8 - Stugusjøen

600.0,
606.0,
50.0,
9,9,9,
15,

Selbusjøen

* Modul: 15 - Selbusjøen

151.9,
158.2,
348.0,
11,16,16,
200,
5,
151.9,0.0,
153.9,106.0,
155.9,215.0,
157.9,330.0,
158.2,348.0,
300,
5,
0.0,0.0,
1.0,50.0,
2.0,100.0,
3.0,250.0,
4.0,500.0,
600,
5,
1,0.0,
2,0.1,
3,0.4,
4,0.2,
5,0.1,
21,
Slindelva/Dragstsj

251.87,
258.17,
126.2,
15,15,15,

*KR

2,
Vessingfoss

3,3,3,
92.0,
0.116,
200,
50.0,
705.0,
675.1,
0.0004,
3,
0.0,0.91,
87.0,0.91,
100.0,0.89,

* Modul: 21 - Slindelva/Dragstsj

***** KRAFTVERKET *****

* Modul: 2 - Vessingfoss

3,
Nea kraftverk

* Modul: 3 - Nea kraftverk

4,4,4,
54.0,
0.91,
200,
376.6,
660.0,
298.8,
0.0,
11,
0.0,0.83,
7.0,0.83,
18.0,0.88,
26.0,0.91,
31.0,0.91,
36.0,0.88,
47.0,0.91,
52.0,0.91,
58.0,0.89,
69.0,0.91,
100.0,0.91,

* Modul: 4 - Gresslifoss

4,
Gresslifoss
10,10,10,
90.0,
0.075,
200,
33.0,
291.9,
256.4,
0.00089,
8,
0.0,0.85,
33.0,0.85,
44.0,0.88,
56.0,0.89,
66.0,0.91,
78.0,0.91,
89.0,0.9,
100.0,0.89,
600,
5,
1,0.0,
2,0.1,
3,0.4,
4,0.2,

5,0.1,

7,

Tya

4,4,4,

21.5,

0.49,

200,

201.9,

497.0,

298.8,

0.0,

7,

0.0,0.9,

51.0,0.9,

58.0,0.92,

65.0,0.91,

72.0,0.93,

93.0,0.93,

100.0,0.92,

10,

Nedre Nea

15,15,15,

85.0,

0.22,

200,

96.0,

255.0,

155.0,

0.0,

6,

0.0,0.85,

36.0,0.85,

57.0,0.91,

71.0,0.93,

85.0,0.9,

100.0,0.85,

12,

Nedalsfoss

2,2,2,

30.9,

0.23,

200,

99.65,

828.0,

728.6,

0.0039,

6,

* Modul: 7 - Tya

* Modul: 10 - Nedre Nea

* Modul: 12 - Nedalsfoss

0.0,0.91,
57.0,0.91,
78.0,0.91,
84.0,0.9,
91.0,0.89,
100.0,0.86,

15,
Bratsberg

11,16,16,
103.0,
0.33,
200,
144.1,
150.0,
11.5,
0.0,

10,
0.0,0.82,
20.0,0.82,
30.0,0.89,
35.0,0.9,
50.0,0.88,
60.0,0.85,
70.0,0.86,
80.0,0.85,
90.0,0.83,
100.0,0.8,

16,
Svean/Løkaunet

17,17,17,
98.0,
0.11,
200,
55.0,
150.0,
105.0,
0.0,

10,
0.0,0.78,
20.0,0.78,
30.0,0.73,
35.0,0.76,
40.0,0.76,
50.0,0.73,
60.0,0.74,
80.0,0.74,
90.0,0.78,

* Modul: 15 - Bratsberg

* Modul: 16 - Svean/Løkaunet

100.0,0.78,
17,
Fjæremsfossen

* Modul: 17 - Fjæremsfossen

18,18,18,
90.0,
0.06,
200,
27.0,
100.0,
73.0,
0.0,
10,

0.0,0.79,
22.0,0.79,
33.0,0.86,
39.0,0.88,
44.0,0.83,
55.0,0.83,
67.0,0.87,
78.0,0.88,
88.0,0.83,
100.0,0.8,

18,
LEIRFOSSENE krv

* Modul: 18 - LEIRFOSSENE krv

11,19,19,
0.0,
0.14,
200,
61.0,
72.5,
11.5,
0.0008,
5,

0.0,0.85,
62.0,0.85,
75.0,0.89,
87.0,0.91,
100.0,0.89,

19,
Øvre Leirfoss

* Modul: 19 - Øvre Leirfoss

20,20,20,
52.0,
0.08,
200,
34.0,
72.5,
38.5,

0.0,
7,
0.0,0.79,
38.0,0.79,
58.0,0.79,
67.0,0.78,
77.0,0.78,
96.0,0.78,
100.0,0.78,

* Modul: 20 - Nedre Leirfoss

Nedre Leirfoss

11,11,11,
60.0,
0.06,
200,
27.0,
38.5,
11.5,
0.0,
7,
0.0,0.77,
33.0,0.77,
50.0,0.77,
58.0,0.77,
66.0,0.77,
83.0,0.76,
100.0,0.76,

*OF

***** OVERFØRING *****

6,
Gammelvollsjøen

* Modul: 6 - Gammelvollsjøen

7,4,4,
300,
506.15,
497.15,
6,
4.0,6.5,
5.3,8.0,
6.3,9.0,
7.3,10.0,
8.3,11.0,
9.0,11.5,

* Modul: 9 - Håen

9,
Håen
7,4,4,
100,
42.0,

*KO

***** KONTROLLPUNKT *****

11,
Utløp Nidelva
0,0,0,

* Modul: 11 - Utløp Nidelva

*KM

***** KRAFTMARKED *****

2200.0,
22.0,
120,279,
3,
7,
1,0.36,
60,0.3,
120,0.25,
180,0.2,
240,0.25,
300,0.3,
365,0.36,
0,

* Antall preferansefunksjoner

*RS

***** RESTRIKSJONER *****

100,
4,
6,
1,0.0,
133,0.0,
134,3.0,
287,3.0,
288,0.0,
365,0.0,
100,
8,
6,
1,0.0,
133,0.0,
134,0.5,
287,0.5,
288,0.0,
365,0.0,
100,
9,
6,
1,0.0,
133,0.0,
134,0.5,
287,0.5,

* Modul: 4 - Gresslifoss

* Modul: 8 - Stugusjøen

* Modul: 9 - Håen

288,0.0,

365,0.0,

100,

15,

4,

1,35.0,

133,35.0,

288,35.0,

365,35.0,

200,

15,

6,

1,60.0,

120,60.0,

121,70.0,

288,70.0,

289,60.0,

365,60.0,

*ST

***** DRIFTSSTRATEGI*****

500,

1,

6,

1,0.7,

120,0.0,

140,0.0,

250,1.0,

280,1.0,

365,0.7,

400,

2,22.546,

6,

1,1.0,

120,1.0,

121,0.0,

279,0.0,

280,1.0,

365,1.0,

400,

3,23.275,

6,

1,1.0,

120,1.0,

121,0.0,

279,0.0,

280,1.0,

365,1.0,

* Modul: 15 - Selbusjøen/Bratsberg

* Modul: 15 - Selbusjøen/Bratsberg

* Modul: 1 - Sylsjøen - Strategi 500

* Modul: 2 - Nesjøen/Vessingfoss

* Modul: 3 - Vessingsjøen/Nea kraftverk

400,
5,1.3, * Modul: 5 - Finnkoisjøen
6,
1,1.0,
120,1.0,
121,0.0,
279,0.0,
280,1.0,
365,1.0,
300,
7, * Modul: 7 - Sellisjøen/Tya - Balansemag/Ingen data
400,
8,5.264, * Modul: 8 - Stugusjøen
6,
1,1.0,
120,1.0,
121,0.0,
279,0.0,
280,1.0,
365,1.0,
400,
15,60.0, * Modul: 15 - Selbusjøen/Bratsberg
6,
1,1.0,
120,1.0,
121,1.0,
279,1.0,
280,1.0,
365,1.0,
400,
21,4.7, * Modul: 21 - Slindelva/Dragstsj
6,
1,1.0,
120,1.0,
121,0.0,
279,0.0,
280,1.0,
365,1.0,

*HY ***** HYDROLOGISKE INNGANGSDATA*****
1931,1960,
19,
2,
1, * Modul: 1 - Sylsjøen
294.0,0.0,1.0,
2, * Modul: 2 - Nesjøen/Vessingfoss
410.0,0.0,1.0,

3,
23.0,0.0,1.0,
4,
296.0,0.0,1.0,
5,
41.0,0.0,1.0,
6,
168.0,0.0,1.0,
7,
3.0,0.0,1.0,
8,
166.0,0.0,1.0,
9,
108.0,0.0,1.0,
10,
351.0,0.0,1.0,
11,
0.0,1.0,0.0,
12,
7.0,0.0,1.0,
15,
956.0,1.0,0.0,
16,
0.0,1.0,0.0,
17,
0.0,1.0,0.0,
18,
20.0,1.0,0.0,
19,
20.0,1.0,0.0,
20,
0.0,1.0,0.0,
21,
148.0,1.0,0.0,
1,
Rathe VM.
1413,X2,
1.0,
nmagdata.txt
2,
Aune VM.
1418,,
0.001,
tydal2.vsf

*JK ***** JOBKONTROLL *****
Test Nea-Nidelv

1931,
1960,
2200,
70.0,
1, * SERIAL (1) or PARALLELL (0)
1, * START DAY
365, * END DAY
1,1,1,1,
3,
1,
7,
15,
0,
nmagres.bin
0,15,3,excel_01.dat,
0,15,5,excel_02.dat,
0,15,6,excel_03.dat,

*EX

APPENDIX F – MERÅKER DATA SET

365, * Number of timesteps in one year
 2, * Total no of Modules (*MA, *KR, *OF og *KO)
 1, * No of reservoirs
 1, * No of power plants
 0, * No of transfer modules
 1, * No of control points
 7, * Max. permitted no of entries in a Table
 *MO * Mode
 1, * 1=ENMAG mode, 0=nMAG mode

*CO

Dept. of Hydraulic and Environmental Engineering, NTNU

AAK

ENMAG-MODE Test case for Funna power plant in Meraaker

*MA ***** RESERVOIRS *****

1, * Modul nr. 1 - Funnsjøen

Funnsjøen

430.5,

442.0,

64.0,

2,2,2,

200,

7,

430.5,0,

432,5,

434,14,

436,24,

438,35,

440,48,

442,64,

*KR ***** POWER PLANTS *****

1, * Modul nr. 1 - Funna krv

Funna krv

2,2,2,

6.0,

0.707,

200,

333.2,

430.5,

105.0,

1.658,

6,

0,0.85,

36,0.85,
57,0.91,
71,0.93,
85,0.9,
100,0.85,

*OF

***** TRANSFER MODULES *****

*KO

***** CONTROL POINTS *****

2,

* Modul nr. 2 - Funna ndf

Funna ndf

0,0,0,

*KM

***** POWER MARKET *****

50.0,

30.0,

120,279,

3,

2,

1,0.274,

365,0.274,

3,

* Antall preferansefunksjoner

1,

1,120,

9,

-100,-0.4,

-100,-4,

-15,-13,

0,-13,

0,15,

15,15,

8.5,62,

4.5,120,

72,350,

7,2,

2,

121,279,

9,

-100,-0.4,

-100,-2,

-15,-10,

0,-10,

0,14,

15,14,

8.5,62,

4.5,120,

72,350,

7,2,
3,
280,365,
9,
-100,-0.4,
-100,-10,
-15,-13,
0,-13,
0,15,
15,15,
8.5,62,
4.5,120,
72,350,
7,2,

*RS

***** RESTRICTIONS *****

200,
1,
6,
1,0.000,
120,0.000,
121,0.000,
279,0.000,
280,0.000,
365,0.000,

* Modul nr. 1 - Funnsjøen/Funna krv

*ST

***** OPERATIONAL STRATEGY *****

600,
1,
5,
1,40,
120,0,
180,0,
270,40,
365,20,
5,
1,70,
120,40,
180,40,
270,80,
365,70,

* Modul nr. 1 - Funnsjøen/Funna krv

*HY

***** HYDROLOGICAL INPUT DATA *****

1914,1987,
2,
1,
1,

* Modul nr. 1 - Funnsjøen/Funna krv

81.0,1.0,

2,

25.0,1.0,

1,

Høggås bru

666,,

0.001,

666.vsf

*JK

***** JOB CONTROL *****

Funna kraftverk i Meråker

1931,

1940,

35,

70.0,

0,

1,

365,

1,1,1,1,

3,

1,

2,

0,

0,

None

0,1,4,excel_01.txt,

0,2,1,excel_02.txt,

0,2,2,excel_03.txt,

*EX

APPENDIX G – ORKLA DATA SET

365, * Number of timesteps in one year
 33, * Total no of Modules (*MA, *KR, *OF og *KO)
 5, * No of reservoirs
 5, * No of power plants
 16, * No of transfer modules
 10, * No of control points
 4660404, * Max. permitted no of entries in a Table
 *MO * Mode
 0, * 1=ENMAG mode, 0=nMAG mode

*CO

Default dataset nMAG2004

ÅK

Orkla Power System Simulation!

*MA ***** RESERVOIRS *****

1, * Modul nr. 1 - FALNINGSJØEN

FALNINGSJØEN

825.0,

872.5,

125.0,

24,23,23,

200,

6,

825.000,0.000,

830.000,6.390,

834.000,12.400,

840.000,23.000,

846.000,35.900,

852.000,51.700,

500,

12,

1,0.000,

2,0.000,

3,0.000,

4,0.000,

5,2.200,

6,3.500,

7,2.900,

8,1.900,

9,1.000,

10,0.000,

11,0.000,

12,0.000,

2,

* Modul nr. 2 - SVERJESJØEN

SVERJESJØEN

867.7,
872.5,
7.0,
1,24,24,
200,
5,
867.700,0.000,
868.000,0.370,
870.000,3.090,
872.500,6.940,
873.500,8.560,
500,
12,
1,0.000,
2,0.000,
3,0.000,
4,0.000,
5,2.200,
6,3.500,
7,2.900,
8,1.900,
9,1.000,
10,0.000,
11,0.000,
12,0.000,
3,

* Modul nr. 3 - Innerdalsvatnet

Innerdalsvatnet
778.0,
813.0,
150.0,
4,25,25,
200,
10,
778.000,0.000,
780.000,4.500,
784.000,15.600,
790.000,36.500,
794.000,52.800,
800.000,80.500,
804.000,101.100,
810.000,134.900,
813.000,152.900,
814.000,159.200,
500,
12,
1,0.000,

2,0.000,
3,0.000,
4,0.000,
5,2.200,
6,3.500,
7,2.900,
8,1.900,
9,1.000,
10,0.000,
11,0.000,
12,0.000,

4,

* Modul nr. 4 - Storfosdammen

Storfosdammen

503.0,
519.0,
1.7,
26,25,25,
500,
12,
1,0.000,
2,0.000,
3,0.000,
4,0.000,
5,2.200,
6,3.500,
7,2.900,
8,1.900,
9,1.000,
10,0.000,
11,0.000,
12,0.000,

5,

* Modul nr. 5 - Granasjøen

Granasjøen

610.0,
650.0,
144.0,
27,27,27,
200,
13,
610.000,0.000,
612.000,1.280,
614.000,3.340,
618.000,9.710,
622.000,18.200,
626.000,28.500,
630.000,40.800,
634.000,55.300,

638.000,72.100,
642.000,91.400,
646.000,113.500,
650.000,138.800,
651.000,145.500,
500,
12,
1,0.000,
2,0.000,
3,0.000,
4,0.000,
5,2.200,
6,3.500,
7,2.900,
8,1.900,
9,1.000,
10,0.000,
11,0.000,
12,0.000,

*KR

***** POWER PLANTS *****

1,

* Modul nr. 1 - Ulset

Ulset

24,23,23,

13.2,

0.81,

200,

322.0,

825.0,

531.7,

0.0075,

2,

1.000,0.900,

100.000,0.900,

3,

* Modul nr. 3 - Litjfossen

Litjfossen

4,25,25,

31.1,

0.694,

200,

290.0,

778.0,

512.3,

0.025,

2,

1.000,0.900,

100.000,0.900,

4,
Bratset
26,25,25,
35.3,
0.616,
200,
268.0,
503.0,
240.7,
0.009,
2,
1.000,0.900,
100.000,0.900,

* Modul nr. 4 - Bratset

5,
Grana
27,27,27,
20.3,
1.095,
200,
454.5,
610.0,
174.7,
0.03,
2,
1.000,0.900,
100.000,0.900,

* Modul nr. 5 - Grana

6,
Svorkmo
29,29,29,
77.1,
0.221,
200,
99.0,
129.0,
30.0,
0.0038,
2,
1.000,0.900,
100.000,0.900,

* Modul nr. 6 - Svorkmo

*OF

***** TRANSFER MODULES *****

7,
Ya
1,23,23,
100,
100.0,
8,

* Modul nr. 7 - Ya

* Modul nr. 8 - Russu

Russu

1,23,23,

100,

100.0,

9,

* Modul nr. 9 - Gardåa

Gardåa

3,4,4,

100,

10.0,

10,

* Modul nr. 10 - Kvinbekken

Kvinbekken

3,25,25,

100,

100.0,

11,

* Modul nr. 11 - Storbkn

Storbkn

3,25,25,

100,

10.0,

12,

* Modul nr. 12 - Ø.Dølvad

Ø.Dølvad

3,23,23,

100,

100.0,

13,

* Modul nr. 13 - Stavåa

Stavåa

4,26,26,

100,

10.0,

14,

* Modul nr. 14 - Nåva

Nåva

4,25,25,

100,

100.0,

15,

* Modul nr. 15 - Ulvasbkn

Ulvasbkn

4,25,25,

100,

100.0,

16,

* Modul nr. 16 - Jøla

Jøla

5,31,31,

100,

100.0,

17,

* Modul nr. 17 - Fjellbkn

Fjellbkn

5,25,25,

100,
100.0,
18,
Hela
5,27,27,
100,
100.0,
19,
Stavåa
5,27,27,
100,
10.0,
20,
Svartbekken
5,27,27,
100,
0.2,
21,
Svorka
31,28,28,
100,
25.0,
22,
Skardåa
31,28,28,
100,
2.0,

*KO
23,
CP1
24,24,24,
24,
CP2
4,4,4,
25,
CP3
26,26,26,
26,
CP4
27,27,27,
27,
CP5
31,31,31,
28,
CP6
29,29,29,

* Modul nr. 18 - Hela

* Modul nr. 19 - Stavåa

* Modul nr. 20 - Svartbekken

* Modul nr. 21 - Svorka

* Modul nr. 22 - Skardåa

***** CONTROL POINTS *****

* Modul nr. 23 - CP1

* Modul nr. 24 - CP2

* Modul nr. 25 - CP3

* Modul nr. 26 - CP4

* Modul nr. 27 - CP5

* Modul nr. 28 - CP6

29,
CP7
30,30,30,
31,
Bjorset Dam
6,28,28,
30,
CP8
32,32,32,
32,
CP9
0,0,0,

*KM
920.0,
30.0,
171,271,
4,
1,
1,
1,365,
9,
-100.000,-24.000,
-100.000,-24.000,
-15.000,-24.000,
0.000,-24.000,
0.000,24.000,
15.000,24.000,
8.500,24.000,
4.500,24.000,
72.000,24.000,
7,2,

*RS
200,
7,
6,
1,0.050,
119,0.050,
120,0.100,
273,0.100,
274,0.050,
365,0.050,
200,
16,
6,
1,0.000,

* Modul nr. 29 - CP7

* Modul nr. 31 - Bjorset Dam

* Modul nr. 30 - CP8

* Modul nr. 32 - CP9

***** POWER MARKET *****

* Antall preferansefunksjoner

***** RESTRICTIONS *****

* Modul nr. 7 - Ya

* Modul nr. 16 - Jøla

125,0.000,
126,0.100,
272,0.100,
273,0.050,
365,0.050,
200,

4,

* Modul nr. 4 - Storfosdammen/Bratset

6,

1,0.300,

119,0.300,

120,0.500,

279,0.500,

280,0.300,

365,0.300,

200,

31,

* Modul nr. 31 - Bjorset Dam

8,

1,4.000,

119,4.000,

120,20.000,

245,20.000,

246,10.000,

301,10.000,

302,4.000,

365,4.000,

200,

10,

* Modul nr. 10 - Kvinbekken

6,

1,0.500,

120,0.500,

121,2.500,

240,2.500,

241,0.500,

365,0.500,

*ST

***** OPERATIONAL STRATEGY *****

500,

1,

* Modul nr. 1 - FALNINGSJØEN/Ulset

5,

1,70.000,

120,0.000,

150,70.000,

270,100.000,

365,70.000,

500,

3,

* Modul nr. 3 - Innerdalsvatnet/Litjfossen

5,

1,70.000,
120,0.000,
150,70.000,
270,100.000,
365,70.000,
300,
4, * Modul nr. 4 - Storfosdammen/Bratset
500,
5, * Modul nr. 5 - Granasjøen/Grana
5,
1,70.000,
120,0.000,
150,70.000,
270,100.000,
365,70.000,
500,
2, * Modul nr. 2 - SVERJESJØEN
5,
1,50.000,
120,0.000,
150,70.000,
270,100.000,
365,50.000,

*HY ***** HYDROLOGICAL INPUT DATA *****
1950,1980,
33,
2,
1, * Modul nr. 1 - FALNINGSJØEN/Ulset
15.63,1.0,0.0,
2, * Modul nr. 2 - SVERJESJØEN
14.59,1.0,0.0,
3, * Modul nr. 3 - Innerdalsvatnet/Litjfossen
57.09,1.0,0.0,
4, * Modul nr. 4 - Storfosdammen/Bratset
15.0,1.0,0.0,
5, * Modul nr. 5 - Granasjøen/Grana
201.27,1.0,1.0,
11, * Modul nr. 11 - Storbkn
2.64,1.0,0.0,
13, * Modul nr. 13 - Stavåa
29.66,1.0,0.0,
14, * Modul nr. 14 - Nåva
41.2,1.0,0.0,
15, * Modul nr. 15 - Ulvasbkn
3.1,1.0,0.0,
16, * Modul nr. 16 - Jøla

37.7,1.0,0.0, 17,	* Modul nr. 17 - Fjellbkn
2.7,1.0,0.0, 18,	* Modul nr. 18 - Hela
16.7,1.0,0.0, 19,	* Modul nr. 19 - Stavåa
5.3,1.0,0.0, 12,	* Modul nr. 12 - Ø.Dølvad
152.0,1.0,0.0, 20,	* Modul nr. 20 - Svartbekken
2.1,1.0,0.0, 21,	* Modul nr. 21 - Svorka
215.7,0.0,1.0, 22,	* Modul nr. 22 - Skardåa
24.6,1.0,0.0, 23,	* Modul nr. 23 - CP1
121.9,1.0,0.0, 24,	* Modul nr. 24 - CP2
18.9,1.0,0.0, 6,	* Modul nr. 6 - Svorkmo
0.0,0.0,1.0, 6,	* Modul nr. 6 - Svorkmo
0.0,0.0,1.0, 7,	* Modul nr. 7 - Ya
115.4,1.0,0.0, 8,	* Modul nr. 8 - Russu
24.7,1.0,0.0, 9,	* Modul nr. 9 - Gardåa
10.8,1.0,0.0, 10,	* Modul nr. 10 - Kvinbekken
28.5,1.0,0.0, 25,	* Modul nr. 25 - CP3
277.8,1.0,0.0, 26,	* Modul nr. 26 - CP4
4.0,1.0,0.0, 27,	* Modul nr. 27 - CP5
165.7,1.0,1.0, 28,	* Modul nr. 28 - CP6
204.5,0.0,1.0, 29,	* Modul nr. 29 - CP7
0.0,1.0,0.0, 31,	* Modul nr. 31 - Bjorset Dam
210.0,0.0,1.0, 30,	* Modul nr. 30 - CP8
104.0,0.0,1.0, 32,	* Modul nr. 32 - CP9
0.0,0.0,0.0,	

1,
Naverdal
1000,121.9,
1.0,
Naverdal.prn
1,
Bjorset
1001,121.10,
1.0,
Bjorset.prn

*JK

***** JOB CONTROL *****

Power plant
1951,
1980,
920,
70.0,
0,
1,
365,
1,1,1,1,
3,
27,
5,
5,
0,
None
0,25,6,BypassFlow_Upstream_Brattset.txt,
0,27,6,Bypassr_inflow_UpstreamGrana.txt,
0,5,6,Bypass_Grana.txt,

*EX