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Evaluation and upgrade of the Telemark flood model

Louis Addo

Hydropower Development
Submission date: June 2016
Supervisor: Knut Alfredsen, IVM

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M.Sc. THESIS IN

HYDROPOWER DEVELOPMENT

Candidate: Louis Addo

Title: **Evaluation and upgrade of the Telemark flood model.**

1 BACKGROUND

The flood forecasting model for Telemarkvassdraget (FMTV) was developed in 2003 and is a tool for operational flood forecasting in the lower part of Telemarksvassdraget. The model consists of an inflow forecasting module and a reservoir routing module. The modeled system has three reservoirs and an unregulated lake, and it is also dependent on large hydropower systems upstream of the model domain. The inflow to the model system is based on a rainfall-runoff model calibrated for three unregulated catchments and then a scaling procedure from these to all catchments covered by the FMTV. The routing model uses level-pool type routing in all reservoirs and lakes with an adaptation to handle hydraulic dependencies between Norsjø and Heddalsvatn.

In September 2015 two large storms hit the Telemark area and the model was used to forecast flood levels and in operational control of the floods. Even if the model in general performed well, issues with inflow to some modules and the reservoir operation in Hjellevatn was uncovered. The purpose of this assignment is to do an analysis of the September flood and propose updates to the model to improve the performance.

2 MAIN QUESTIONS FOR THE THESIS

1. Based on observed data from September 2015, a thorough analysis of the hydrology of the event should be undertaken. A particular focus will be to back calculate inflow to all model units and to find the water levels and outflow from all lakes and reservoirs.

The observation data should then be compared with the model simulations to evaluate the model performance and to find which model units that need improvement.

2. The scaled inflow to the model should be evaluated.
    a. Based on the data from 1), evaluate the scaling factors for each catchment. Units with discrepancies should be selected for further analysis.

    b. Review potential alternative strategies for providing input to the ungauged catchment. Assess their potential for inclusion in the current version of FMTV. Do an analysis if the current scaling factors could be improved.

    c. The most promising methods should be evaluated by including them in the model and then rerunning the September flood.

3. Evaluate the reservoir routing in Norsjø and Hjellevatn, and test options for improving their performance. The improved setup should be implemented in FMTV.

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Knut Alfredsen will supervise the thesis work and assist the candidate in making relevant information available. Associate Professor II Trond Rinde and Professor Ånund Killingtveit could also provide input on the Telemark model and the hydrology of Telemarksvassdraget.

Discussion with and input from colleagues and other research or engineering staff at NTNU, SINTEF, power companies or consultants are recommended. Significant inputs from others shall, however, be referenced in a convenient manner.

The research and engineering work carried out by the candidate in connection with this thesis shall remain within an educational context. The candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in a contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The thesis report shall be in the format A4. It shall be typed by a word processor and figures, tables, photos etc. shall be of good report quality. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references and a signed statement where the candidate states that the presented work is his own and that significant outside input is identified.

The report shall have a professional structure, assuming professional senior engineers (not in teaching or research) and decision makers as the main target group.

The thesis shall be submitted no later than 10th of June 2016.

Trondheim 15th of January 2016

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Knut Alfredsen

Professor

FOREWORD

I declare that this masters thesis titled "*Evaluation and upgrade of the Telemark flood model*" is submitted to the Department of Hydraulic and Environmental Engineering at the Norwegian University of Science and Technology as partial fullfilment for a masters degree in Hydropower Development.

This thesis started from February 2016 to June 2016 at the Norwegian University of Science and Technology under the superviosion of Prof. Knut Alfredsen and Co-supervison of Associate Professor II Trond Rinde and Professor Ånund Killingtveit

The author of this thesis hereby declears that the work presented in this work is own and all information solicited from external material have be acknowledged

Louis Addo

June,2016

Tronsheim, Norway

ACKNOWLEDGEMENT

I would like to use this opportunity to express my gratitude to my main Supervisor Professor Knut Alfredsen from the Department of Hydraulic and Environmental Engineering at Norwegian University of Science and Technology for his advice, commitment, and remarks during this master's thesis.

I would also like to express my sincere gratitude to Professor Ånund Killingtveit for all the support in providing useful maps, explanations regarding project site and most importantly for his guidance during site visits.

I would also like to express my gratitude to Associate Professor II Trond Rinde for all his help especially explanations regarding FMTV model and its working principle.

I would like to say big thanks to the Norwegian Government for giving me the scholarship to enroll in this master's program. I would also like to thank the Volta River Authority (VRA), Akosombo Ghana for internship placement during summer break in 2014.

I would like to thank my classmates for all academic assistance whiles undertaking this master's program. Lastly, I would like to say thanks to my family in Ghana for helping with my education up to my bachelor's level.

ABSTRACT

Flood forecasting models are important tools that could be used to find the optimum way to operate hydropower reservoirs in order to reduce flood disasters of especially human settles close to these reservoirs. The flood forecasting model for Telemarkvassdraget (FMTV), a model specifically made for the lower part of the Telemark watercourse for operational flood forecasting was used during the two floods that hit the Telemark area in September 2015 but unfortunately significant discrepancies were found in simulated reservoir level by the FMTV and the observed reservoir levels from two out of a total of four unit in the FMTV. Each model unit uses inflow foresting and reservoir routing to determine the forecast flood levels. The forecasted inflow into each model unit in the FMTV is based on a scaling of 10 days forecasted runoff series from a rainfall-runoff model (HBV model) for three unregulated catchments calibrated on historical data.

The aim of this master thesis is to evaluate the existing scaling for all model units in the FMTV model by comparing a manual computation of local inflow into each model unit and comparing to the FMTV computed local inflow. This would help identify the deficient model units that need improvement. Potential strategies were evaluated for improving the scaling and the best strategy was used to come up with new scaling factors. In addition to the evaluation and upgrade of the scaling, the reservoir routing at model units Norsjo and Hjellevatn had to be evaluated to determine the best option to improve the model set up if necessary.

The hydrological analysis in this master thesis is based on the September 2015 flood. Again the evaluation and upgrade of the FMTV model focused mainly on the techniques used in scaling and reservoir routing.

The results of the evaluation revealed that Tinnsjo and Heddalsvatn (the first two model units) had a fairly acceptable discrepancy between simulated and observed reservoir level. The last two models, Norsjo, and Hjellevatn had a very poor discrepancy as they had a significant mismatch between their simulated and observed reservoir levels. The results of the several evaluations of all inputs into Norsjo and Hjellevatn showed that ***Farelva ndf Skotfoss*** (a gauging station situated between Norsjo and Hjellevatn measuring flow out of Norsjo and flow into Hjellevatn) was faulty and therefore is the explanation for the significant discrepancies observed in last two models.

The evaluation of scaling of local inflow into Tinnsjo and Heddalsvatn showed that the scaling factors at Tinnsjo and Norsjo were really correct and hence needed some adjustment to get a better match between observed and simulated reservoir level.

Trial and error analysis was used as a method of upgrading the scaling factors better the models at Tinnsjo and Heddalsvatn. New scaling factors could not be found for Norsjo and Hjellevatn due to faulty *Farelva ndf Skotfoss.* Another master's thesis running parallel with this project

focusing on spills in Tinnsjo revealed that the current FMTV model did not include spills from Brook Intakes in the Marvatn and Mosvatn Hydropower Systems. The inclusion of the spills in Tinnsjo influenced the scaling factors that were derived without the spills from brook intakes.

In conclusion based on findings in this study, it was suggested for local inflow to Tinnsjo to be scaled with donor catchment Hørte with a scaling factor of **9** if a ***50 years return period flood or more*** is expected and (***4.5*Austbygdåi*** **)** if expected flood levels is ***less than 50 years***.

It was recommended for a new gauging station to be built and positioned downstream of Hjellevatn to make it easier to estimate the total outflow from Hjellevatn due to the difficulty in determining the outflow from Hjellevatn from its complex gates. Outflow from Vrangfoss should be audited by appropriate authority to ensure reliable outflow data since the alternative of building another gauging station downstream of Vrangfoss may be challenging technically and financially costly. A reliable stage-storage relationship for Hjellevatn should be developed to reduce the uncertainty in the water balance equation of Hjellevatn.

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LIST OF ABBREVIATIONS

FMTV	Flood Forecasting Model Telemarkvassdraget
HBV	Hydrologiska Byrånas Vattenbalansavdelning (Hydrological Agency Water Balance Department)
mill m^3	Million cubic meters
m^3	Cubic metres
EEKV	Energy Equivalent
OTB	Ost-Telemark Brukseierforening
NVE	Norwegian Water Resources and Energy Directorate
m^3/s	Cubic meters per second
ADCP	Acoustic Doppler Current Profiler
Avg	Average
K	Scaling Constant or Scaling factor
km^2	Square Kilometers
m.a.s.l	meters above sea level
HRWL	Highest regulated water level
LRWL	Lowest regulated water level
HRV	Highest regulated water level
LRV	Lowest regulated water level
RIFA	River Flood and Accident Simulator

1 INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

There is no doubt that flood is the most common destructive natural disaster that has the capability of causing severe damage to life and property (Bin, Kruse, & Landry, 2008; Bin & Polasky, 2004; Sanders, 2007). This has proven to be the situation in Notodden, Gvarv, Ulefoss and Skien (all located along the banks of the Telemark water course in the Telemark county of Norway) (A. Killingtveit et al., 2008b). It was mentioned byMorss (2009) that, the ability to predict correctly potential flood levels give a lead time for precautionary measures to be put in place to reduce or completely avoid its negative impact on life and property. Telemarkvassdraget is Norwegian noun which means Telemark Watercourse in English.

The often recurring floods and the presence of hydropower regulated reservoirs in Telemark watercourse made it necessary for a flood model to be developed to forecast flood levels in other to help better manage this natural disaster in a manner that will ensure optimal use of water and avoid economic losses to the existing hydropower companies operating with reservoirs on the Skienselva thereby creating a win–win situation for flood protection and hydropower companies. Killingtveit et al., (2003) developed a **Flood Forecasting Model Telemarkvassdraget (FMTV),** an operational flood forecasting system in response to finding a solution to the persistent flooding in the Telemark water course. A full description about the FMTV will be introduced in Chapter 2.1.

In September 2015, two flood events hit the Telemark area and FMTV was used to forecast flood levels and in operational control of the floods. Although the model performed well, in general, some significant discrepancies regarding inflow to some modules and the reservoir operation in Hjellevatn (a reservoir located at the lower part of the Skienselva River) were uncovered.

The September 2015 50-years flood inundated mostly the southern and eastern parts of Norway. The E134 (a very important road which crosses the Numedalslagen river) was closed down because the water level in the river rose inundating the E134 road which runs through Kongsberg. Other roads that were closed down due to the September 2015 floods include FV88 at Bevergrenda, FV96 in Lundalen, FV133 in Sigdal and FV64 at Bingen in Over Eiker. The situation at the Notodden Airport was not surprising as the airport was closed down due to the flooding of Heddalsvatn (lake situated very close one end of the runway of Notodden Aiport). Gardens and Cellars of residents were also flooded(Berglund, 2015).

1.2 OBJECTIVES AND RESEARCH TASKS

The main aim of this master's thesis is to do an analysis of the September 2015 flood and propose updates to FMTV to improve its performance and therefore increase the model's reliability regarding accurate forecasting of flood levels in the lower part of the Telemark watercourse. Potential damage could be assessed based on the forecasted flood levels. A flood disaster management plan could be developed to greatly help mitigate the damages the flood could cause to life and property.

The objective of this research is to investigate the local inflows into each module of the FMTV and their respective water levels by comparing a manually computed local inflow and water levels in Microsoft excel from the water balance of each module unit and compare with FMTV's computed local inflow. A deviation from the manual computation and FMTV results for each module unit would expose the parts of the model that have issues and therefore needs an update for improvement.

The following tasks were carried out to evaluate and upgrade the FMTV:

- Performance of a thorough hydrological analysis on the September 2015 flood by back calculating local inflows into each model unit
- Comparison between manually computed local inflow to FMTV's local inflow to identify the model units that need improvement
- Evaluation of various flow input and output from each model unit
- Reliability assessment of gauging stations
- Collection of runoff data for all relevant stations to the Tinnsjo, Heddalsvatn, Norsjo, Hjellevatn reservoirs together with releases and flood spill data from regulated reservoirs of hydropower plants.
- Data quality assessment for all data types.
- Evaluation and upgrade the reservoir routing in Norsjo and Hjellevatn.
- Evaluation and upgrade of scaling of existing model

1.3 DESCRIPTION OF STUDY AREA

In the southern part of Norway within the Telemark county is situated the Skien watercourse. Skien is located close to the outlet of the Skien River. The river takes its source from several tributaries upstream and all flows down through Porsgrunn before it enters the ocean. The Skien watercourse has a total catchment area of **10772 km^2** and an annual runoff of **274 m^3/s**.(A. Killingtveit et al., 2008b). Due to recurring events of floods at some parts of the Skien water course, several reservoirs for hydropower regulation were built to help control the flood but unfortunately, these reservoirs had limited capacity to accommodate the huge flood events.

On the northern part of the catchment are the Mar hydropower system and Mosvatn hydropower system which have their releases and flood spills entering Tinnsjo. The catchment Austbygdåi is a non-regulated gauged catchment located in the northern part of Tinnsjo. Its river flows into Tinnsjo. There are other ungauged catchments that flow into Tinnsjo too. These catchments make up the total local catchment at Tinnsjo. We will see later in this report how the flows from these ungauged catchments were incorporated into the model. The Tokke-Vinje hydropower system is located in the western part of the catchment together with two important gauged sub-catchments that played a key role in the model set up. The position of the three ungauged catchments, thus Austbygdåi, Kileai, and Hørte are shown in figure 2-3.These three sub-catchments namely Austbygdåi, Kileai and Hørte played very important role in the inflow modeling which will later be discussed in subsequent chapters.

Notodden, Gvarv, Ulefoss and Skien are towns located along the Skienselva with human settlements located within flood zone area allocated by NVE. A flood zone map from NVE if figures 1-2, 1-4 and 1-5 show some significant number of human settlements within the flood region that could fall victims to flood disaster in an event of a given flood return period. Also, Appendix Y-1 to Y-4, for example, show how human settlement at Skien are inundated during 10,100,200 and 500-year floods. The flood in the Skienselva is usually caused by heavy rainfall and snowmelt.(A. Killingtveit et al., 2008b) These floods inundate houses, important roads and even sometimes airport at Nottoden.

This study considers mainly three hydropower regulated reservoirs and a lake all positioned in series as shown in figure 1-1. The reservoirs are Tinnsjo, Norsjo and Hjellevatn and the lake is Heddalsvatn. Tinnsjo is the topmost reservoir followed by Heddalsvatn, Norsjo then Hjellevatn.

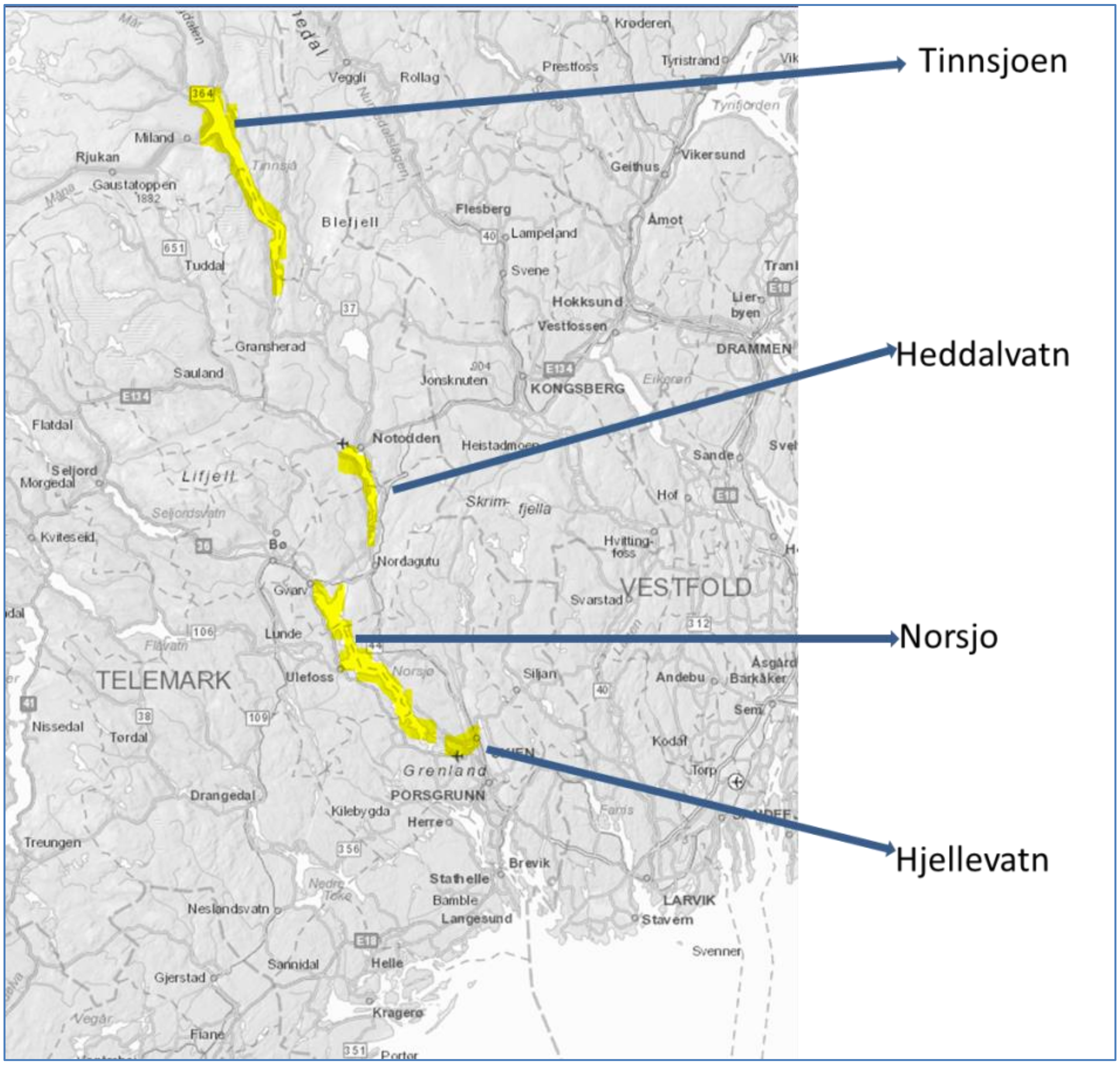

Figure 1-1 Telemark Region with all reservoirs and lake in FMTV model

1.3.1 Tinnsjo

Tinnsjo is the uppermost reservoir and the first or topmost module unit in the FMTV. It has a lowest regulated water level LRWL of 187.2m.o.h and a highest regulated water level of **191.2m.a.s.l**. It has a surface area of **51.56km^2** at HRWL and reservoir capacity of **204.1mill.m^3**. There are human settlements along the banks of reservoir Tinnsjo. The area marked red in figure 1-2 represents a flood zone mapped area with critical human settlements in times of flooding. This flood zone mapping was done NVE and could be assessed on NVE atlas website.

There are two major hydropower systems that have their total release flowing into Tinnsjo. They are; Mosvatn Hydropower Systems and Mar Hydropower Systems. Water flows from Mosvatn Hydropower Plant to Froystul Hydropower Plant to Vermok Hydropower Plant to Saheim Hydropower Plant then to Moflat Hydropower Plant. Flow from Mar Hydropower Plant joins the flow out of Moflat and goes to Mael Hydropower Plant before it enters reservoir Tinnsjoen. There exist several brook intakes between Mosvatn and Mael Hydropower Plant that collect water into various hydropower plants located within the area. When the capacities of the brook intakes are exceeded, the excess water flows down through rivers into Tinnsjo. Figure 1-2 shows the positions of hydropower plants (Black Squares), brook intakes (Circles), and flood zone area (Marked Red) relative to reservoir Tinnsjo.

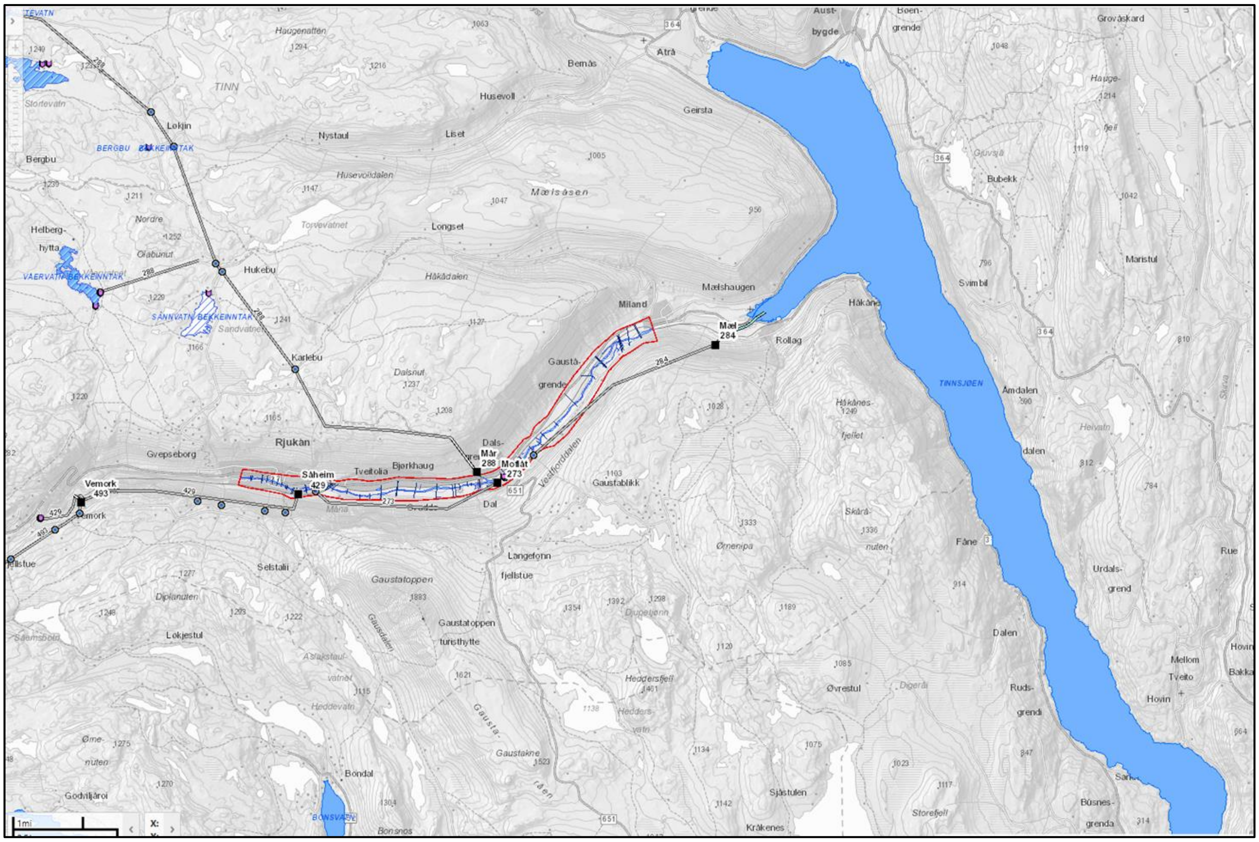

Figure 1-2 Positions of hydropower plants (Black Squares), brook intakes (Circles), and flood zone area (Marked Red)

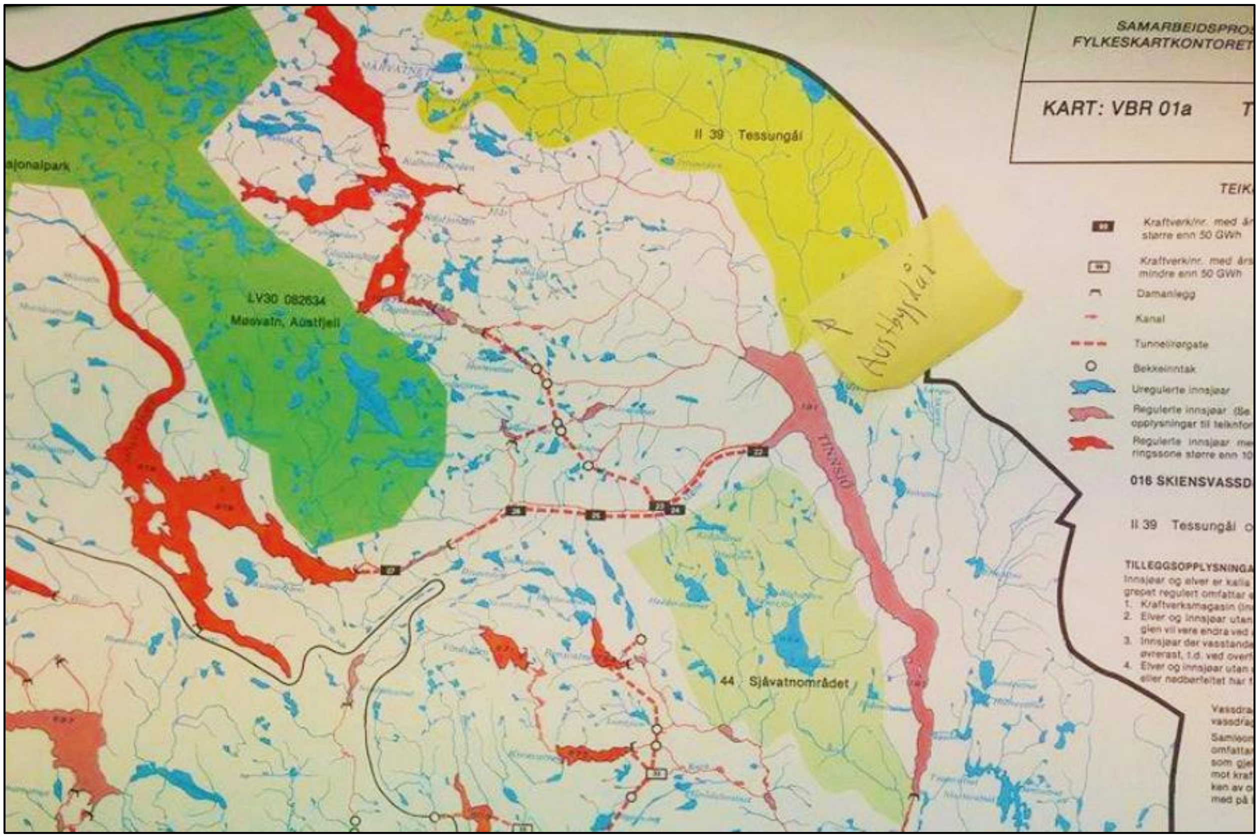

Figure 1-3 Total inflow into Tinnsjo from regulated sources (red rivers) and unregulated sources (blue rivers)

In figure 1-3, the total inflow to Tinnsjo which is made of the sum of total release from regulated and unregulated sources could be seen. The regulated inflow into Tinnsjo is equal to the total release from Mosvatn and Mar Hydropower systems and all small red rivers. The total unregulated flow into Tinnsjo is made of all the blue rivers flowing into Tinnsjo in figure1-3. For the purposes of simplicity all the small blue rivers flowing into Tinnsjo will be referred to as Local Tinnsjo in this report, even though technically the red rivers and release from hydropower plants are also part of the local inflow into Tinnsjo. This applies to the other model units Heddalsvatn, Norsjo, and Hjellevatn.

1.3.2 Heddalsvatn

Heddalsvatn is a lake located in Notodden (a city and a municipality in the Telemark county of Norway). There are human settlements located along the banks of the lake. The most critical feature or infrastructure during flood events in Notodden would be the Notodden Airport located at Tuven and a very important road like the E134. Figure 4a and 4b in figure 1-4 below show the location of Notodden Airport, E143 road and some human settlement close the Heddalsvatn the experience flooding. The red boundary lines in 4a (figure1-4) show the flood zone mapped area by NVE.

On Tinnelva (the river stretch between the outlet of Tinnsjo and the inlet of Heddalsvatn), there exist four hydropower plant receiving water in series before the flow enters Heddalsvatn. The flow from Tinnsjo enters Arlifoss Hydropower Plant to Gronvollfoss Hydropower Plant to Svaelgfoss Hydropower Plant then to Tinfos Hydropower Plant near Nottoden before it exits into Heddalsvatn.

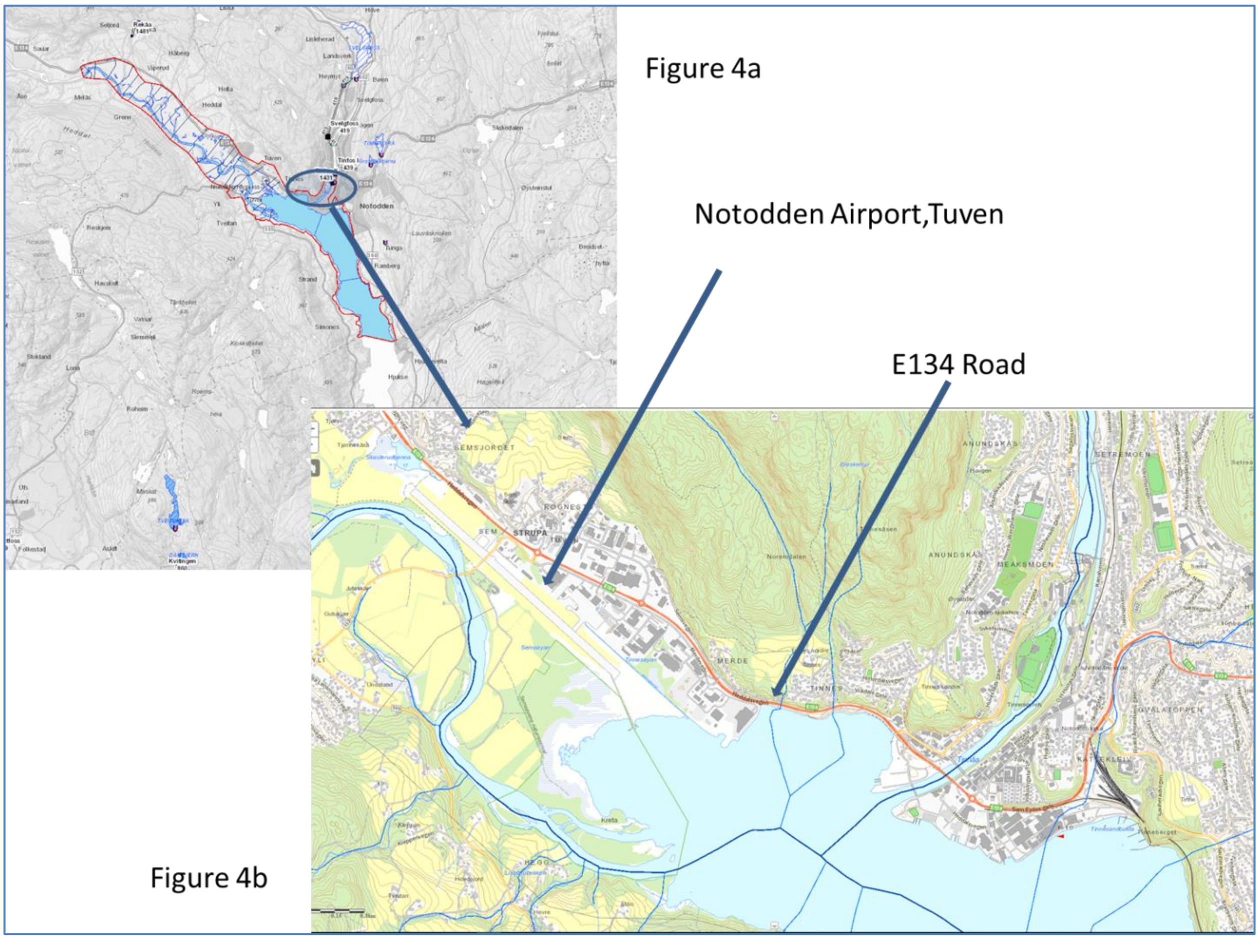

Figure 1-4 Geographical positions of Nottoden Airport, E143 Rod and human settlements relative to Lake Heddalsvatn

1.3.3 Norsjo

Reservoir Norsjo is a regulated reservoir situated after Heddalsvatn in the downstream direction. It has a LRWL of **51.18 m** and HRWL of **15.30m**. It has a surface area of **55.12km^2** at HRWL. Its reservoir capacity is Ca. **76.4 mill m^3**. Norsjo reservoir feeds water to Skotfoss (a 24 MW hydropower plant) located at the outlet of reservoir Norsjo. Norsjo receives flow from other hydropower plants like Vrangfoss Hydropower System and local inflow from other local rivers and rivers. There are human settlements around the banks of Norsjo with the most critical settlement shown in the flood zone mapped area shown in Figure 1-5 below. In this area, it could be seen that the hydropower plants; Aall-Ulefoss and Ulefoss both with installed capacity of 5.7 MW and 6.4 MW could be submerged in very high floods

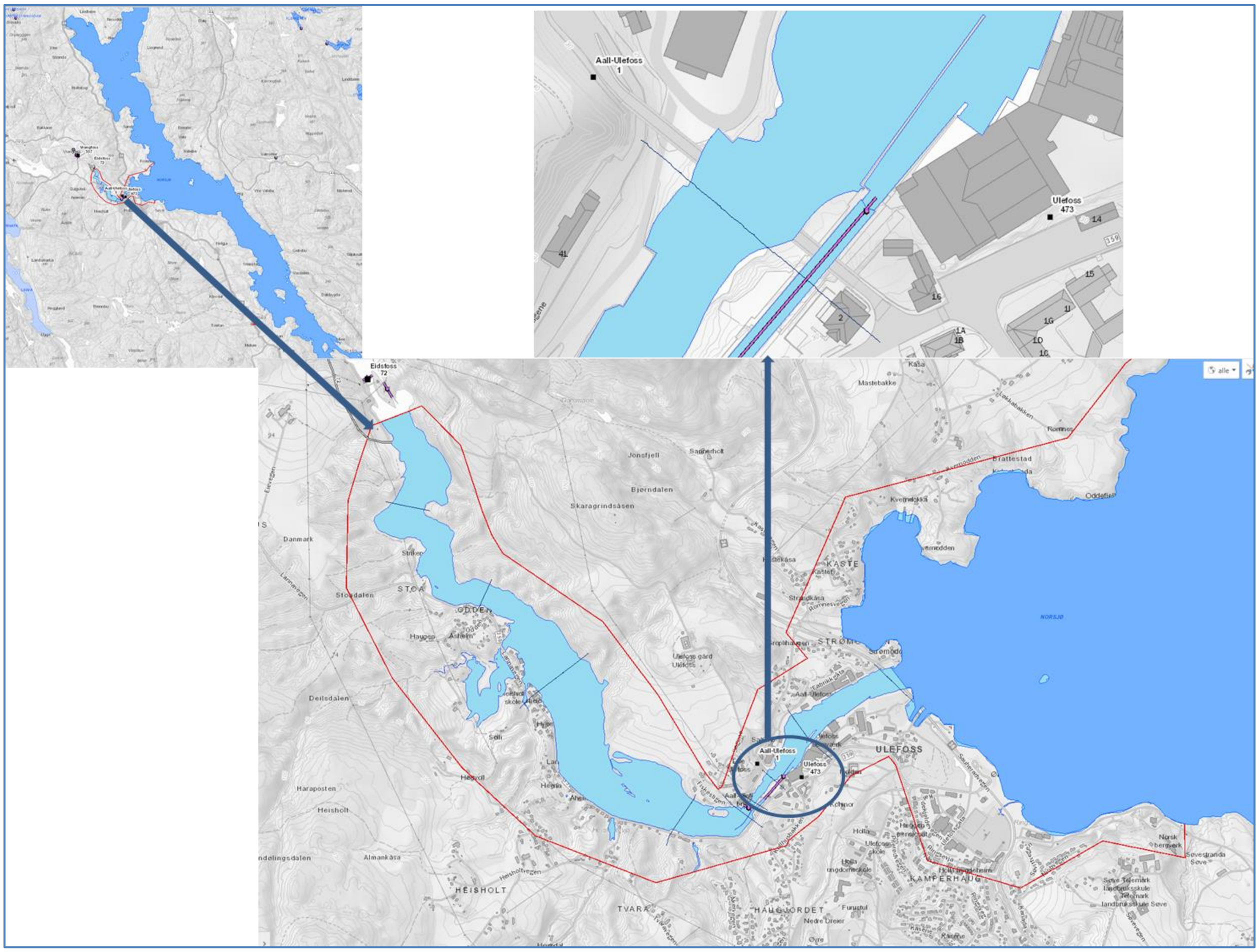

Figure 1-5 Human settlement and hydropower plant located within flood zone at Norsjo

1.3.4 Hjellevatn

Hjellevatn is the last reservoir and the most vulnerable with regards to flooding because of its flat terrain and very little reservoir capacity. Flow from Tinnsjo comes to Hjellevatn before entering the ocean. It has the least reservoir capacity compared to the Tinnsjo, Heddalsvatn, and Norsjo. It has a HRWL of **5.20m**, LRWL of **5.0m** and surface area of **0.44km^2** at HRWL. Hjellevatn is regulated such that the reservoir level is kept at a constant level when the inflow from Farelva ndf Skotfoss (a nearby gauging station) up to **1000 m^3/s**. Above this flow, the level begins to rise because all gates are fully opened and there are no more gates to open. Hjellevatn feeds water to Klosterfoss, Eidet 2, Eidet and Eidet 1 hydropower plants with installed capacities of 10 MW, 1.6 MW, 0.67 MW and 0.6MW respectively. Hjellevatn seems to be the most affected part of the study area because of its flat terrain and densely populated human settlements located along the banks of Hjellevatn as shown in Figure 1-6. The flood zone area near the banks of Hjellevatn is shown in figure 1-6.

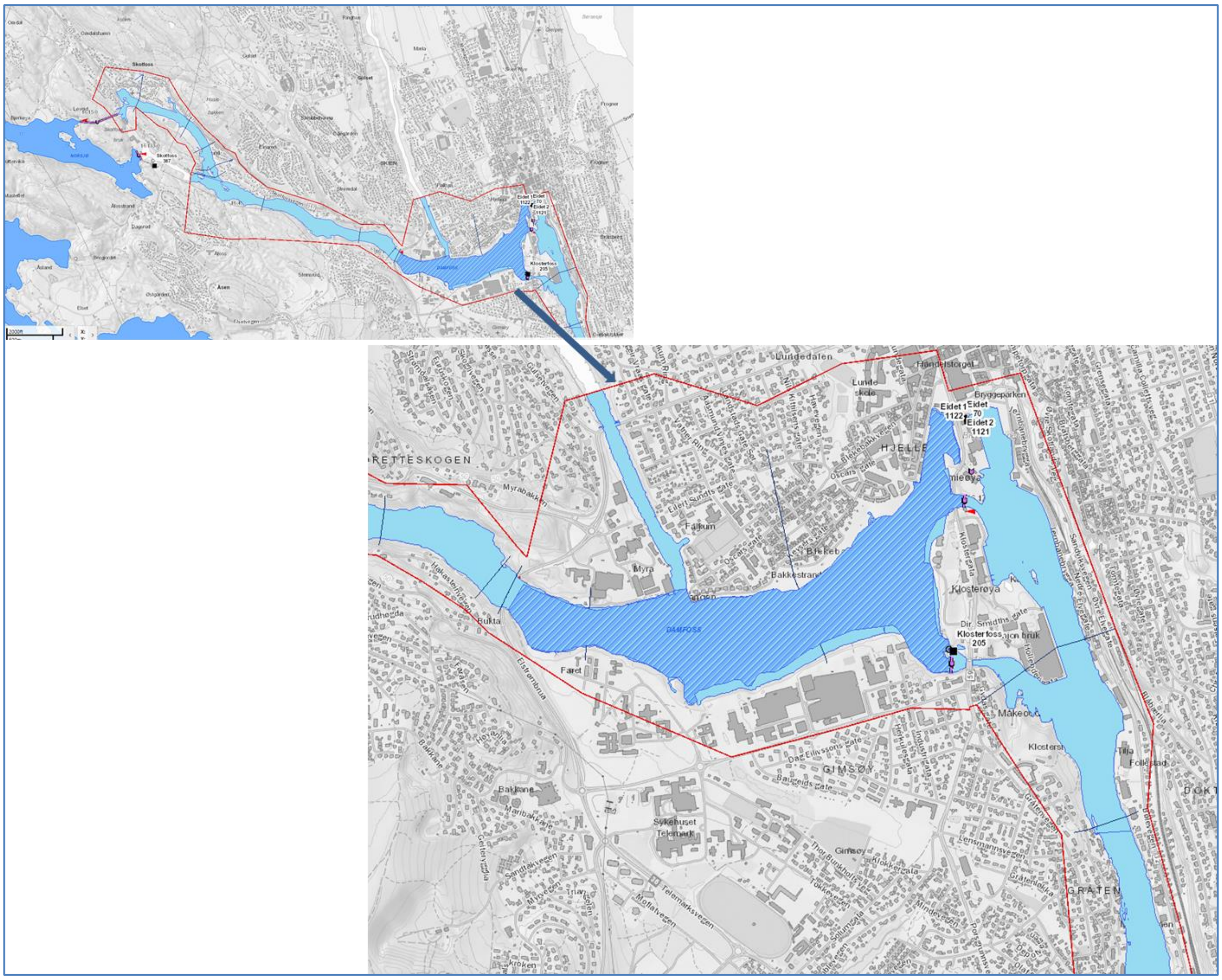

Figure 1-6 Human Settlements flood zone areas (marked with red lines) along Hjellevatn, Skien

1.4 STRUCTURE OF THE THESIS

Chapter 1titled Introduction and its sub-sections introduce the background, problem statement, description of the project area and most importantly the research objectives of this master thesis.

Chapter 2 titled literature review outlines important subjects in previous work relevant to this master thesis. It includes an introduction to the FMTV model, its working principle, and components. The embedded HBV model for three catchments calibrated on historical data is also discussed. Scaling and general issues regarding scaling were also discussed.

Chapter 3 titled Methodology discusses the various topics investigated to solve the research tasks or objectives. It includes Evaluation of the performance of the FMTV model, Water balance study for each model unit to compute local inflow, Evaluation of routing at Norsjo and Hjellevatn and finally a trial and error test for choosing scaling constants.

General conclusion and discussion was included in chapter 4. Pictures of some external documents, excel sheets showing important computation, pictures from site visit, etc

1.5 LIMITATIONS

The initial goal of this master thesis was to identify FMTV model unit or units with issues that needed improvement based on a thorough analysis of the hydrology of each model unit during the September 2015 flood. The strategy proposed as part of the research task was to evaluate the existing scaling and routing in the FMTV model, choose the best improvement alternative and implement the best alternative in the FMTV model to upgrade it.

This thesis took a little bit different path as some problems were encountered with regards to data and especially lack of a detailed description of the existing FMTV model and how each component in the model was made to form the basis for developing an improvement strategy.

Much of the time was spent on carrying out several investigations to prove that Farelva (a station located in between the last two models) was the cause for the poor performance of the FMTV for those two model units. The evaluation and upgrade of the routing model at Norsjo and Hjellevatn could not be deeply investigated due to faulty Farelva gauging station. Trial and error test was used to find new scaling factors as a means of upgrading the FMTV model.

2 LITERATURE REVIEW

2.1 FMTV MODEL

2.1.1 Overview

The flood forecasting model for Telemarkvassdraget (FMTV) is simply a flood model built for the lower part of the Telemark Watercourse (Telemarksvassdraget). It is made up of a hydrological model for inflow forecasting, a reservoir routing model and later will be linked to flood zone map to analyze areas prone to flooding. Thus, the FMTV model is in principle made to combine a forecasted regulated flow and forecasted local inflow into each model unit, send this to a reservoir routing model to compute the forecast level of reservoir and lake and use this as a basis to make a flood zone map of the area prone to flooding. A schematic flow chart in figure 2-1 below shows the connections between the various components of the FMTV and how they interact with each other. The FMTV model has also a flood routing model which is used to investigate impacts of various operational decisions in the hydropower systems(A. Killingtveit, Alfredsen, Rinde, Rohr, & Osthaus, 2008a). A schematic chart of the working principle of the FMTV is also displayed in figure 2-2.

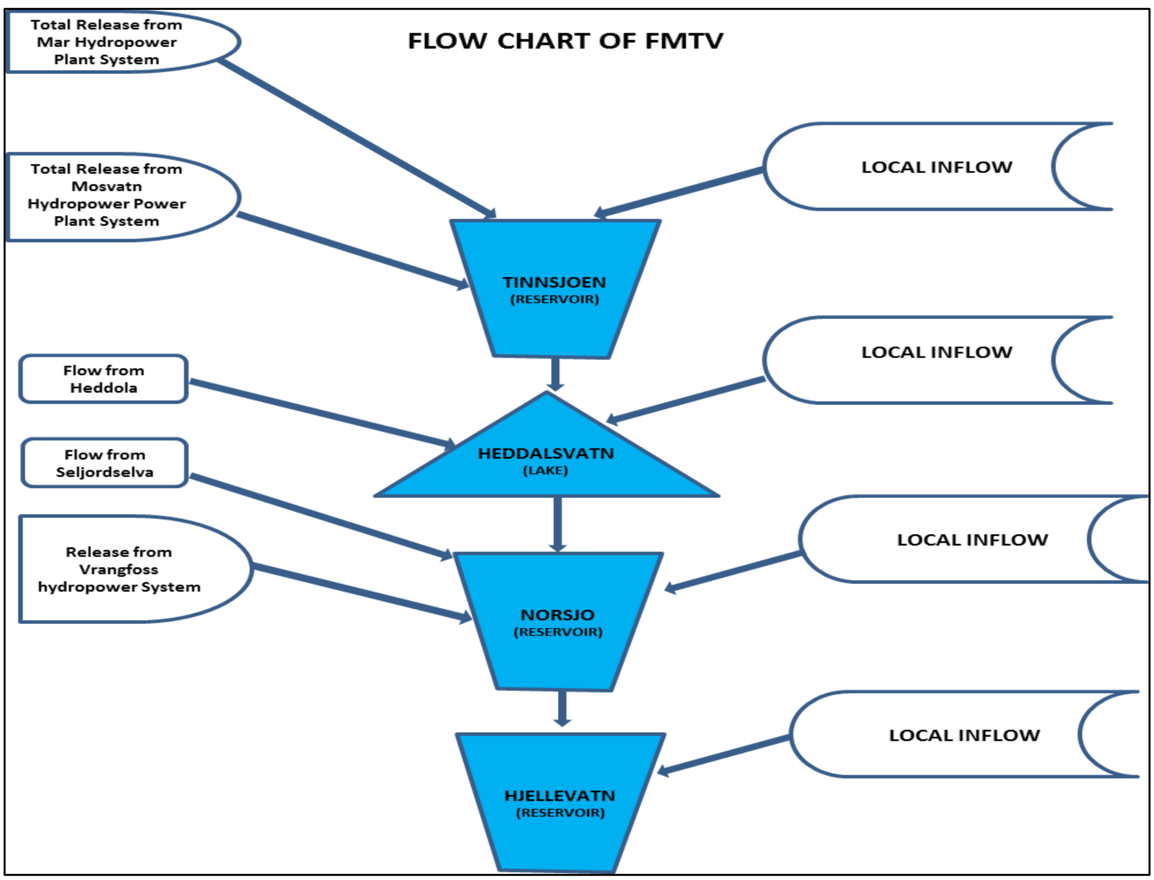

Figure 2-1 Flow chart in the FMTV model showing all sources of water into each model unit(A. Killingtveit et al., 2008b)

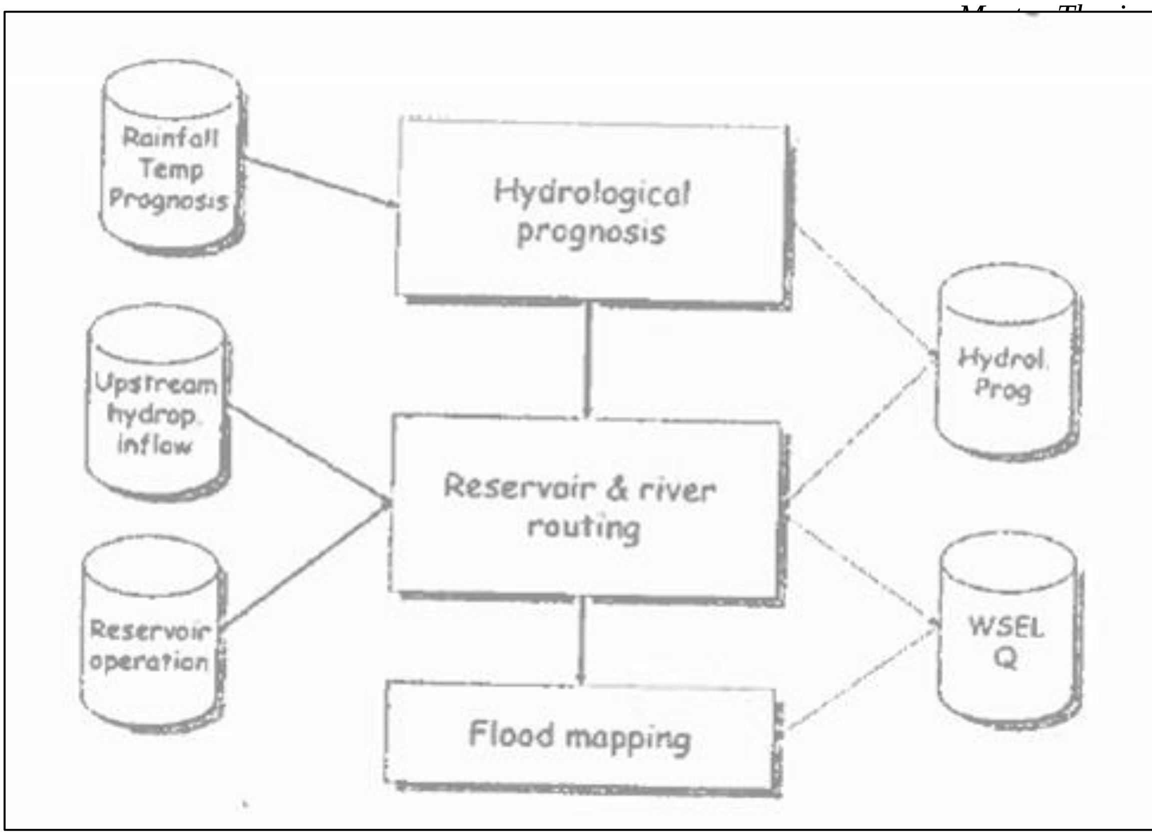

Figure 2-2 A schematic chart showing the working principle of the FMTV model(A. Killingtveit, Alfredsen, Rinde, Rohr, & Osthaus, 2008b)

2.1.2 Inflow Forecasting with HBV model

The local inflow into each module as displayed in figure 2-1 above is computed by scaling the flows from three gauged unregulated catchments namely Austbygdåi, Hørte and Kileai, to ungauged catchments. The three gauged catchments in this master thesis have been defined as ***donor catchments*** and the ungauged catchments ***target catchments***. The three donor catchments have been called so because they 'donate' their flow series to the **target catchments** through scaling. Technically speaking, local inflow to a model unit or a particular reservoir or lake refers to all the local flows into that specific model unit, lake or reservoir but in this context ***Local Inflow*** refers to sum all local from unregulated rivers (blue rivers in figure 1-3) flowing into each model unit except the known flows from the regulated source earlier explained in chapter 1.3. For example, if we consider the model unit Tinnsjo from figure 2-1, Total release from Mar and Mosvatn Hydropower systems are regulated inflows into the model unit and are therefore not considered as local inflow to Tinnsjo even though technically speaking they are but rather the inflows from Austbygdåi and all small streams (blue rivers) flowing into Tinnsjo are referred to as ***Local Inflow*** to Tinnsjo. In the same way, the ***Local Inflow*** to Heddalsvatn is the sum of all unregulated rivers (blue rivers) flowing into Lake Heddalsvatn except flows from Omnesfoss(Heddola) and Tinnai(Kirkevoll Bru). This analogy applies to Norsjo and Hjellevatn which are the last two model units in the FMTV model.

The three donor catchments are all sub-catchments located within the big catchment area for the outlet of the Telemark watercourse. Several sub-catchments exist apart from the donor catchments but only those three were selected because they were the only gauged catchments suitable for making a hydrological model but the others were not gauged and hence a hydrological model could not be built for such catchments. The actual position of these three sub-catchments relative to the big catchment is showed in Figure 2-3. These catchments were calibrated on historical data, updated and used to forecast runoff and flood for 10 days and scaled to unregulated catchments to compute local inflow into each model unit. This hydrological prognosis was done using a version of the well-known HBV model by (Killingtveit and Saelthun,1995).

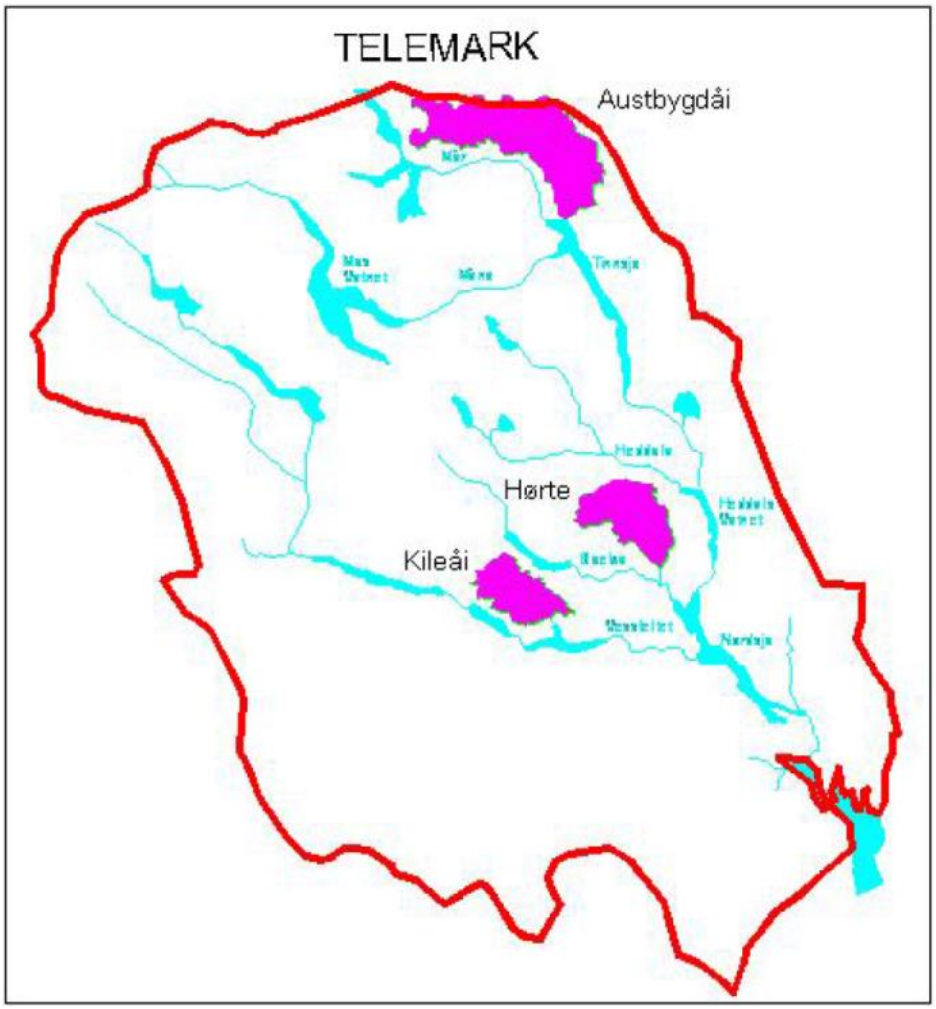

Figure 2-3 Catchment of the outlet of Telemarkvassdraget showing the positions of three donor catchments relative to the reservoir and lake in the FMTV model (Mahat, 2006)

Prior to running of an inflow prognosis, currently observed discharge data for the selected station for each selected catchment is fed into the model to update the model, thus establishing the correct starting conditions for the prognosis. Temperature and Precipitation prognosis for 10 days is collect from the meteorological department and fed into the model as forecast input. The model generates the runoff based on the temperature and precipitation prognosis. The inflows to a reservoir or lake from the local catchments in the FMTV model are scaled from the three HBV catchments using a scaling factor based on specific runoff and area.

2.1.3 Reservoir Operation and Routing

The forecasted external inflow from the hydropower plants and local inflow from the scaling are set as input to the routing model to compute the forecasted water levels in each lake and reservoirs.

Reservoir routing was defined by (Å. Killingtveit & Sælthun, 1995) as "*a technique for computing the reservoir or lake level and its outflow hydrograph during a flow event given the initial reservoir or lake level, the inflow hydrograph into lake or reservoir, the reservoir or lake stage – volume relationship and the reservoir or lake stage-outflow relationship*". There are generally two computation procedures for reservoir routing. These are;

- The Puls method and
- Numerical integration method

The Puls method has a simpler calculation than the Numerical integration method (Å. Killingtveit & Sælthun, 1995) and was therefore used to for routing in the existing FMTV model. Details about the Puls method is explained in chapter 3.5

A summary of current FMTV model routing procedure is explained below;

- The total inflow into each model unit (reservoir or lake) is made of local inflow from unregulated catchments and hydropower regulated rivers. The future local inflow into each reservoir from unregulated catchments is computed through scaling flow from three donor catchments whose runoff are generated from a hydrological model calibrated on historical data. The future release plan is acquired from hydropower power companies in the project area.
- A release strategy for each reservoir and lake is set by the user of the system to get the outflow from each reservoir or lake.
- The observed reservoir and lake levels (acquired from OTB) for some days before prognosis period are defined to have a better control of the computations. By 'having a better control' means to be able to have the opportunity to ***'update'*** the model where there is a deviation between the observed and simulated reservoir or lake levels. This helps to ensure proper starting conditions for the prognosis period. The update of the

model was accomplished by simply adjusting the scaling factors until the best match between observed and simulated lake or reservoir levels is obtained by some criteria of goodness of fit. The scaling factors for computing local inflow from unregulated catchments are subject to high uncertainties due to general issues in scaling. More about scaling issues will be discussed in chapter 2.3.3

- Lake Heddalsvatn and reservoir Norsjo were given special attention and consideration simply because these two were in ***hydraulic contact***. The flow out of Heddalsvatn was influenced by the Norsjo reservoir level. Previous work on this project indicated that the flow out from Heddalsvatn was computed for various levels in Norsjo with the curve in Appendix H. More details about this computation will be seen in chapter 3.3.3.2.

2.2 HBV SETUP FOR THREE DONOR CATCHMENTS

2.2.1 Overview

The HBV hydrological model, when calibrated for a catchment, makes it possible to forecast flood and runoff for that catchment(Å. Killingtveit & Sælthun, 1995). The FMTV has an embedded HBV model which forecasts runoff for 10 days The FMTV model has an inbuilt HBV hydrological model that forecasts inflow for 10days from donor catchment which adds up to flow from regulated catchments to determine the total flood magnitude and the fluctuations of reservoir or lake level based on the inflow and outflow from each reservoir or lake(Fenton, 1992). The forecasted flows from the donor catchments are scaled to the local inflows of each of the model units.

Details about HBV model could be found in (Bergström & Singh, 1995). The HBV model is a Conceptual Lumped hydrological model and hence handles the whole catchment as a homogenous unit except the snow routine which is distributed. Its conceptual nature makes it dependent on calibration in order to get a good match between the observed and model simulated output simply because of its inability to mimic 100 percent the natural hydrology of a catchment. Most of the mathematical equations describing the physical hydrological processes in the HBV model for a catchment are linear(Å. Killingtveit & Sælthun, 1995)

2.2.2 Setting Up of the Hydrological Model

The hydrological modeling for each donor catchment was set up as follows; Several Precipitation and Temperature stations within the vicinity of each sub-catchment were combined as input to the hydrological model. Each combination had one pair of Precipitation and Temperature data for the same time scale. The single pair of precipitation and temperature was fed into the hydrological model to get the pair that gave the best goodness of fit. The criterion for goodness of fit between the simulated and observed runoff was determined using the objective method which uses the *Nash efficiency criterion(Å. Killingtveit & Sælthun, 1995; Seibert, 2000)* . The mathematical of the expression is given in equation (1) below;

$$R^2 = \frac{\sum(Q_O - \overline{Q}_O)^2 - \sum(Q_S - Q_O)^2}{\sum(Q_o - \overline{Q}_o)^2} \qquad (1)$$

Where Q_o is Observed runoff, Q_s is simulated runoff, $\overline{Q}_o$ is average observed runoff

The Precipitation and Temperature combination that gave the highest R2 value was selected as the best combination for making the hydrological model and hence for the runoff forecasting. From the results of (Mahat, 2006), the best precipitation and temperature stations for each of the donor catchments are showed in table 2-1.

Table 2-1 HBV results from(Mahat, 2006)

Name of Catchment	Precipitation [mm]	Temperature[°C]	R2	
			Calibration Period	Acc. Diff [mm]
Austbygdai	P3108(Tessungdalen)	T3293(Oyfjell)	0.79	-111
Hørte	P3220(Lifjell)	T3293(Oyfjell)	0.75	-92
Kileai	P3490(Postmyr)	T3293(Oyfjell)	0.66	-116

The results from (Mahat, 2006) was not implemented in the existing FMTV model because precipitation and temperature stations with the capability of transmitting data via the internet were of priority. This was to help easy usage of the model once internet was available. The HBV results in the existing FMTV model are shown in Table 2-2.

Table 2-2HBV results in the existing FMTV model

Name of Catchment	Precipitation [mm]	Temperature[°C]	R2	
			Calibration Period	Acc. Diff [mm]
Austbygdai	P3108(Tessungdalen)	T3162(Mosvatn)	0.788	-5079.8
Hørte	P3235(Lifjell)	T3162(Mosvatn)	0.544	-81.6
Kileai	P3285 (Kviteseid-Moen)	T3162(Mosvatn)	0.430	2501

The results of the calibrated HBV model for the three donor catchment can be found in Appendix M,N and O

2.2.3 Flood or Runoff Forecasting

Prior to running a runoff or flood forecasting, the FMTV is updated with latest observed runoff, precipitation and maximum and minimum temperature data up to the last day before the start of prognosis. Through updating, the model's simulated runoff is manipulated to match as much as possible the observed runoff over the run-up period to ensure correct starting conditions for the prognosis (Rakovec, Weerts, Hazenberg, Torfs, & Uijlenhoet, 2012). Also, the forecasted precipitation and temperature for the next 10 days are also fed into the system. The forecast for 10 days is performed after the updating. The results of the forecasted runoff have the various possibilities of forecasted runoff based on the different assumption of the forecasted temperature and precipitation data.

The existing FMTV model used similar donor catchments as in (Mahat, 2006) but different scaling and different choice of donor catchment for scaling. The Table in Appendix P summarizes the scaling for each target catchment and the donor catchments used in the existing FMTV. The results of (Mahat, 2006) is also displayed in Appendix Q just to help us see the difference in the scaling and choice of donor catchment used for each part of the model that needed scaling.

2.3 SCALING

2.3.1 Overview

‘***Scaling***’ literally means zooming in or out but the hydrological point of view and in the context of this work, scaling means transfer of hydrological data from one catchment with known data(donor catchment) to another catchment without data (target catchment) for the same time period. The scaling is possible if the donor and target catchments have similar runoff pattern, climatic regime and catchment characteristics (Blöschl, 2013; Blöschl & Sivapalan, 1995; Post & Jakeman, 1999). ‘***Scaling up’*** means transferring the hydrological data from a small donor catchment to a large target catchment without flow data , on the other hand, scaling down means transferring data from a large catchment to a small catchment without data (Blöschl & Sivapalan, 1995). There are several statistical methods for predicting runoff in an ungauged catchment. These include Regression Methods, Index Method, Geo-Statistical and Proximity Method, and Runoff Estimation from Short Record Method(Blöschl, 2013). In this work, Regression Method was used to generate the data for target catchments based on the specific runoffs and catchment areas of the donor and target catchments.

Previous work on this research done by (Mahat, 2006) revealed that three sub-catchments within Telemark Skienselva outlet catchment namely ***Austbygdåi, Hørte,*** and ***Kileai*** were used as the basis for computing local inflow to each module unit. All small ungauged unregulated catchments (target catchments) flowing to each module units were identified from NVE Atlas. The total area of the local catchment of each module unit was computed by summing up all small catchments flowing to their respective model unit. The specific runoff (l/s*km^2) and local catchment area (km^2) of each model unit and all river reach connecting the module units were found from NVE website. The runoff series for each small stream flowing into a module were computed as the product of the flow series of the most suitable donor catchment and a ***scaling factor or scaling constant*** as showed in Eq.2. This scaling factor was calculated based on the specific runoffs and catchment areas of the local area and that of suitable donor catchment(A. Killingtveit et al., 2008a; Å. Killingtveit & Sælthun, 1995). The donor catchments that gave the highest correlation were used as the basis for scaling. Other criteria such as elevation distribution, climate regime, catchment form, lake percentage, surface type and the distance between donor and target catchment were considered in selecting the best donor catchments for scaling. Lyon et al. (2012) defined specific runoff at any point in a catchment as the discharge observed at that point per unit catchment area to that point.

The formula for computing scaling factor is shown in equation 3.

$$Q_{(ung)} = K*Q_{(gau)} \qquad (2)$$

Where K is scaling constant defined by equation (3)

$Q_{(ung)}$ is the flow for target catchment and $Q_{(gau)}$ is the flow measurement for donor catchment.

$$K=\frac{A(ung)*S(ung)}{A(gau)*S(gau)} \quad (3)$$

Where

K = scaling constant
$A_{(ung)}$ = catchment area of ungauged station
$S_{(ung)}$ = mean specific runoff of ungauged catchment
$A_{(gau)}$ = catchment area of gauged or donor catchment
$S_{(gau)}$ = mean specific runoff of gauged or donor catchment

The catchment area and specific runoff of the three donor catchments used in the current FMTV model are shown in table 2-3 below.

Table 2-3Catchment properties of donor catchments

Location	Catchment Name (Donor Catchment)	Catchment Area [km^2]	Elevation [m.a.s.l]		Avg. Specific Runoff [l/s*km^2]
			Minimum	Maximum	
1	Kileai	118.5	120	1070	15.69
2	Hørte	115	80	1172	31.78
3	Austbygdai	347	230	1485	25.6

2.3.2 Scaling Constants for the local catchments areas in the study area

2.3.2.1 Local Tinnsjoen

The local catchment area for Tinnsjoen was found by summing up the areas for the sub-catchments; 016.G5A, 016.G52Z, 016.H, 016.G3Z, 016.G1Z, and 016.GO. All these catchments formed the local area whose flow entered Reservoir Tinnsjoen. The Scaling Factor of 3.71 was obtained by (Mahat, 2006) but in the FMTV a scaling factor of 2.71. The catchment Austbygdåi was used to scale Local catchment area for Tinnsjoen.

2.3.2.2 Local Tinnelva

Tinnelve is the river stretch that links Tinnsjoen to Heddalsvatn. There exist three power plants in this part of the water course that control the flow from Tinnsjoen to Heddalsvatn. The local catchment area for Tinnelva was found by summing up the sub-catchments 016.F3Z and 016.FO.

Donor catchment Austbygdåi was used to compute the local inflow series for Tinnelva with a scaling constant of 0.67 was used.

2.3.2.3 Local Heddøla

The local inflow series of local Heddøla a tributary to Heddalsvatn located on the northern part of Lake Heddalsvatn was scaled from Hørte with a scaling factor of 0.414

2.3.2.4 Local Heddalsvatn

The local catchment areas for Heddalsvatn were 016.E1Z and 016.E. These two areas were summed up to represent the total local area for Heddalsvatn. Donor catchment Kileai was used to scale local inflow into Heddalsvatn with a scaling constant of 2.982.

2.3.2.5 Local Saua

Local Saua is the local area the drains into the river stretch between Heddalsvatn and Norsjo. From nve area, 016.D represents local Saua. The local inflow to Saua was computed by scaling of runoff series from Kileai with a scaling factor of 0.36.

2.3.2.6 Local Norsjo

The local catchment area for Norsjo was computed as a sum of local areas 0.16.AD, 016.AF, 016.AE, 016.AC, 016.AA, 016.AB, 016.B0 and 016.CO. The local inflow into Norsjo was computed by scaling runoff series from Kileai with a scaling factor of 1.592.

2.3.2.7 Local Boelva

Local Boelva is the area that drains into the river stretch from Hagadrag gauging station to point where Boelva enters Norsjo. The local inflow to local Boelva was computed with donor catchment Kileai with a scaling constant of 0.754.

2.3.2.8 Local Skien

Local Skien located at the lower part of the Skienselva has a local area computed from 016.AO. Catchment Austbygdåi was used to generate the local inflow series for local Skien. A scaling factor of 0.58 was used.

2.3.2.9 Local Hjellevatn

The local inflow series for the local area of Hjellevatn was computed with donor catchment Kileai with scaling constant of 2.082.

2.3.3 Scaling Issues

The stream flow time series for ungauged or target catchments could be acquired by transferring flow time series from a donor catchments through scaling or by making a hydrological model for target catchment if it has stream flow data (Blöschl & Sivapalan, 1995; Zelelew & Alfredsen, 2013). In this project, target catchments were not gauged and hence their stream flow series were acquired by scaling stream flow data from the three donor catchments ***Austbygdåi, Kileai,*** and ***Horte.***

Blöschl and Sivapalan (1995) defined scaling in the hydrological point of view as "*the transfer of hydrological data from one catchment to another*". They went on to define **Upscaling** as the transfer of data from larger to smaller catchment and **Downscaling** as the transfer of data from smaller to a larger catchment. They went further to define scaling issues as the problems encountered during scaling.

Several researchers revealed that hydrological physical processes in natural catchments demonstrate a high degree of heterogeneity and variability in time and space and hence the explanation to scaling issues (Blöschl & Sivapalan, 1995; Gentine, Troy, Lintner, & Findell, 2012; Sivapalan, Grayson, & Woods, 2004). Gentine et al. (2012) argued that the physical processes in hydrology are nonlinear however most of the laws in physical models are based on linear approximations. This linearization of the non-linear physical hydrological process leads to major challenges for models to exactly describe natural hydrology of a natural catchment. Again Gentine et al. (2012) argued that natural heterogeneity of catchments strongly affect the hydrological responses through many non-linear processes that cannot be scaled either up or down to the scale of interest.

Gentine et al. (2012) focused on three systemic issues namely nonlinearities and heterogeneities, non-local transport processes and scale discrepancies between observation and model output. Gentine et al. (2012) suggested that parameters like Soil Moisture (derived from Richards equation), Evapotranspiration (derived from Richardson or Monin-Obukhov theories) and Snow were found to be parameters with non-linearity and heterogeneity issues. According to Gentine et al. (2012) most fundamental laws that describe the physical hydrological processes were derived from small scales like 1-100m. This is a convincing proof that many hydrological processes are non-local in nature. Gentine et al. (2012) discussed scale discrepancy between observation and modeling as a major challenge in surface hydrology. This is because of the different conditions in their space and time(Blöschl & Sivapalan, 1995).

3 METHODOLOGY

3.1 DATA ACQUISITION AND CORRECTION

3.1.1 Overview

For an effective evaluation and possible upgrade of the FMTV, it is important to have good quality data for the stated period where flooding was experienced. For the purpose of this study the data for the month of September 2015 is the main focus. The data types for the hydrological analysis include River flow data, Reservoir or Lake Data, Topographical maps and Power Plant flow data

The following authorities are the source of all data used for this study:

- NVE
- Statkraft
- Norsk Hydro
- OTB
- Norconsult

3.1.2 River Flow Data

River flow data for the gauging stations relevant to the study were collected from NVE xhydra database for the period September 2015. These data were daily runoff data. River flow data were collected for the following stations within the study area;

Table 3-1List of river flow station in the FMTV model

No.	Gauging Station	River Name	Station Number
1	Kirkevoll Bru	Tinne	16.23.0
2	Omnesfoss	Heddola	16.10.0
3	Austbygdåi	Austbygdåi	16.128.0
4	Kilen	Kileai	16.194.0
5	Hagadrag	Boelva	16.51.0
6	Farelva ndf. Skotfoss	Farelva	16.497.0

3.1.3 Reservoir Data

Reservoir volume, level, and total release are the reservoir data types collected for this study. Table 3-2 show the sources of this data.Reservoir volume data for daily time step was used to compute the change in storage on a daily basis. In situations where reservoir volume data were lacking, other methods were used to obtain the stage/volume relationship for the reservoirs. Reservoir data were collected for the following lake and reservoirs following stations of concern were;

Table 3-2 Reservoir or lake data types and sources

Name	Data Type	Source	Station Name	Station Number
Tinnsjo	Level and Volume	Statkraft and Hydro	-	-
Heddalsvatn	Level	NVE	Notodden (Heddalsvatnet)	16.1.0.
Norsjo	Level and Volume	NVE	Norsjø v/Løveid ovf	16.15.0
Hjellevatn	Level	NVE	Hjellevatn	16.17.0.
Mosvatn	Level and Volume	Hydro AS	-	-
Marvatn	Level and Volume	Statkraft AS	-	-
Vrangfoss	Total Release	Vest-Vassdraget	-	-

3.1.4 Topographical Maps

Topographical maps showing the structure of each model unit and their relative positions to one another including the positions of important gauging stations was acquired from NVE-Atlas.

3.1.5 Plant Flow Data

Daily Plant flow data for each of the Hydropower Plants in each model were acquired from either Norsk Hydro or Statkraft depending on which of these two companies own the particular power plant in question in each model.

. The following Power plants include;

1. Mosvatn Hydropoer Systems
2. Marvatn Hydropoer Systems
3. Vrangfoss Hydropower Plant
4. Skotfoss Hydropower Plant
5. Klosterfoss and
6. Eidet Hydropower Systems

3.2 EVALUATION OF FMTV MODEL

3.2.1 Overview

The lake and reservoir levels of the FMTV were evaluated based on the FMTV prognosis report issued by OTB. The purpose of the evaluation was to access the performance of the model and where necessary identify the model units with discrepancies and find ways to improve them. The water level prognosis was evaluated for each module unit by comparing the deviation between the observed reservoir and lake level to the FMTV forecasted reservoir or lake levels for both the simulated period and the prognosis period.

3.2.2 Reservoir Tinnsjo

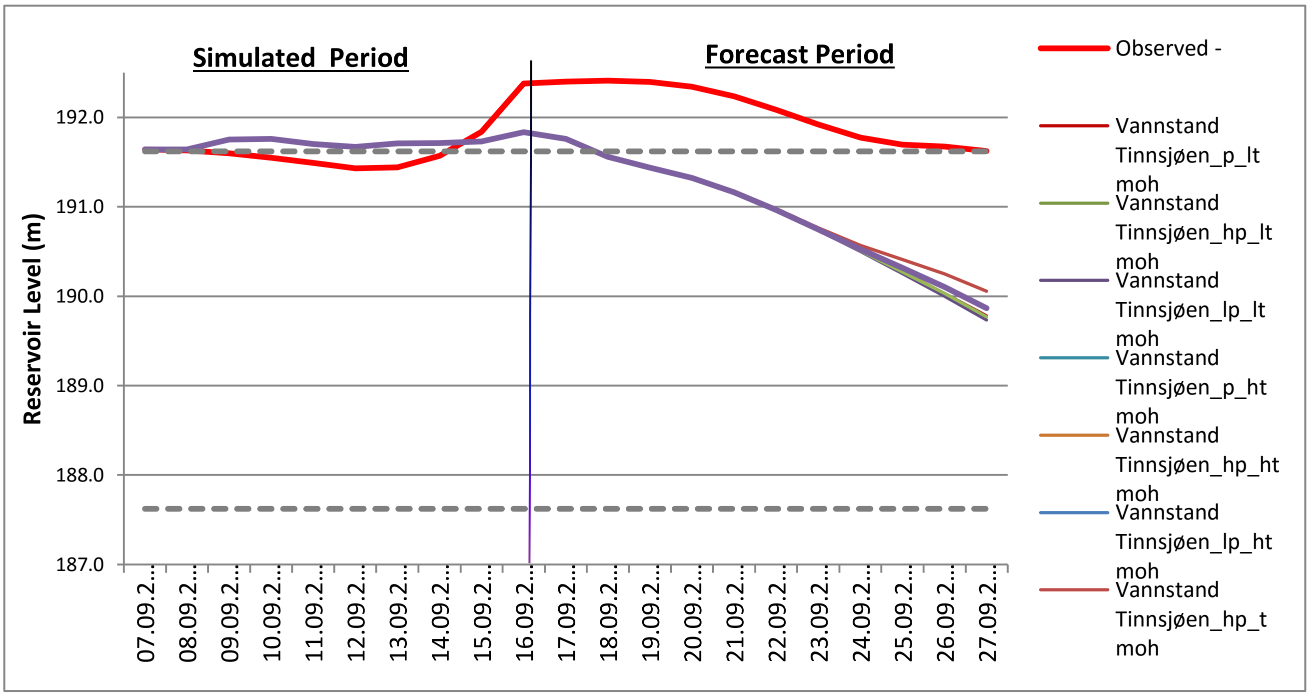

Figure 3-1 Performance check for Tinnsjo

Observed reservoir level for Tinnsjo was obtained collected nve xhydra from the station number 16.7.0 (Tinnsjo) for the period 7th to 27th September 2015. The forecast or prognosis period was from 18th to 27th September 2015. A comparison between the prognosis water level of FMTV report issued by OTB and observed Tinnsjo water level from xhydra station 16.7.0. The simulated period was 7th to 17th September 2015 was included in this plot just to see the goodness of fit between the simulated and observed water level for Tinnsjo just before the prognosis**.** The results of the FMTV performance check for Tinnsjo is shown in the Figure 3-1 above.

These data points were extended to the whole month of September 2015 and comparison between observed and FMTV simulated reservoir level for Tinnsjo was done to evaluate the performance of the FMTV. This is shown in the figure 3-2 below.

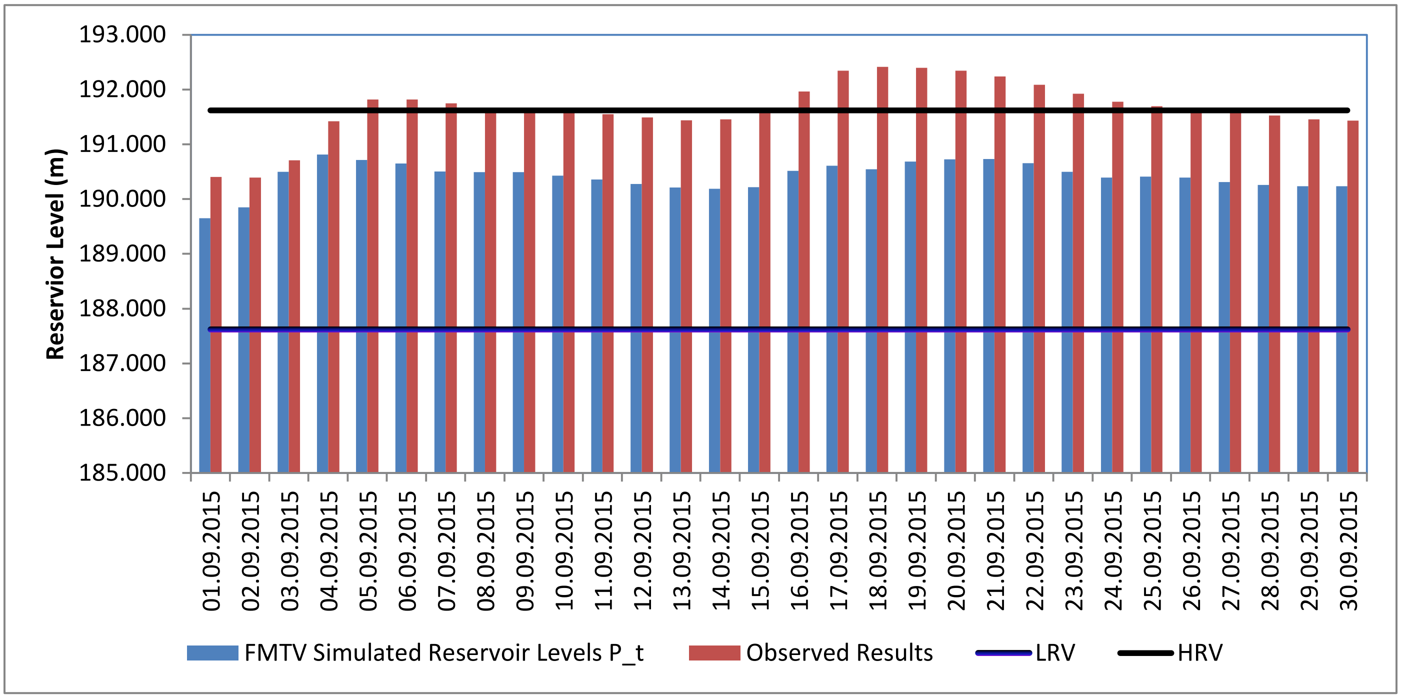

Figure 3-2 Comparison between observed and FMTV simulated reservoir level for Tinnsjo for September, 2015

A plot of the deviation between observed reservoir level and FMTV simulated reservoir levels for Tinnsjo for the month of September 2015 is shown in figure 3-3. This deviation was computed as the difference between the Observed and the simulated reservoir levels for the Tinnsjo for each day. The average deviation for September 2015 was found to be **1.234m**

$$\textbf{Deviation} = \textbf{OBS}_L\ \textbf{(m)} - \textbf{SIM}_L\ \textbf{(m)} \qquad (4)$$

Where OBS_L is Observed Reservoir level in (m) and SIM_L is Simulated Reservoir Level (m)

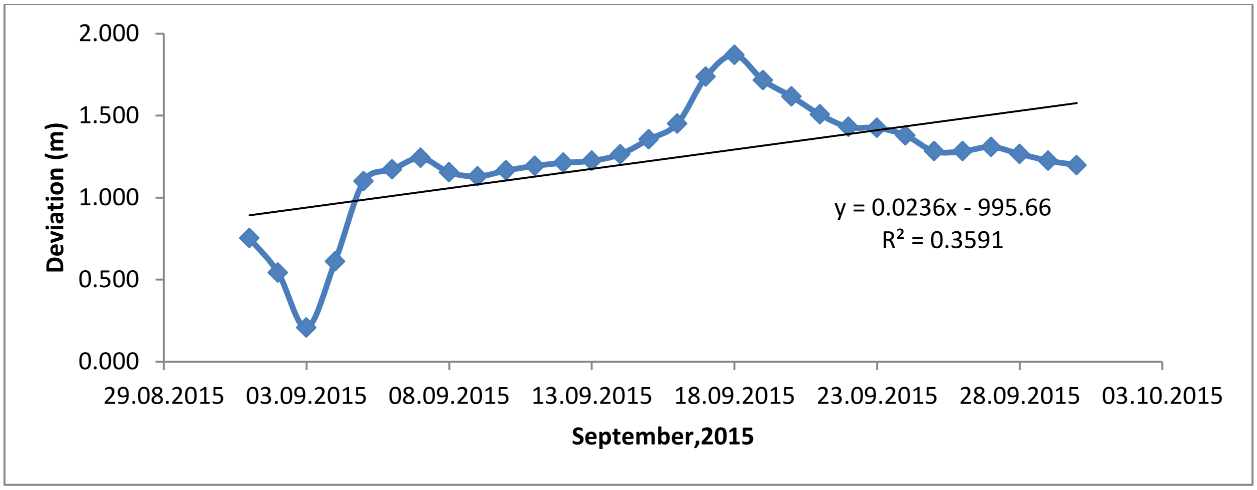

Figure 3-3 Deviation between observed reservoir level and FMTV simulated reservoir levels for Tinnsjo

3.2.3 Heddalsvatn

Performance evaluation was done for Heddalsvatn in the same way as Tinnsjo. This time observed lake level for Heddalsvatn was collected from xhydra station 16.1.0.1000.1 (Notodden) from the period 7th to 27th September 2015. The prognosis period was 18th to 27th September 2015. The results of this analysis are shown in figure 3-4 below. A Comparison between

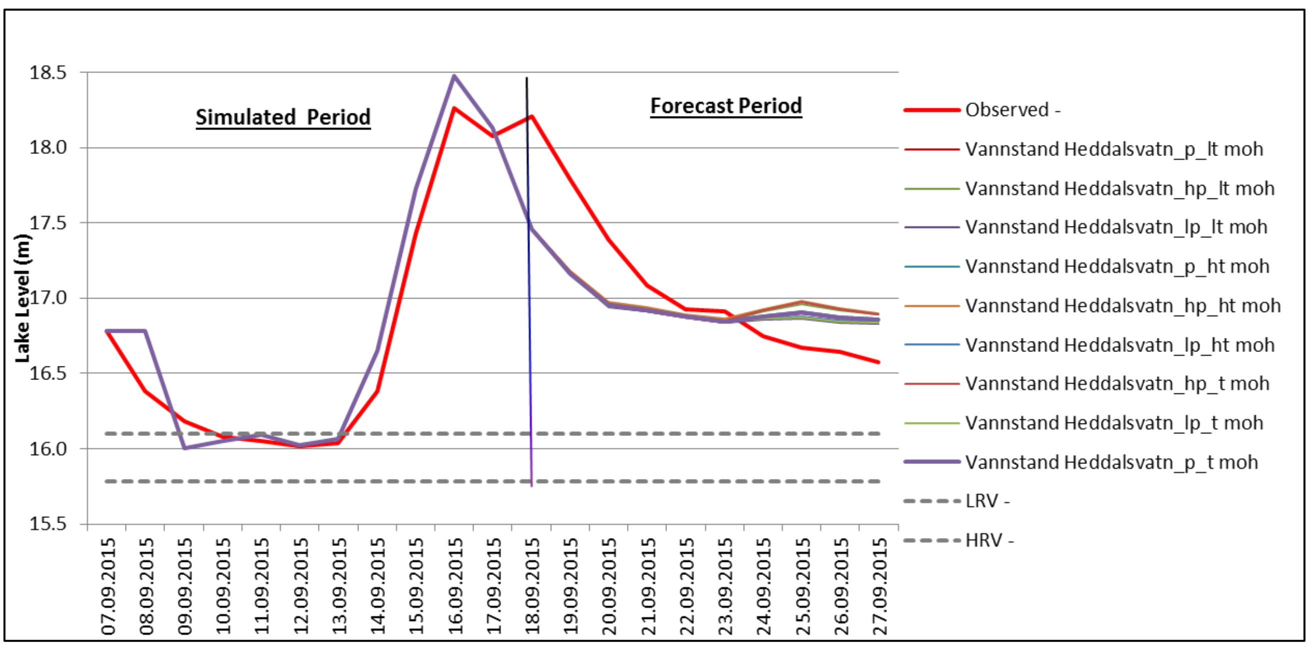

Figure 3-4 Performance check for Heddalsvatn

observed and FMTV simulated reservoir level for Heddalsvatn for September 2015 is shown in figure 3-5

An extension of this data points for the whole of September 2015 made it possible to find the deviations between the Observed and Simulated Lake Levels for Heddalsvatn. The results of this are shown in figure 3.2.3-3

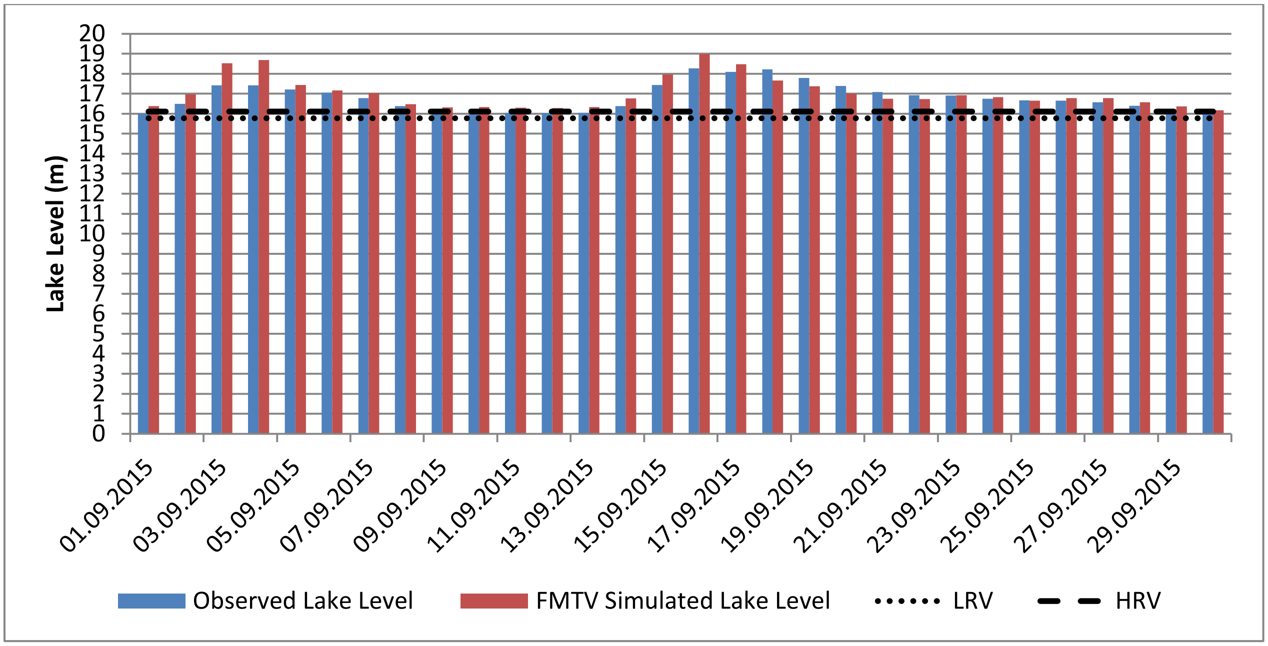

Figure 3-5 Comparison between observed and FMTV simulated reservoir level for Heddalsvatn for September 2015

A plot of the deviation between the observed lake level and FMTV Lake levels for the prognosis and the before the prognosis period (Simulation Period) are shown in figure 3-6 below.

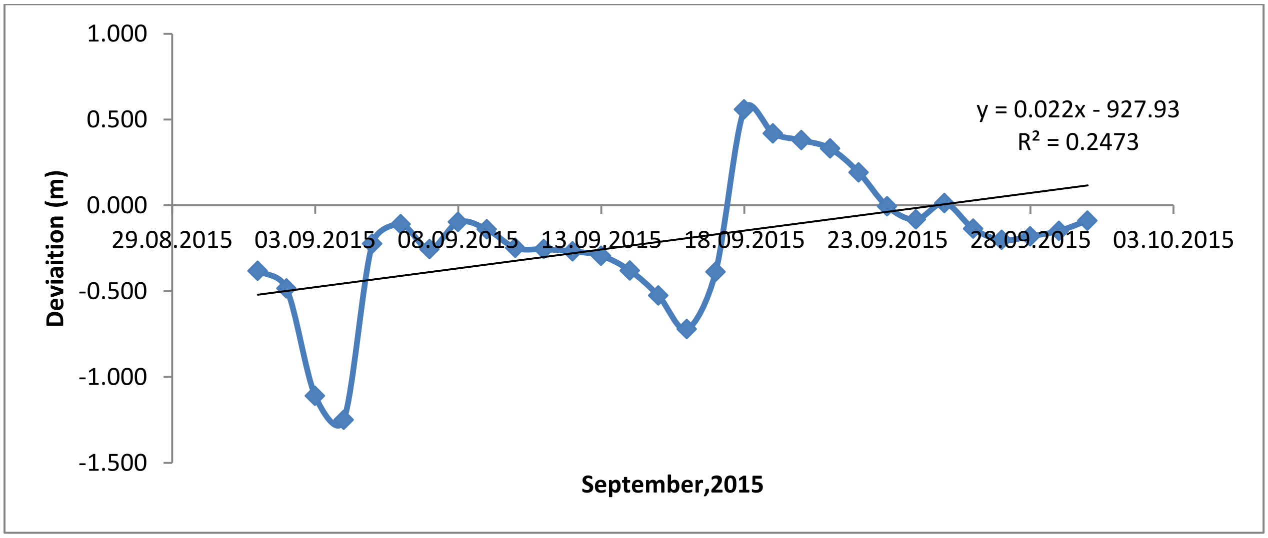

Figure 3-6 Deviation between observed reservoir level and FMTV simulated reservoir levels for Heddalsvatn

3.2.4 Norsjo

Observed Reservoir level was obtained from NVE's xhydra database from station 16.15.0.1000.1 (Norsjø v/Løveid ovf) and compared with the FMTV forecasted Norsjo reservoir water level retrieved from the FMTV report issued by OTB for the period 7th to 27th September 2015. The result of this evaluation is shown in figure 3-7 below. A plot showing the comparison between the observed reservoir levels and FMTV's reservoir levels for Norsjo is shown in figure 3.2.4-2

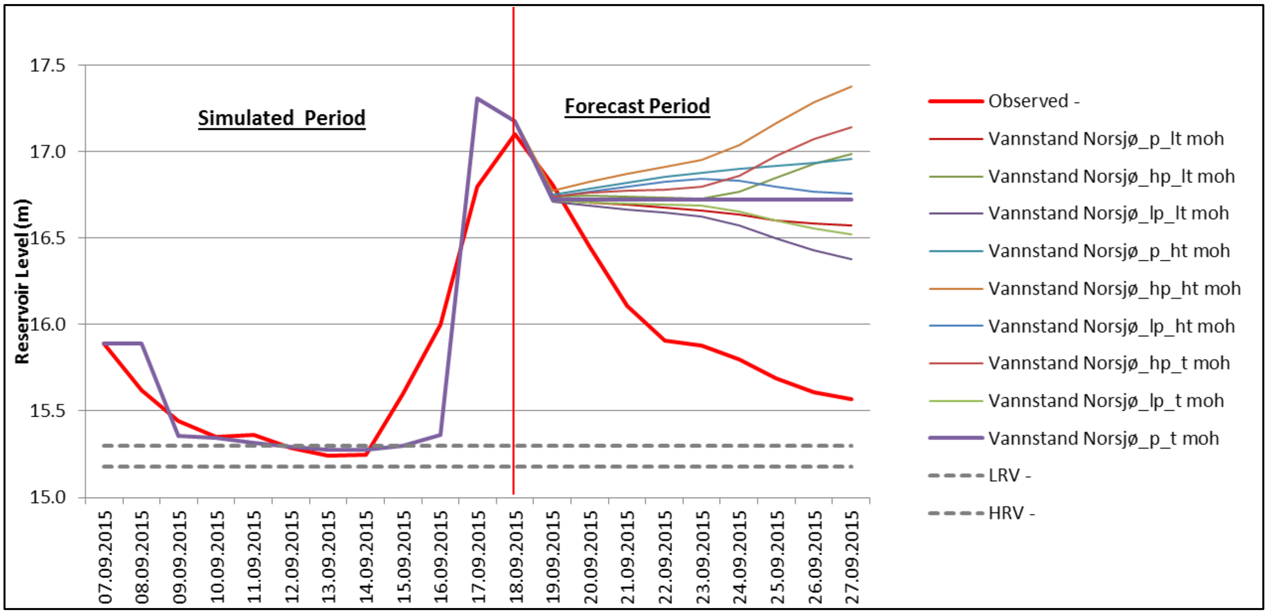

Figure 3-7 Performance check for Norsjo

The data points were once more extended for the September 2015 and the comparison between the Observed Reservoir level and the FMTV Simulated reservoir levels for Norsjo was computed. These are shown in Figures 3-8.

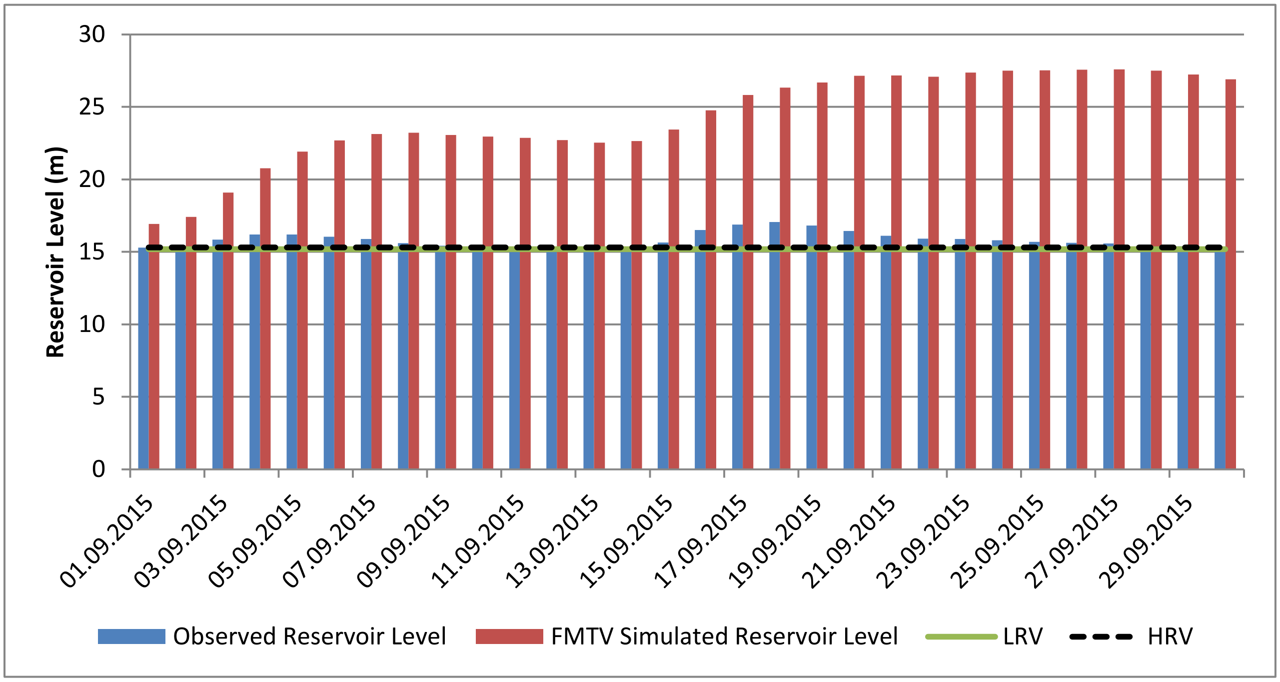

Figure 3-8 Comparison between observed and FMTV simulated reservoir level for Norsjo for September 2015

The plot of the error between the observed and FMTV simulated water levels for the entire period is shown in figure 3-9 below

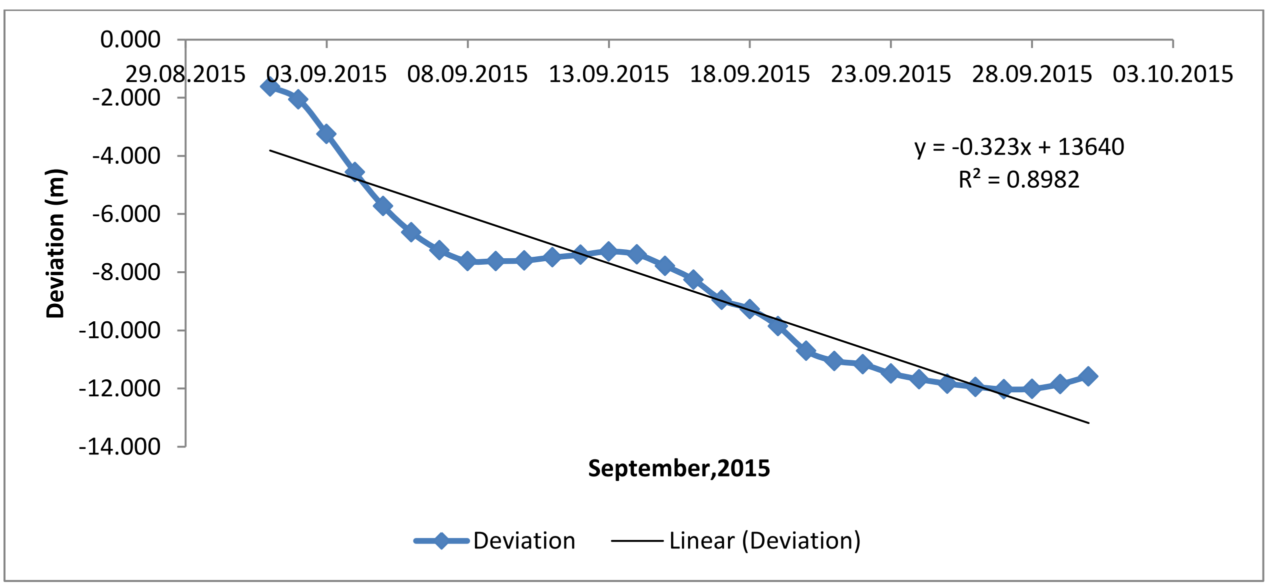

Figure 3-9 Deviation between observed reservoir level and FMTV simulated reservoir levels for Norsjo

3.2.5 Hjellevatn

Reservoir level was obtained from NVE's xhydra database station 16.17.0.1000.1 (Hjellevatn) and compared with FMTV forecasted Hjellevatn reservoir level actual. The simulated period and prognosis period is same for Tinnsjo, Heddalsvatn, and Norsjo. The result of this analysis is shown in Figure 3-10.

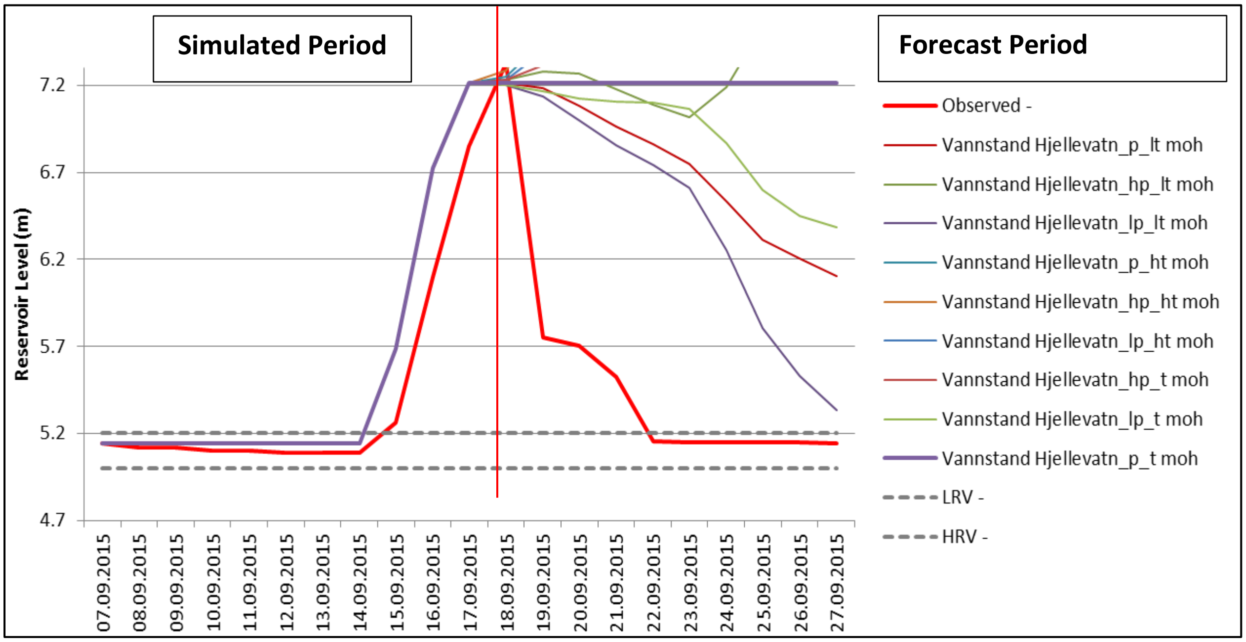

Figure 3-10 Performance check for Hjellevatn

These data points were extended for the month of September 2015 to enable a comparison between the simulated and observed reservoir levels for Hjellevatn. This is shown in Figure 3-11.

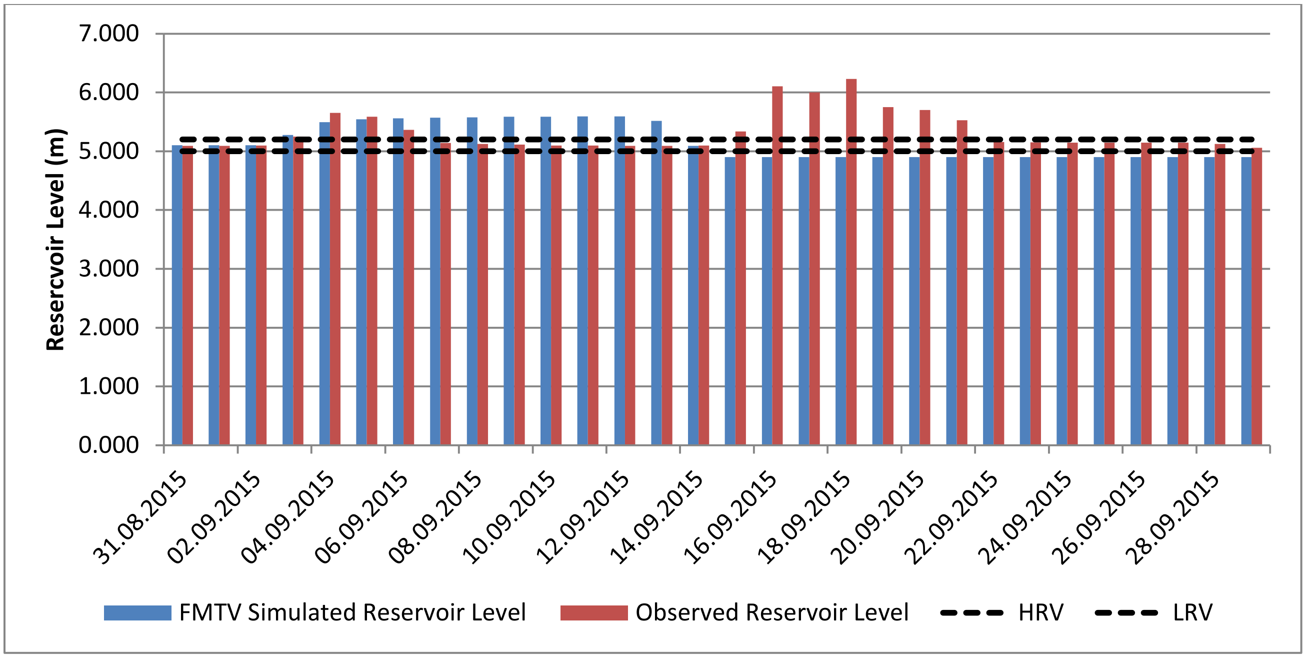

Figure 3-11 Comparison between observed and FMTV simulated reservoir level for Hjellevatn for September 2015

A plot of deviation between the observed and simulated reservoir levels for Hjellevatn is shown in Figure 3-12.

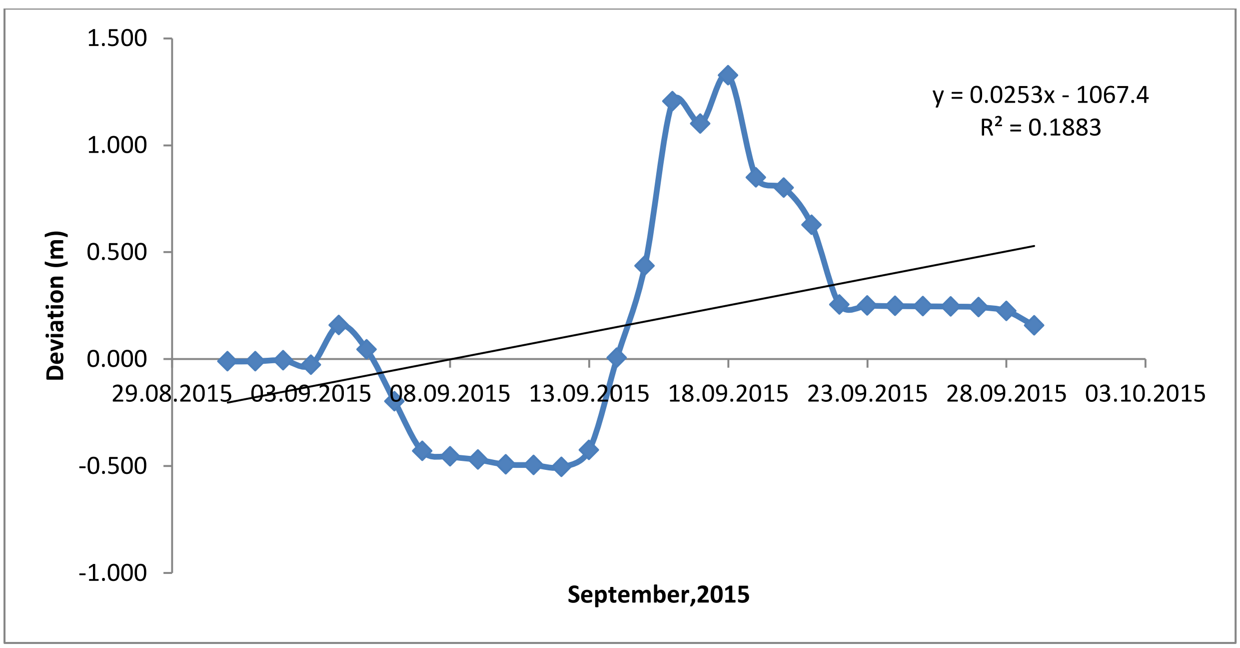

Figure 3-12 Deviation between observed reservoir level and FMTV simulated reservoir levels for Hjellevatn

3.2.6 Discussion and Conclusion

An overview of the general performance after evaluation of each model unit is displayed in figure 3-13. It was seen in figure 3-13 that Tinnsjo and Heddalsvatn gave a better match between the observed and simulated reservoir or lake levels than Norsjo and Hjellevatn.

Tinnsjo, Heddalsvatn, and Hjellevatn showed a generally positive trend in deviation whiles Norsjo showed a negative trend in deviation.

At Tinnsjo, it was observed that the simulated and the observed reservoir levels have a similar pattern but with a significant gap. The gap possibly suggests that some water is lost in the FMTV model or simply the FMTV model has not considered some amount of water that flowed into Tinnsjo. Another possible cause of this could be that the scaling factor or factors used to scale local inflow by the FMTV model were too low.

The simulated lake levels of Heddalsvatn were higher than the observed lake level throughout the period. The problem at Heddalsvatn was suspected to be related to its scaling.

Norsjo showed a significant mismatch between observed and simulated reservoir level throughout the period. The situation at Hjellevatn was similar to Norsjo with a very significant and a complete mismatch between observed and simulated reservoir levels. The problems identified at Norsjo and Hjellevatn were suspected to be caused by errors in the scaling and or errors in either inflow or outflow data readings fed into the FMTV model.

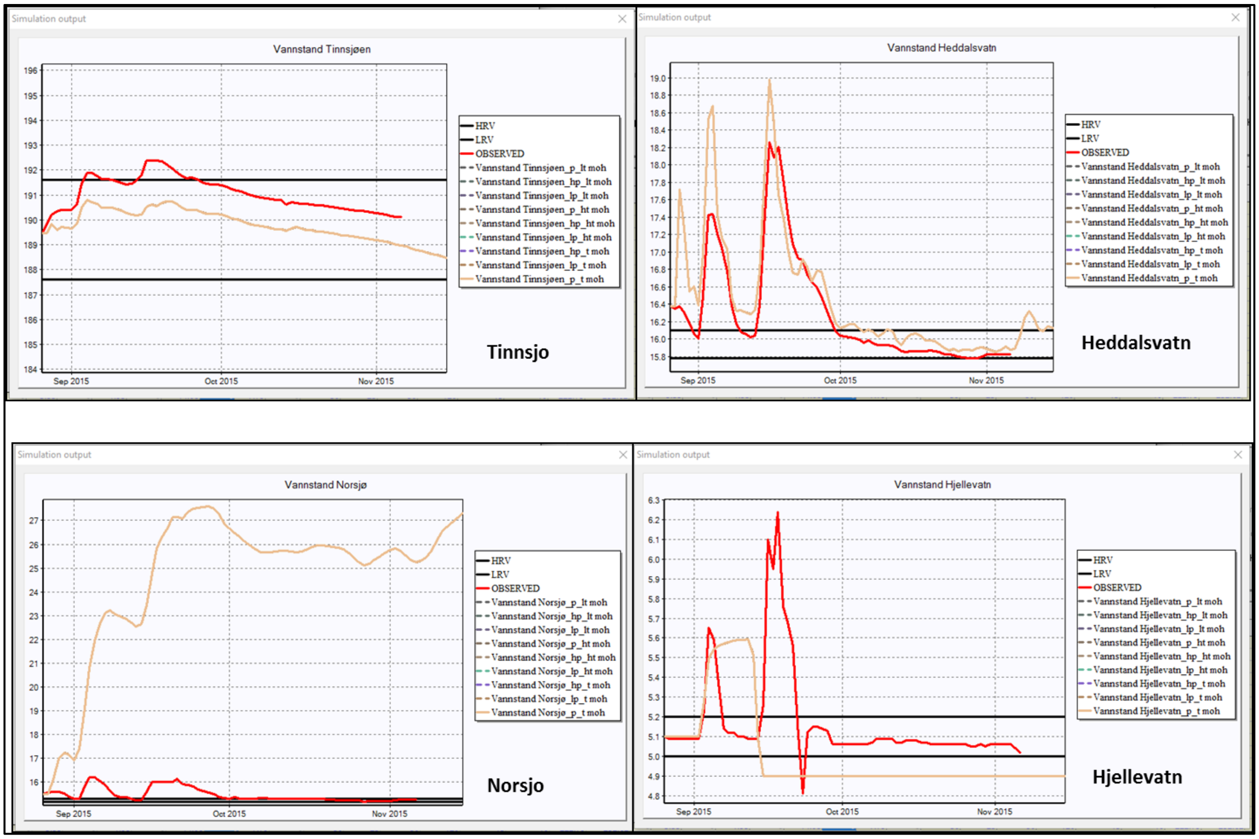

Figure 3-13 Overview of the general performance of FMTV model

In conclusion, all four model units of the FMTV showed some deviation between the observed reservoir or lake level and FMTV's forecasted reservoir or lake level. It can be seen in figure 3-13 that the discrepancy increased as we go in the downstream direction. Tinnsjo and Heddalsvatn showed fairly acceptable results but Norsjo and Hjellevatn showed significantly unacceptable deviation. The focus of my thesis is to focus on the last two model units namely; Norsjo and Hjellevatn.

A proposed strategy to evaluate and increase the performance in the lower part of the model is to carry out a thorough analysis on the hydrology of each model unit according to the September 2015 flood in the Telemark water course. By this, it means to back-calculate all local inflows into each module unit and compare with FMTV model simulations to identify parts of the model that require improvement. Although the evaluation done above indicate that Norsjo and Hjellevatn are the model units with poor performance compare to Tinnsjo and Heddalsvatn, this back-calculation will be done for all the model units to see if their performance could be improved.

The FMTV computed local inflow into each module unit by scaling with one of the three gauged unregulated catchments namely; Austbygdåi, Horte, and Kileai (Mahat, 2006). A strategy to evaluate the local inflow to each model unit will be to compare specific runoff for the local inflow to the specific runoff of Kilea,Horte and Austbygdåi to see which of the three catchments follow best the specific runoff of the local inflow. This will help to tell if the appropriate catchment was used to scale each model unit or not. The newly found better alternatives will be fed into the existing FMTV to see if they improve the models performance.

The FMTV computes the reservoir and lake levels by the method of routing with total inflow and total outflow from each model unit. A strategy to evaluate the reservoir routing for Norsjo and Hjellevatn could help us to evaluate the FMTV simulated reservoir levels. The best alternative would also be fed into the existing FMTV as input to see if it improves the performance of the model or not.

3.3 WATER BALANCE STUDY AND LOCAL INFLOW COMPUTATIONS

3.3.1 Overview

Water balance study was done for each module unit. Based on this, water balance equations were developed for each reservoir and lake. The purpose of this was to help in back-calculating the local inflow into each model unit.

Evaporation has been neglected in this calculation due to their little magnitudes and therefore insignificant influence on the on the Water balance Norway is located in the Temperate region. The local inflow to each reservoir and lake was computed according to equation (5) below (Å. Killingtveit & Sælthun, 1995).

$$Qloc = Qout - Qin + \frac{\Delta S}{\Delta t} \qquad (5)$$

Where Q_{loc} is the total local inflow to the reservoir or lake under consideration(m^3/s)

Q_{in} means total upstream inflow to the reservoir or lake under consideration (m^3/s)

Q_{out} is the total outflow from the reservoir or lake under consideration (m^3/s)

ΔS is the change in storage (m^3)

Δt is the time observation interval (s)

$\frac{\Delta S}{\Delta t}$ is change in reservoir volume or storage per time step.

3.3.2 Water Balance and Local inflow computation for Reservoir Tinnsjo

The regulated known inflows into Tinnsjo are made of inflow from Mosvatn Hydropower Systems and Marvatn Hydropower Systems. Amongst these two inflow systems, Marvatn has a more complex system structure than Mosvatn due to the several small reservoirs in hydraulic contact with the marvatn hydropower system. Details of inflow computation for each system is outlined in the next paragraphs

3.3.2.1 Mosvatn

The inflow from mosvatn power system was computed from the sum of total release from mosvatn reservoir and production flow from Froystul Hydropower Station located downstream of Mosvatn as shown in Figure 3-14.

Mathematically, this is expressed as

$$Q_{\text{inflow mosvatn}} = Q_{\text{release mosvatn}} + Q_{\text{production Froystul}} \quad (6)$$

Where $Q_{\text{inflow mosvatn}}$ is total inflow into Tinnsjo from mosvatn hydropower system (m^3/s)

$Q_{\text{release mosvatn}}$ is release from mosvatn reservoir (m^3/s).

$Q_{\text{production Froystul}}$ is production flow from Froystul Hydropower Station (m^3/s).

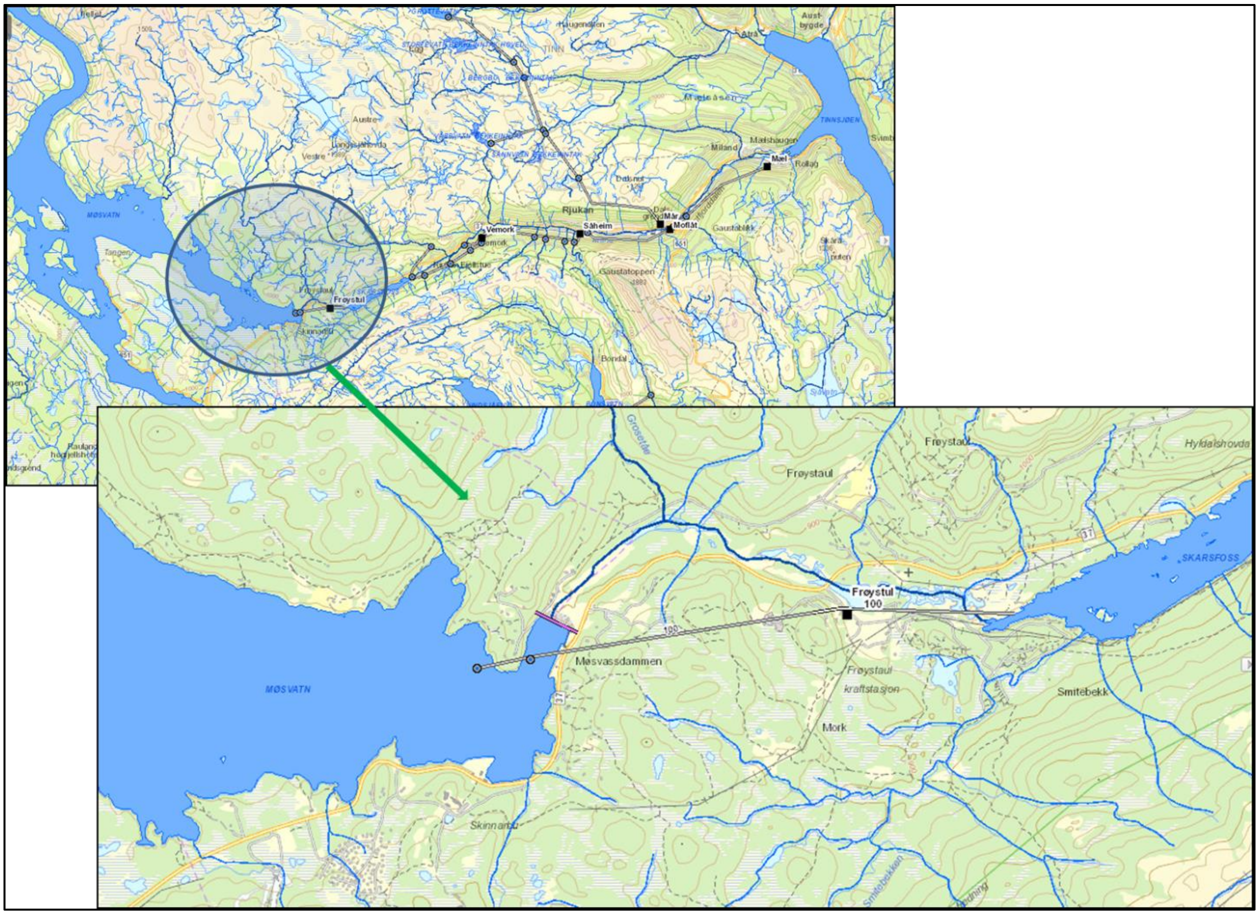

Figure 3-14 Total release from Mosvatn

3.3.2.2 Marvatn

Marvatn Hydropower Sytem has several small reservoirs with the system. The release from Marvatn flows into Kalhovdmagasinet/Strengen. Kalhovdmagasinet/Strengen are two reservoirs in hydraulic contact. This means that the flow between the two reservoirs is strongly influenced by the difference in their lake levels. Kalhovdmagasinet/Strengen releases water to Tinnsjo through two spillways onelocated in Kalhovdmagasinet and the other at the outlet of Strengen.

The mathematical equation used to compute local inflow to Tinnsjo is given by equation 7;

$$Q_{loc} = QT_{tinnsjo} - Q_{marvatn} - Q_{mosvatnet} \qquad (7)$$

Where $QT_{tinnsjo}$ is total inflow into reservoir Tinnsjo (m^3/s).

$Q_{marvatn}$ is total inflow into reservoir Tinnsjo from Marvatn Hydropower System (m^3/s). $Q_{mosvatn}$ is the total inflow into reservoir Tinnsjo release from Mosvatn Hydropower System (m^3/s).

A summarized excel computation of the local inflow to Tinnsjo is shown in Appendix K.

3.3.2.3 Comparing manually computed and FMTV simulated local Inflow into Reservoir Tinnsjo

The local inflow computed manually from the above Eq.7 was compared with FMTV computed local inflow into Tinnsjo. The result of this is shown in figure 3-15 below.

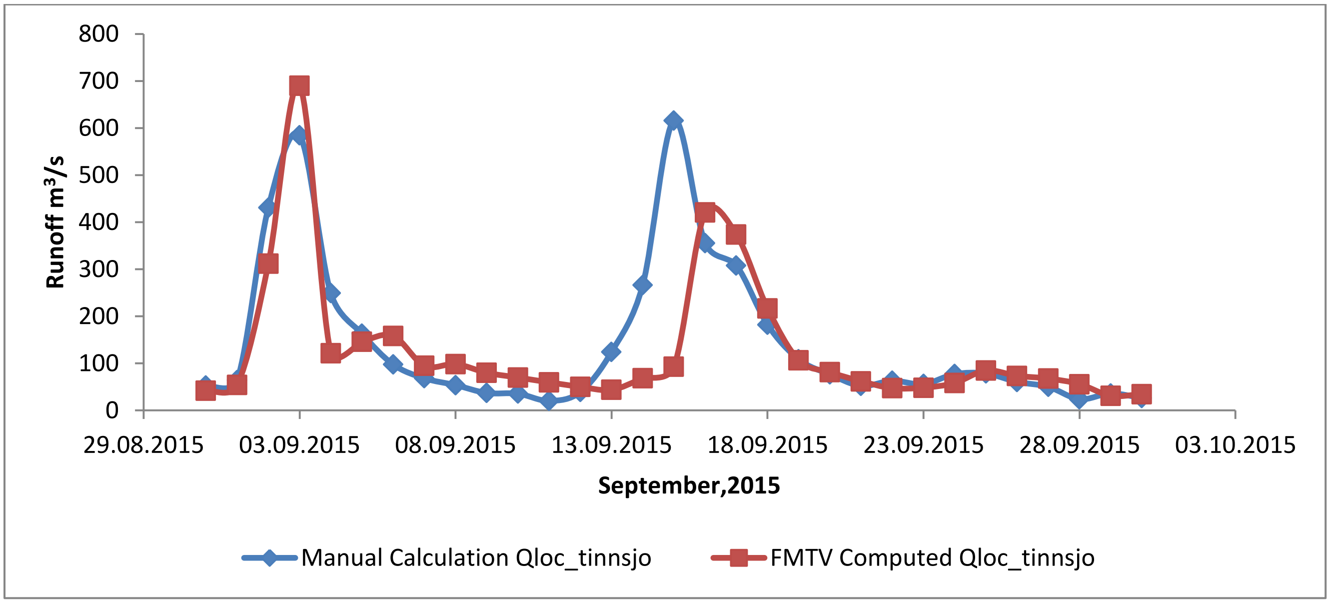

Figure 3-15 Comparing manually and FMTV computed local inflow into Tinnsjo

3.3.3 Water Balance and Local inflow computation for Lake Heddalsvatn

Lake Heddalsvatn is the only lake amongst the four water storage structures in the FMTV model. The inflows to Heddalsvatn consist of flow from Heddola (Q_Heddola), Tinnai(Q_Tinnai) and the local inflow (Q_local_Heddals). Q_Tinnai is the flow from Tinnsjo.

3.3.3.1 Computing daily volume and Change in Storage for Lake Heddalsvatn

The stage volume relationship for Heddalsvatn was derived based on three points in Table 3-3 below. The best line of fit to the plot from three points in table 3-3 gave the Stage volume equation in Eq.8 as shown in Figure 3-16. Only these three points were used because they were the only available data to help generate the daily reservoir volume.

Table 3-3 Stage-volume relationship for Heddalsvatn

Lake Level [m]	Volume [m3]
15	26000000
19	78000000
21	112670000

$V = 722500h^2 - (1*10^7)h + 4*10^7$ (8)

Where V is reservoir volume in m^3

h is lake level

Change in level between two successive reservoir volumes was computed by the difference between final volume (V_f) and initial volume (V_i). Thus

$\Delta V = (V_f) - (V_i)$ (9)

Where ΔV is change volume in m^3

V_f is final volume m^3 for a time step

V_i is the initial volume for the time step.

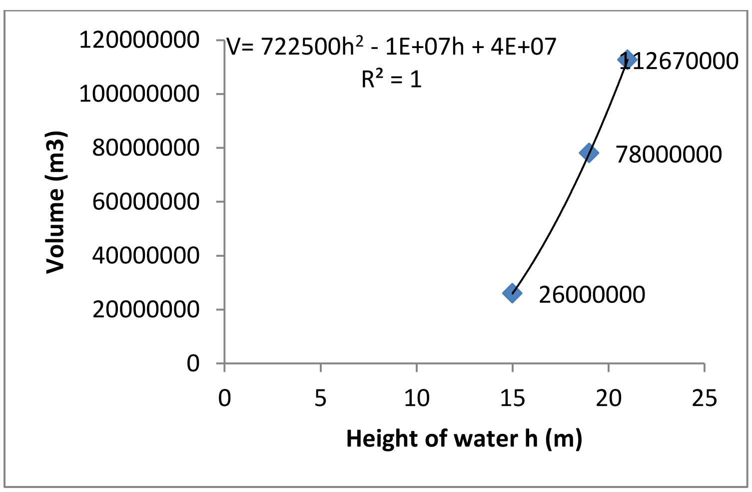

Figure 3-16 Stage-Volume Relationship for Heddalsvatn

3.3.3.2 Computing outflow from Heddalsvatn

The outflow from Heddalsvatn (Q_outflow_Heddals) flows through the river stretch at Saua. This river stretch is shaded with yellow color in figure 3-17 below.

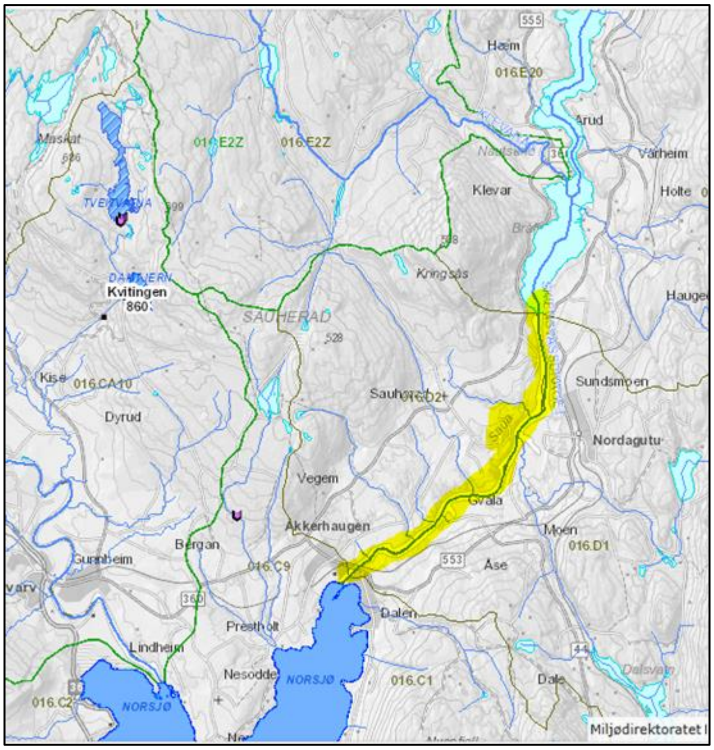

Figure 3-17 River stretch connecting Heddalsvatn to Norsjo

The computation of flow out of Heddalsvatn was very complex because no gauging station exists on the river stretch Saua to give a more reliable and a better control of the flow from Heddalsvatn. Apart from the non-existence of gauging station, the lake Heddalsvatn and the immediate reservoir Norsjo located downstream of Heddalsvatn are in hydraulic contact. This means that the outflow from Heddalsvatn was controlled by the difference between Heddalsvatn lake level and Norsjo reservoir level. The computation of outflow was therefore done by referring to a special graph from a report in Appendix H. The graph shows lake level of Heddalsvatn on the y-axis and Outflow from Heddalsvatn on the x-axis. There are several curves on this graph and each curve is for a specific reservoir level of Norsjo as shown in Appendix H.

The local inflow was computed mathematically by equation 10 found below.

$$Q_{loc\_Heddals} = \Delta V - Q\_{(Tinnai)} - Q\_{(Heddola)} + Q\_{outflow(Heddals)} \quad (10)$$

Where ΔV is change in reservoir volume with respect to time interval (m^3/s).

$Q\_{(Tinnai)}$ is the flow from Tinnsjo (m^3/s).

$Q\_{(Heddola)}$ is the from Heddola (m^3/s).

$Q\_{outflow(Heddals)}$ is the total outflow from Reservoir Heddalsvatn (m^3/s).

The computation of Local Inflow is shown in Appendix I. The local inflow to Heddalsvatn was plotted with FMTV computed local inflow for Heddalsvatn on the same graph to help us to evaluate the performance the FMTV model. This is shown in Figure 3-18.

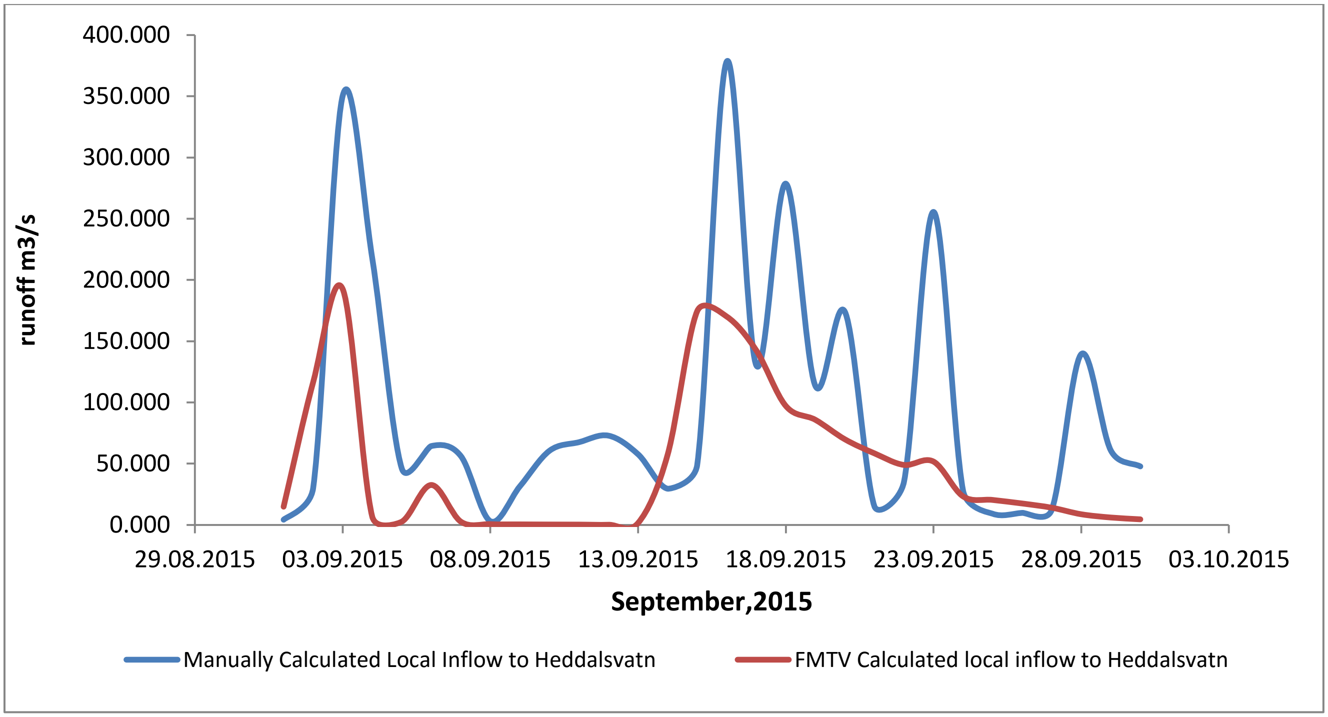

Figure 3-18 Comparing manually and FMTV computed local inflow into Heddalsvatn

3.3.4 Water Balance and Local Inflow Computation for Reservoir Norsjo

A calculation of local inflow into reservoir Norsjo was made to use as a way access and evaluate FMTV's computed local inflow into Norsjo. The calculation was done with the same procedure as Heddalsvatn.

The inflows into Norsjo include; flow from Heddalsvatn (Q_Heddalsvatn), flow from Seljorselva(Q_Hagadrag), release from Vestvatna(Q_Vrangfoss) and the local inflow into Norsjo (local_Norsjo). The outflow from Norsjo was computed from a gauging station located downstream of Norsjo called Farelva (Q_Farelva).

The change in reservoir volume was computed based on a stage-volume curve from NVE's xhydra database. This curve is shown in figure 3-19 below. Fitting the best curve to this curve gave equation (11).

$V = 6*10^7h - 7*10^8$ (11)

Where **V** is reservoir volume in m^3

h is lake level or stage m.o.h

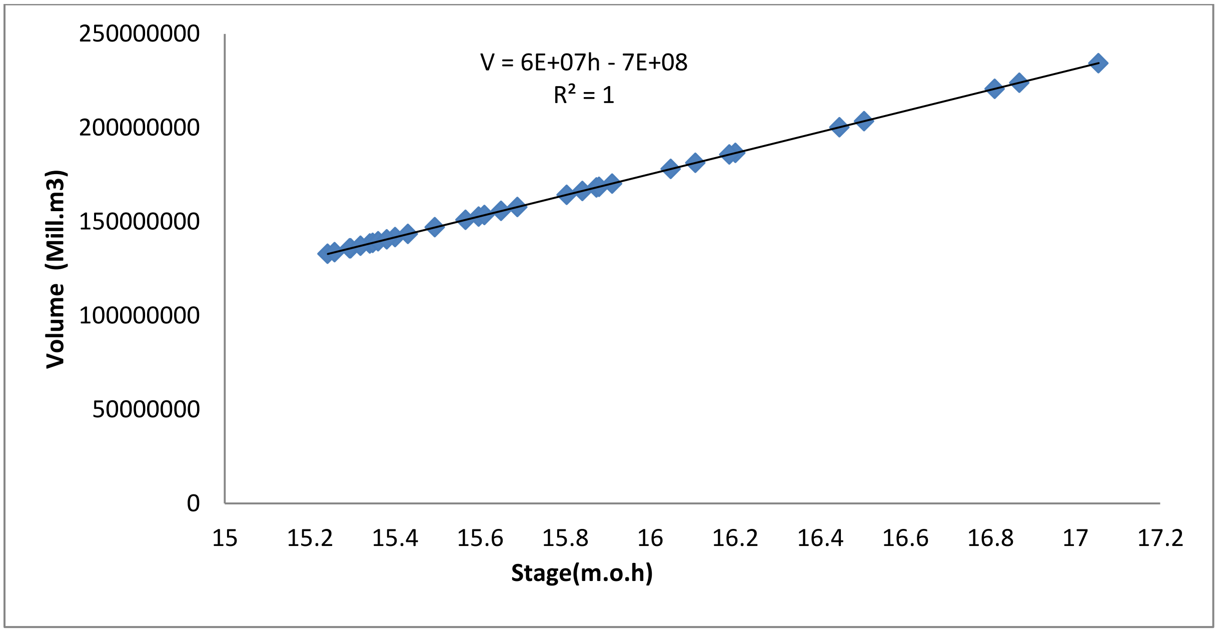

Figure 3-19 Stage-Volume relationship for Norsjo

Change in level between two successive reservoir volumes was computed by the difference between final volume (V_f) and initial volume (V_i) just as was done for Heddalsvatn. The mathematical equation for computing local inflow to Norsjo was

$$Q_{(local\_Norsjo)} = \Delta V - Q_{(Heddalsvatn)} - Q_{(Hagadrag)} - Q_{(Vrangfoss)} + Q_{(Farelva)} \quad (12)$$

Appendix C shows the local inflow computation in Excel

The result of this computation was plotted on the same graph with FMTV computed local inflow to Norsjo. This was done with the aim of evaluating the performance of FMTV .Figure 3-20 shows these plots.

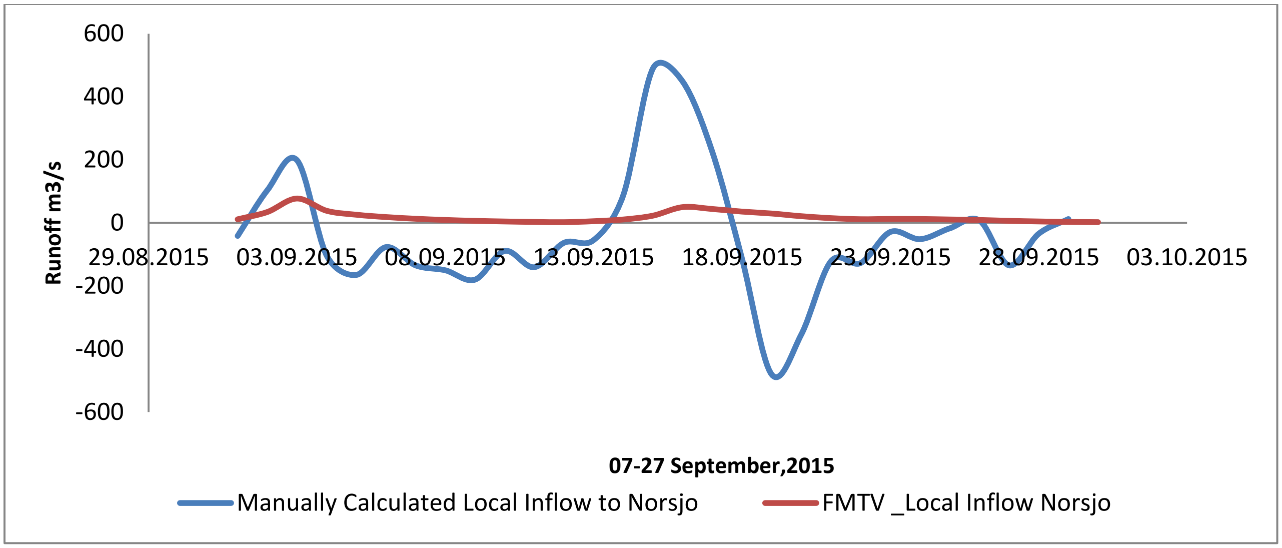

Figure 3-20 Comparing manually and FMTV computed local inflow into Norsjo

3.3.5 Water Balance and Local Inflow Computation for Reservoir Hjellevatn

3.3.5.1 Overview

The local inflow into reservoir Hjellevatn was computed based on its water balance given by equation (13).

$$Q\_local = \Delta V - Q\_farelva + Q\_outflow \quad (13)$$

Where Q_local is the local inflow to Hjellevatn in m^3/s

ΔV is the change in volume in m^3/s

Q_farelva is flow from Farelva station m^3/s

Q_outflow is flow out of Farelva m^3/s

The following subsections explain how each parameter in Eq. (13) was estimated. Q_Farelva was simply downloaded from Farelva gauging station (16.497.0) at NVE xhydra database.

3.3.5.2 Change in Volume (∆V) at Hjellevatn

Evaluation of the Stage/Volume relationship from the system data files of the existing FMTV.

An initial stage-volume data points for reservoir Hjellevatn retrieved from the system data file of the existing FMTV believed to be the basis of the determination of the stage-volume relationship for Hjellevatn was evaluated by simply plotting these data points and testing with the volume of Hjellevatn at highest regulated level (HRV). The volume of Hjellevatn reservoir at HRV was computed as the product of the surface area of Hjellevatn at the HRV and the depth of water at HRV. The surface area for Hjellevatn was found to be **0.44km^2** at a reservoir depth of **5.2 m**. This translated into **2.29mill m^3** of water. The data set retrieved from the system database of the existing FMTV is shown in Table 3-4

Table 3-4 Three data points describing stage-volume relationship for Hjellevatn

3D Volume Curve Hjellevatn	
Lake Level[m]	**Volume [m^3]**
4.9	0
5	0
10	25000000

A plot of these data point and a line of best fit to the resulting curve yielded the stage-volume relationship $V = 5*10^6H - 2*10^7$ (14)

Where V is volume in m^3 and H is reservoir level measured in m.

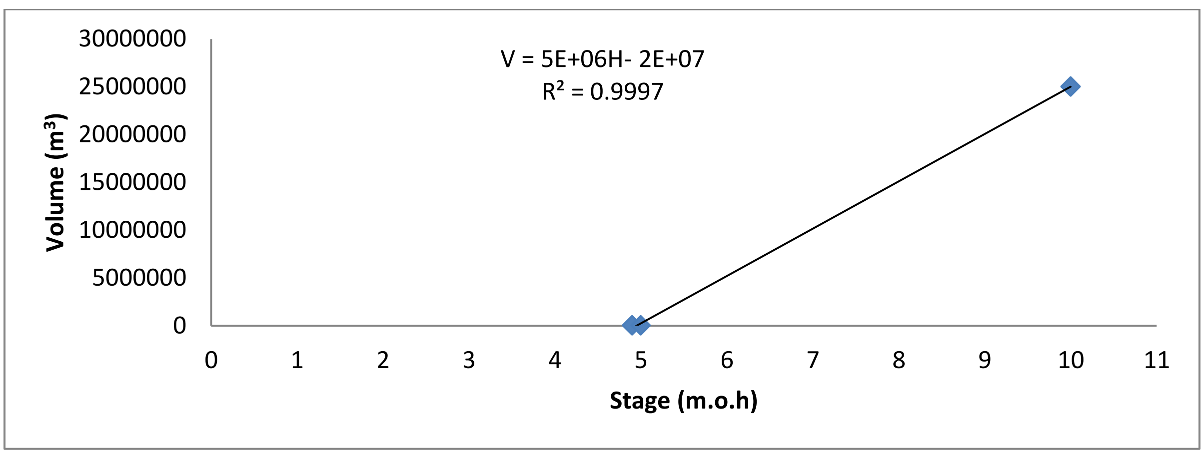

Figure 3-21 Resulting stage-volume curve with data points from Table 3-4.

During testing of the resulting stage-volume equation, the reservoir level at HRV was substituted into Eq.(15) and the resulting volume was 6 mill m3. This 6mill.m3 was found to be significantly higher than the 2.3 mill.m3 which was initially found at NVE hence a new volume/stage for Hjellevatn had to be made.

3.3.5.3 New Hjellevatn reservoir stage/volume curve

The new volume stage relationship was developed from data points from the area of Hjellevatn at HRV and flood inundation maps at Q10, Q100, Q200 and Q500 flood return periods. All these data were acquired from NVE atlas database. The reservoir level and volume of water for flood return periods Q10, Q100, Q200, and Q500 were also calculated and the results of that are displayed in table 3-5 below. The sides of the reservoir were assumed to be continuous inclined so that the reservoir level is proportional to the volume of water in the reservoir. The volume at each flood return period was calculated at the product of the surface area flood water and the average depth of flood water.

The surface area was computed by making equal squares of area 0.5 by 0.5 km2 on the flood maps. The total inundated area for each return was equal to number of squares covering inundated area multiplied by the area of a single square. The average depth of flood water was computed by taking the average of the depth of water between sections 16 and 13 Vannlinjer graphs displayed on each flood map. All flood maps with calculations could be found in appendix J 1, J2, J3 and J4

Table 3-5 New data points for Hjellevatn stage-volume curve

Reference	Reservoir Level [m]	Volume [m^3]
HRV	5.2	2288000
Q10	6.8	14450000
Q100	8.6	21500000
Q200	9	22950000
Q500	10	31250000

A graph of these data points shown in figure 3-22 with a line of best-fit yield a stage-volume function given by $V= 6*10^6H – 3*10^7$, where V is volume in m^3 and H is reservoir level at Hjellevatn in m. Figure 3-22 shows the new stage-volume curve for Hjellevatn

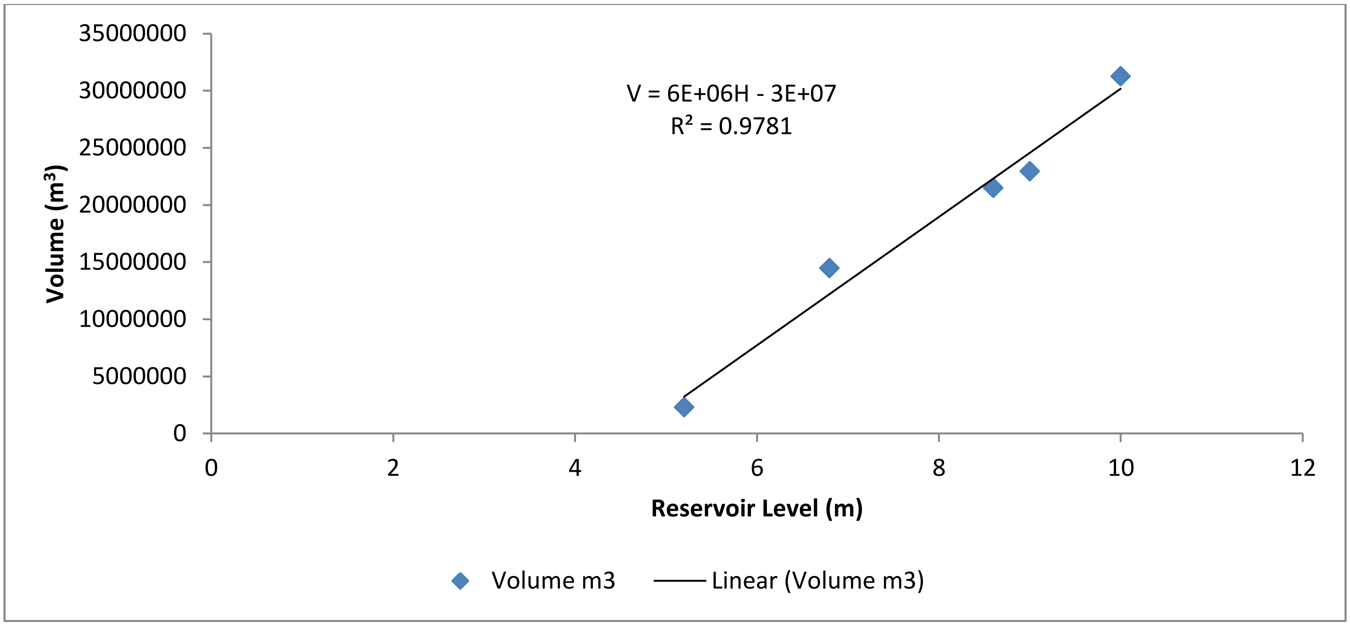

Figure 3-22 New stage-volume curve for Hjellevatn

3.3.5.4 Outflow (Q_outflow) from Hjellevatn

Hjellevatn had a complex outflow. This was because it had three power plants, four gates, a boat lock and lift system, a fish ladder for salmon and other passages for the exit of water during high floods. In all Hjellevatn had eight (8) outlets plus production flow from Eidet Hydropower Systems and Klosterfoss Hydropower Plant. Data on gate opening was not available so it was difficult to estimate the actual amount of flow through the gates. Production flow to Klosterfoss Hydropower plant the largest of the three power plants was also not available. The flow to Klosterfoss Hydropower Plant was computed from its Energy Equivalent (EEKV) and installed capacity found at NVE Atlas database. A constant production flow of 243m3/s to Klosterfoss Hydropower Plant was used throughout the month of September 2015. The production flow for Eidet Hydropower Systems comprising of Eidet 1, Eidet and Eidet 2 Hydropower Plants were available. According to the production flow data for Eidet Hydropower Systems, a total of 60m3/s of water from Hjellevatn was fed to Eidet 1, Eidet and Eidet 2 Hydropower Plants. During the peak of the seconds flood in September 2015 thus from 17^{th} to 29^{th} September 2015 Eidet 1, Eidet and Eidet 2 Hydropower Plant were shut down due to too much inflow.

A stage-outlet capacity curve for Hjellevatn acquired from Norconult was used as the basis of determining the flow of the eight gates at Hjellevatn. This stage-outlet capacity curve from Norconsult assumed a 100% gate opening. The 100% gate opening was maintained and hence used in computations since information from Hjellevatn said the gates were not used during the September 2015 flood. The stage-outlet capacity of Hjellevatn is showed in figure 3-23.

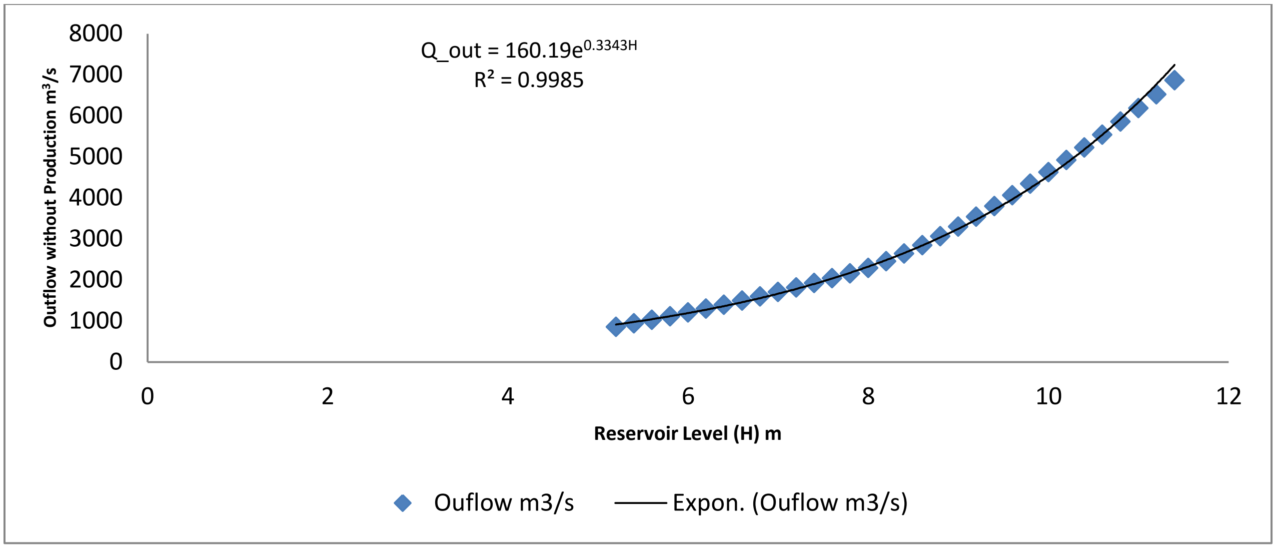

Figure 3-23 Stage-outlet capacity of Hjellevatn

The water level at Hjellevatn is usually kept constant level for all flows below approximated **950m^3/s**. Above this threshold, the reservoir level begins to rise and follow the blue curve in Appendix G. The blue curve is a rating curve which helps to tell the flow at Farelva if the reservoir level at Hjellevatn is known

3.3.5.5 Local inflow (Q_local) for Hjellevatn

The local inflow into Hjellevatn was computed for each time step according to was computed with equation (13). The results of local inflow were compared with river flow measurement at Austbygdåi, Horte, and Kileai for the September 2015. The river flow data for Austbygdåi, Kileai and Hørte were retrieved from NVE xhydra database. Appendix B shows the excel computation of the local inflow into Hjellevatn.

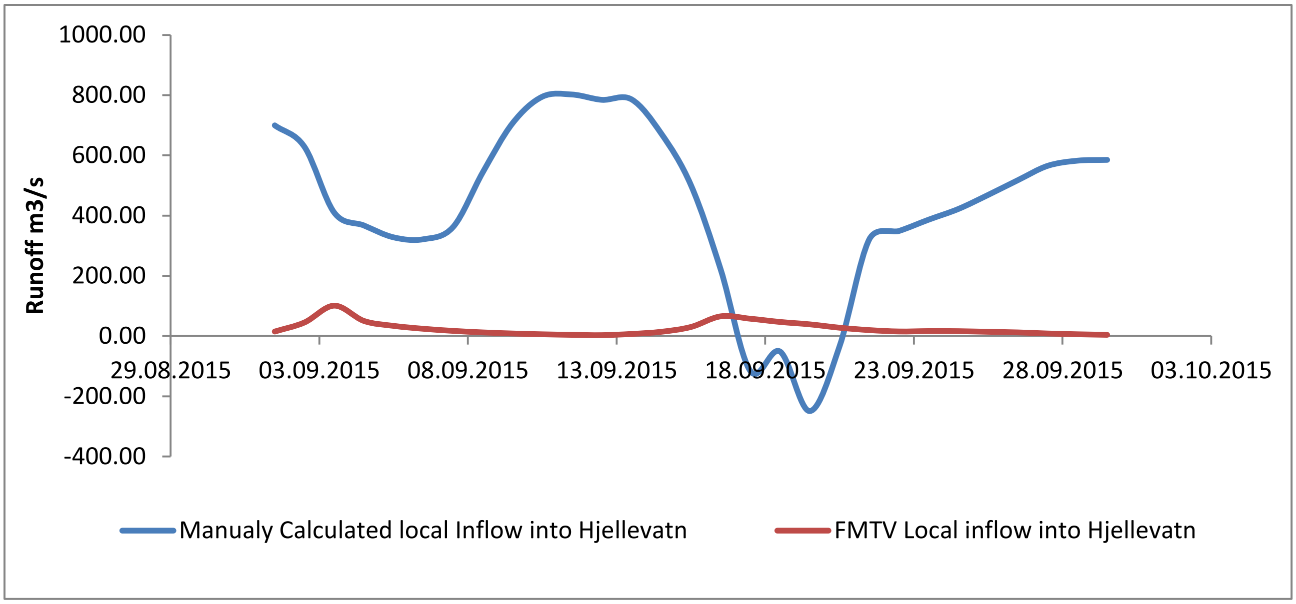

Figure 3-24 Comparing manually and FMTV computed local inflow into Hjellevatn for September, 2015

In figure 3-24, the local inflows into Hjellevatn for September 2015 were plotted with FMTV computed local inflow. The purpose of this was to help evaluate the performance of the model at Hjellevatn.

3.3.5.6 Discussion and Conclusion

- **Tinnsjo**

The results showed by the comparison of manually computed local inflow into Tinnsjo and that of FMTV showed a good match but needs little bit adjustment to give a better match. This manually computed local inflow will give a similar effect on the observed and simulated reservoir level during the evaluation of Tinnsjo. A way to improve the model will be to first check the FMTV model to check the scaling and access if the scaling constants were ok or not.

- **Heddalsvatn**

The manually computed local inflow into Lake Heddalsvatn was significantly different from the FMTV computed local inflow. In general, the manual computation gave a more flow than the FMTV results. The cause of this difference is likely to with the flow out of Heddalsvatn to Norsjo. The flow out of Heddalsvatn was computed from a curve based on the reservoir level at Norsjo and Heddalsvatn because Heddalsvatn and Norsjo are in hydraulic contact. This could lead to some uncertainties in the flow out of Heddalsvatn. An evaluation of this flow and method for computing flow through the hydraulic contact region between Heddalsvatn and Norsjo will require a lot of time and special knowledge not adequately covered in the MSc Hydropower Engineering program hence the flow out of Heddalsvatn was assumed and accepted to be correct . A way to improve the model results at Heddalsvatn would be to verify the scaling and probably alter the scaling factors to get a better match between observed and simulated lake level at Heddalsvatn.

- **Norsjo and Hjellevatn**

The manually computed local inflow to Norsjo and that of the FMTV model showed a complete mismatch with significant local inflow values in the manually computed local inflow. The negative local inflow obtained indicates unphysical values and this necessitated a relook into all data and calculations in the water balance equation of Norsjo. The negative inflow values persisted after checking all calculations and data.

3.3.5.7 Choosing between Farelva and Firingfoss as outflow for Norsjo

A decision was made to replace Farelva gauging station with the outflow from Firingsfoss. Firingsfoss is located in reservoir Norsjo some few meters away from the Spillway of Skotfoss. The outflow from Firingsfoss was computed from the curve in Appendix F. The new inflow replacing Farelva with Firingsfoss was computed as shown in Appendix E

The results of the local inflows both with Farelva as the outflow from Norsjo were plotted with the local inflow with Firingsfoss as the outflow from Norsjo. These two were compared with the FMTV local inflow into Norsjo figure 3-25.

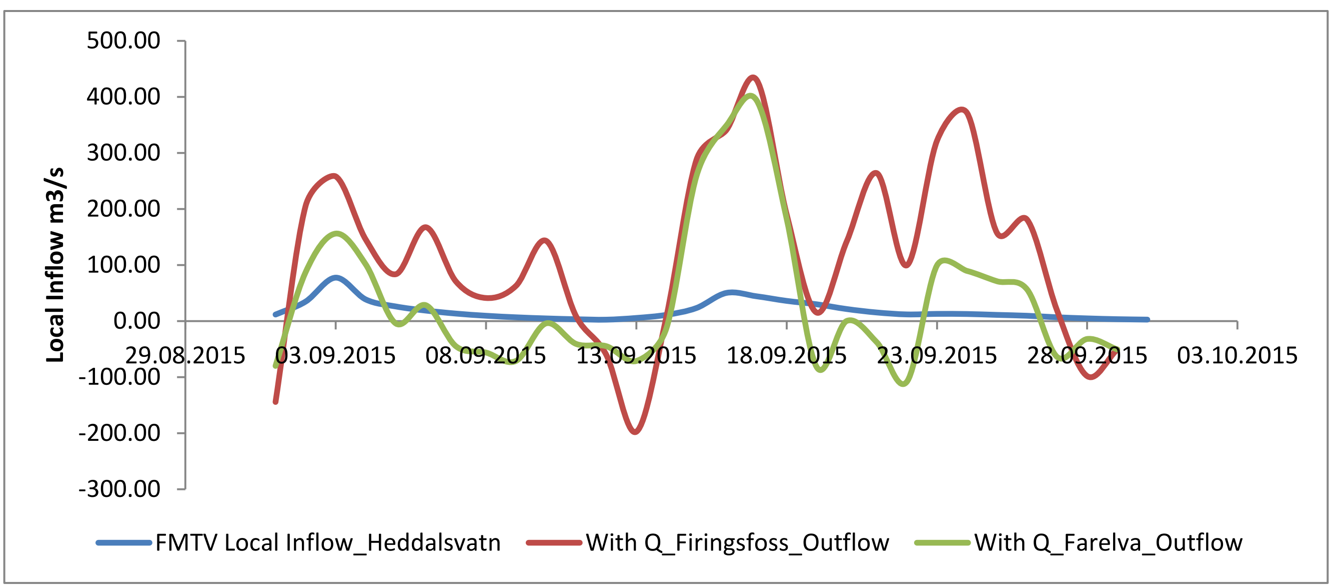

Figure 3-25 Comparing local inflow into Norsjo using Farelva as outflow and Firingsfoss as outflow with FMTV computed local inflow into Norsjo

Fewer negative inflows were present compared to using Farelva as the outflow from Norsjo. To be able to tell between Farelva and Firingsfoss which is the better, the correlations between the specific runoffs of their respective local inflows and the specific runoffs of the three catchments Austbygdåi, Hørte and Kileai could be compared to see which gives the best correlation. The following sub-chapters explain how this was done.

3.3.5.8 Computing Specific Runoff for local Norsjo with Farelva as outflow

The answer to the question *'Does Firingsfoss better measure outflow from Norsjo than Farelva or not*?' was accessed in two scenarios. In the both scenarios, the specific runoff of Local Norsjo was compared the specific runoff of the three donor catchments and the pair with the best correlation was selected as the best. In the first scenario, the local inflow was computed using Farelva as outflow and then after a specific runoff was computed with the help of the local Norsjo catchment area. In the second scenario, Firingsfoss was used as the outflow from Norsjo and the same computations in the first scenario was repeated. The specific runoffs computed from the two scenarios were plotted on the same graph with Austbygdåi, Horte, and Kileai as shown in figure 3-26 below.

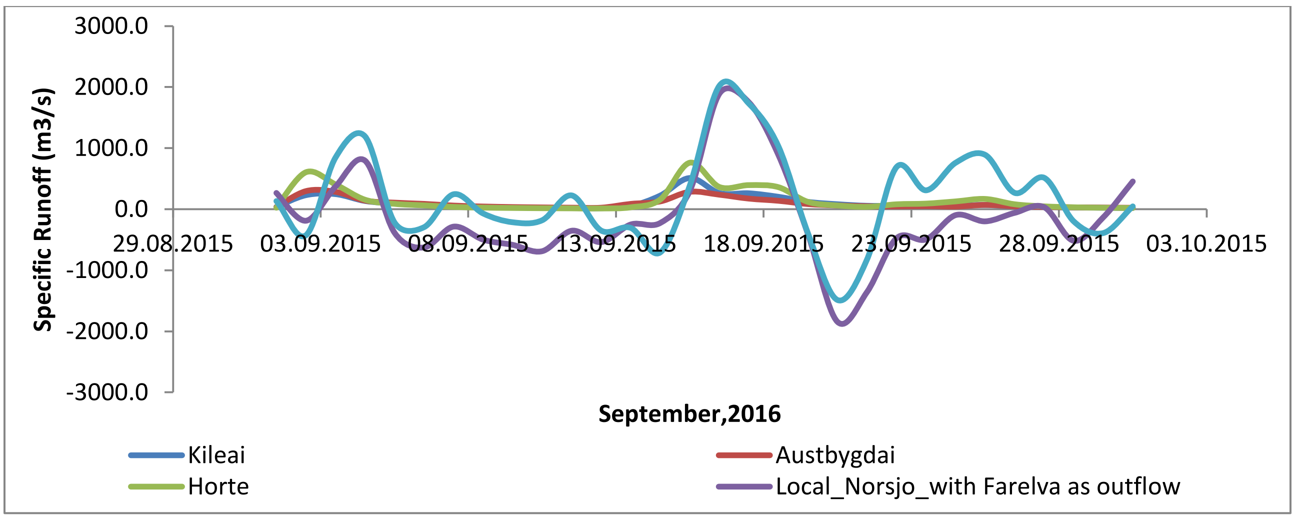

Figure 3-26 Comparing specific runoff of local inflow into Norsjo and the three donor catchments

The results of both scenarios were separately correlated with Austbygdåi, Kileai and Hørte to find the best correlation. The results of the correlations are shown in Table 3-6

Table 3-6 Correlations between specific runoff of local inflow into Norsjo and the three donor catchments

	Farelva (Scenario 1)	Firingsfoss (Scenario 2)
Correlation between Local Norsjo and Kileai	0.506	0.360
Correlation between Local Norsjo and Austbygdåi	0.501	0.364
Correlation between Local Norsjo and Hørte	0.500	0.395

3.3.5.9 Discussion and conclusion

It was seen that scenario 1 had better correlations with the three catchments than scenario 2. Based on these results it's advisable to use Farelva as the outflow from Norsjo instead of Firingsfoss.

The suspicion that the persistent negative local inflow could be as caused by the flow between Heddalsvatn and Norsjo led to a new idea where Heddalsvatn and Norsjo were combined to form one single reservoir. The total local inflow calculations were computed. This was done to eliminate the uncertainty in the flow through Heddalsvatn and Norsjo defined by the curve in figure 3-20.

3.3.5.10 Local inflows computation for combined Norsjo and Heddalsvatn

Heddalsvatn and Norsjo were combined and local inflows computed from the resulting water balance equation . A single water balance equation was developed by summing up all inflows and outflows of Heddalsvatn and Norsjo. Farelva gauging station (Farelva ndf Skotfoss) was used as the outflow from Norsjo due to the results in the previous sub-chapter. The flow between Heddalsvatn and Norsjo was ignored from this calculation. The new water equation obtained was:

Q(local inflow) = ΔVol Hedd_Norsjo - Q_Heddola - Q_Tinnai - Q_Vrangfoss - Q_Hagadrag + Q_outflow_Farelva (15)

The result of combined local inflow into Heddalsvatn and Norsjo was compared with FMTV combine Heddalsvatn and Norsjo flow. The results are shown on the same graph in figure 3-27 below. The computation of this is shown in Appendix A

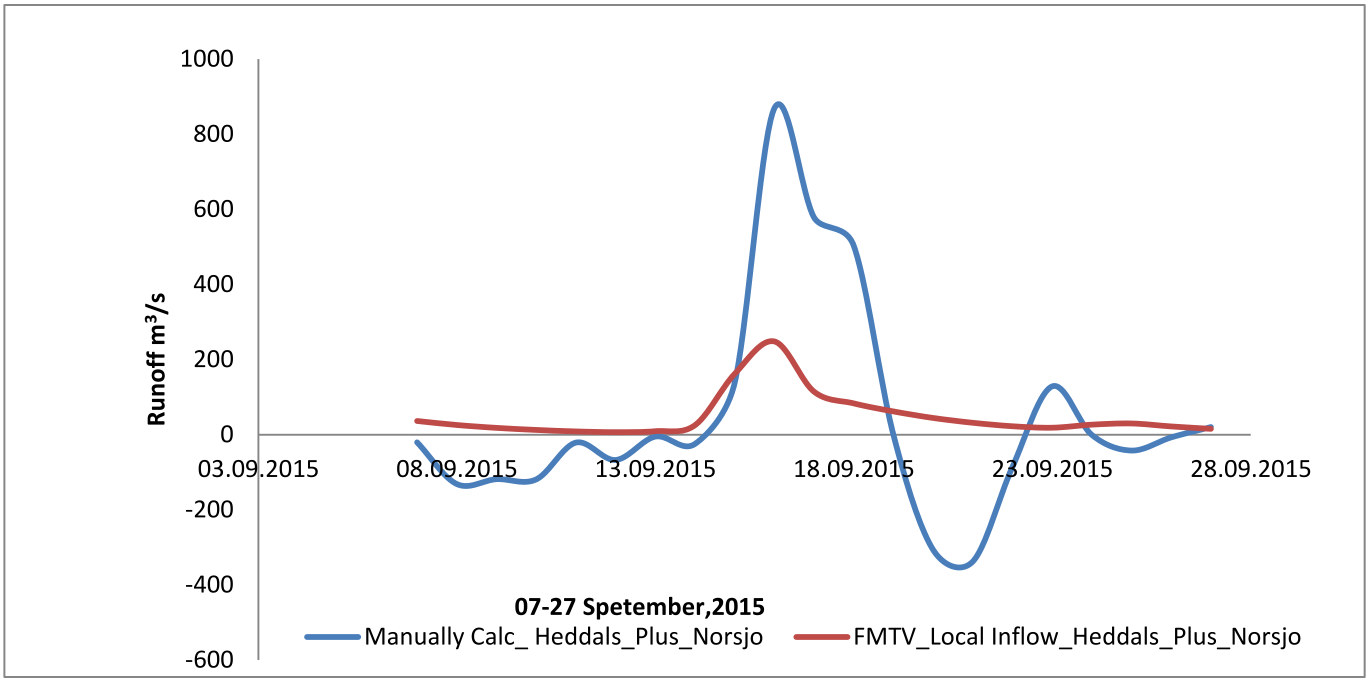

Figure 3-27 Combined local inflow compared with combined FMTV local inflow of Heddalsvatn and Norsjo

3.3.5.11 Discussion and conclusion

The negative inflows still persisted like it was in the single Norsjo and Heddalsvatn local inflow computation. According to Å. Killingtveit and Sælthun (1995) local inflows should not be negative, however, high evapotranspiration from large water bodies or extensive irrigation schemes or river bed infiltration to groundwater could cause negative inflows over short periods. High evapotranspiration is certainly not the cause of this situation because the projected location is in Norway. Norway has very little evapotranspiration since it's located in the temperate zone. In addition to this, there are no intensive irrigation activities from any of the reservoirs or lakes in this project. So, therefore, irrigation could not be the cause of the negative inflows. The only factor that could be the reason for the negative inflows is river bed infiltration to groundwater but unfortunately, there is no data available to accurately evaluate this to prove if this is the case or not.

The flow through Heddalsvatn into Norsjo could also be the reason to the negative inflows but a look into this will require a lot of time. According to a discussion with the main supervisor about re-evaluating the flow through the hydraulic contact stretch between Heddalsvatn and Norsjo, his response was that could be a master's thesis on its own and for that matter, this could not be done considering the short time for completion for this master's thesis and the lack of adequate knowledge.

The inflow into Norsjo from Vrangfoss could also contribute to the negative local inflow computed. There seemed not to be a way to evaluate the flows from Vrangfoss.

The only suspicious flows that could be investigated is the flow measured at Farelva ndf Skotfoss located downstream of Norsjo. A decision was made to check the gauging station Farelva as it was suspected that Farelva station could be faulty thus measuring inaccurate flows.

3.3.5.12 Evaluation of Farelva ndf Skotfoss gauging station

The reservoir Norsjo had two water exit points which comprise plant flow to Skotfoss hydropower plant and the spillway. The spillway had a stage-discharge relationship described by Eq (16). This equation was formulated from a reservoir stage-outlet capacity data for Norsjo as part of the available data for reservoir Norsjo for this master's thesis. Figure 3-28 shows the graph of the relationship between the stage-outflow capacities of the spillway for Norsjo.

$$Q_{\_spillway} = 796.09H-11973 \quad (16)$$

Where $Q_{\_spillway}$ is the outflow from spillway in m^3/s

H is the reservoir level in (m)

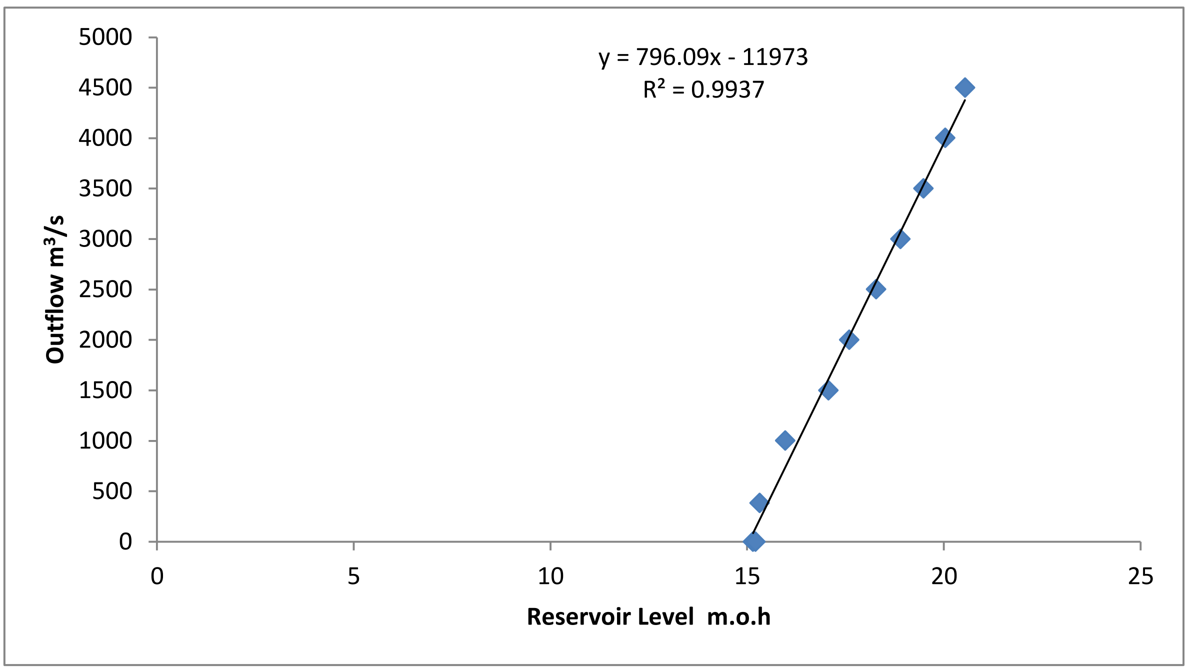

Figure 3-28 Stage-outflow capacities of the spillway for Norsjo

The outlet capacity and flow measured at Farelva was plotted together on the same graph to find out if Farelva measured significantly less flow through the spillway. Farelva is located downstream of the spillway of Norsjo and therefore it was not expected for Farelva to measure less flow than the flow through the spill. If this was so then it meant Farelva was faulty. The results of this analysis are displayed in figure 3-29.

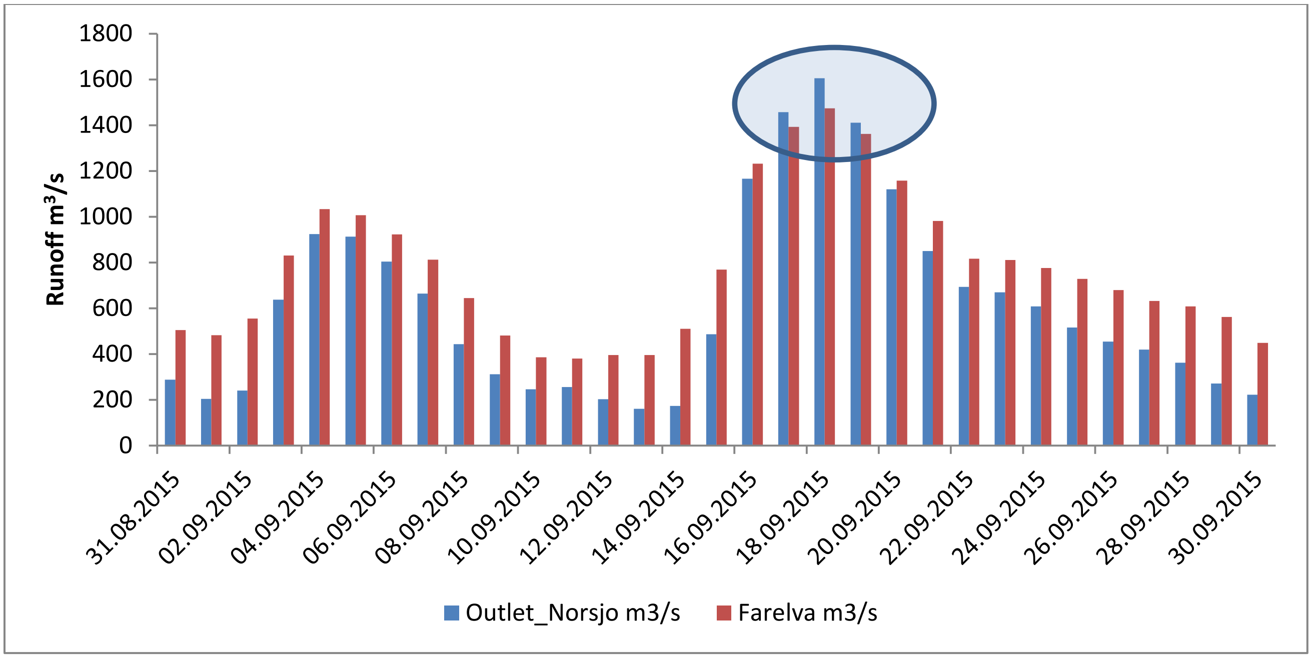

Figure 3-29 Comparing spill from Norsjo to measurements at Farelva

3.3.5.13 Observation and Discussion

It was seen that for all the period in September 2015, Farelva measured more flow than the outlet of Norsjo. The outlet of Norsjo refers to the flow through the spillway of Norsjo. However for the period 18^{th} to 20^{th} September Farelva gauging station measured less water than the outlet of Norsjo. This is not possible as Farelva was always expected to measure more flow than the outlet of Norsjo.

The above results suggest Farelva gauging station could be faulty and therefore more investigations were carried out on Farelva to confirm this suspicion.

3.3.5.14 Re-evaluation of Farelva gauging station from Hjellevatn

Farelva gauging station was evaluated by using the blue curve in Appendix G to compute new inflow data for Farelva (new Farelva readings). The results of this were compared with the initial Farelva data retrieved from NVE xhydra. This is shown in figure 3-30.

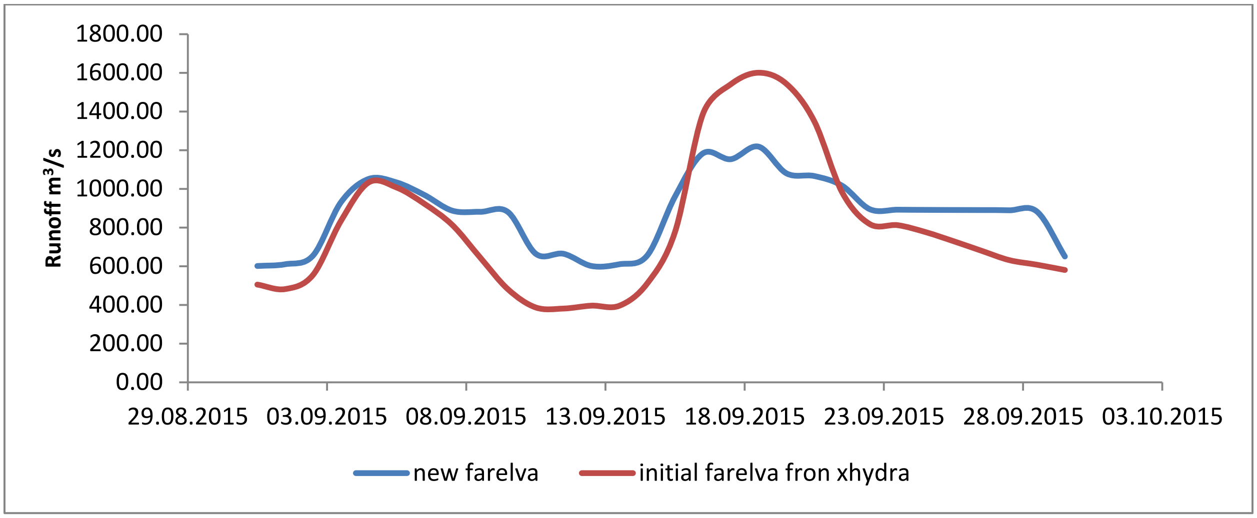

Figure 3-30 Comparing measurements from Farelva ndf Skotfoss gauging station with a new Farelva measurement computed from blue curve in Appendix G

The data series from NVE xhydra database were inspected for the month of September 2015. The results of this are shown in Figure 3-31

3.3.5.15 Observations and Discussion

It was observed that measurements from the NVE station (initial Farelva readings) were lower than the new Farelva readings from the blue curve except during the second flood period where the initial Farelva readings were more than new Farelva reading. This can be seen in Figure 3-30

The data observation during the second flood led to a re-look into the data from NVE for the September 2015 Farelva measurements to see if anything could be found. It was found that that the runoff data for the second flood in September 2016 was computed based on a manual and therefore explains why those readings were different from those measured by the gauging station itself. Figure 3-31 shows the hydrograph of the runoff data from NVE. It could be seen that from 16th to 21st September 2015 a manual correction was done to fill the data likely because the gauging station was inoperative.

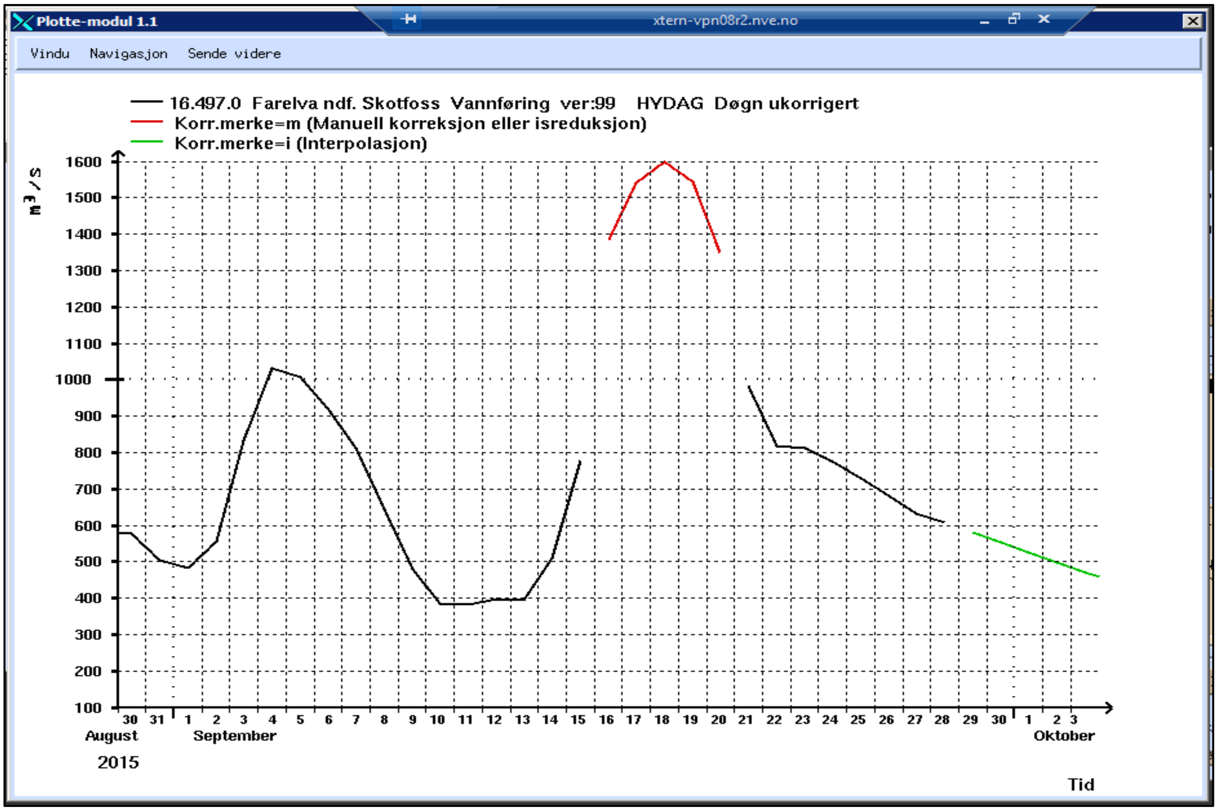

Figure 3-31 Farelva ndf Skotfoss measurements from NVE database

A further assessment of Farelva gauging station was carried out by back calculating the total local into Hjellevatn and comparing to the Farelva and computing the inflow from Falkumelva. Mathematically this would be

$$Q\_total\ inflow = \Delta V + Q\_outflow \qquad (17)$$

Where Q_total inflow is the total inflow to Hjellevatn in m^3/s

ΔV is the change in volume in m^3/s

Q_outflow is total flow out of Farelva m^3/s

Falkumelva is a river that flows into Hjellevatn from the north. The relative position of Hjellevatn with respect to reservoir Hjellevatn and Farelva (shaded yellow) is shown in figure 3-32

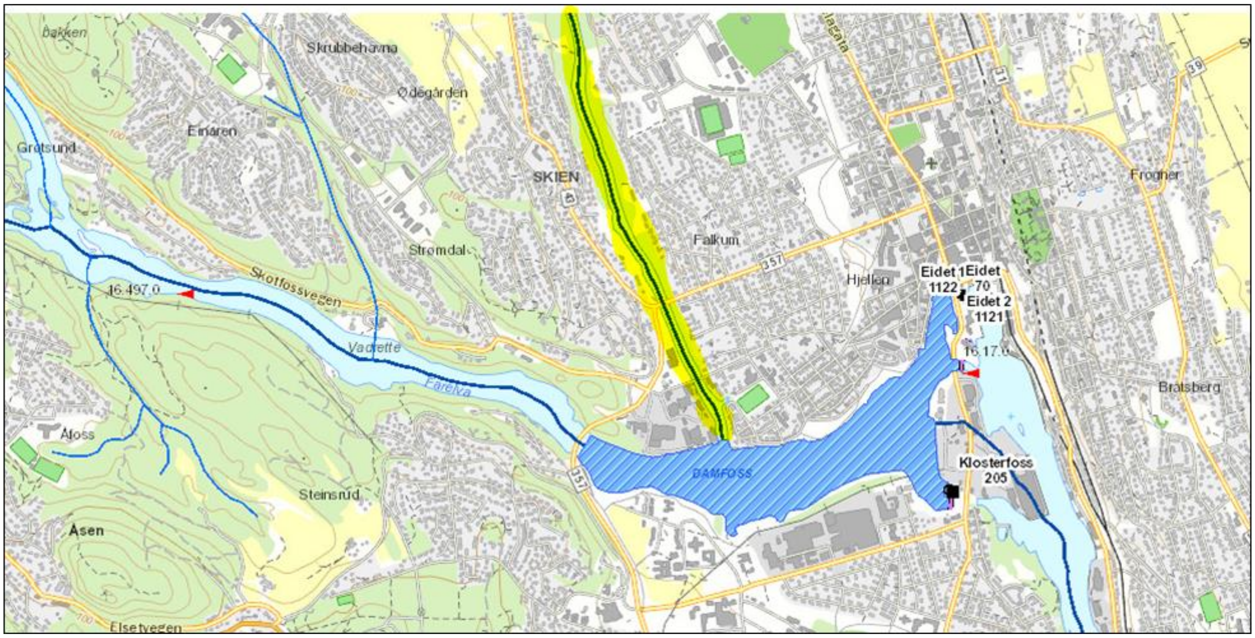

Figure 3-32 Relative position of Falkumelva river (shaded yellow) to Hjellevatn

The total outflow from Hjellevatn, thus spill plus production flow for all hydropower plants were computed from Stage-outlet curve of Hjellevatn and the production flows to the four hydropower plants. These hydropower plants were Eidet 1, Eidet and Eidet 2 Hydropower Plants and Klosterfoss Hydropower Plants. The total production flow for Eidet Hydropower Systems was found to be $60m^3/s$. This plant flow was constant until from 10:42 am on 17^{th} to 20^{th} September 2015 due to too much flow to the power plants which could lead to damage. The production flow to Klosterfoss Hydropower Plant was computed to be **$243m^3/s$** based on its Energy Equivalent EEKV and the installed capacity.

The changes in volume for the daily time step were computed from a stage volume curve shown in figure 3-22. Since there was no stage volume curve available for Hjellevatn one was made by using the flood maps from NVE for return periods 10,100,200 and 500. This also included the average depth of water. These two data sets were then used to compute stage volume curve for Hjellevatn.

The lower part of this stage-volume curve was used to estimate the volume for Hjellevatn with the available reservoir level data for Hjellevatn retrieved from NVE xhydra database. The curve of the lower part is shown in figure 3-32

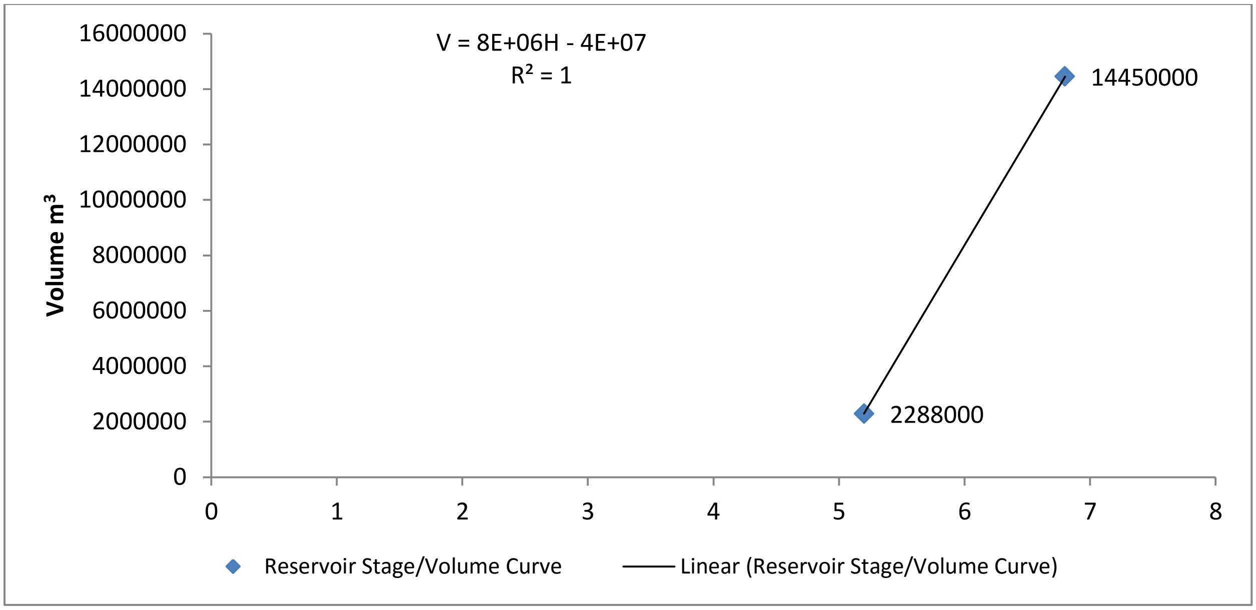

Figure 3-33 Lower part of the new stage-volume relationship for Hjellevatn

The outflow through the 8 gates at Hjellevatn was computed with the equation in figure 3-23.

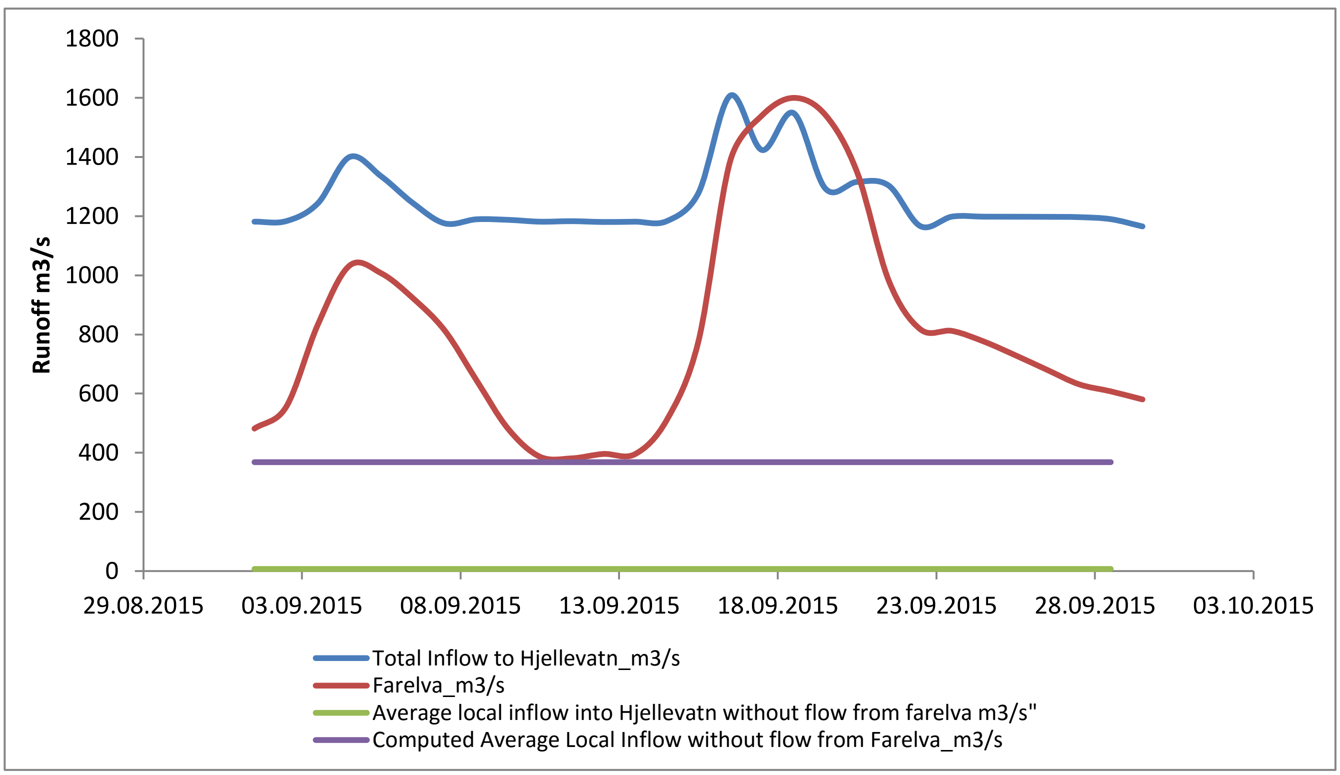

Figure 3-34 Comparing total inflow into Hjellevatn with readings from Farelva

The total inflow to Hjellevatn was computed as the sum of the changes in Volume for each time step and the total outflow computed for each time step. This was same as the equation in Eq (15). The results of this analysis were plotted with Farelva and shown in Figure 3-34.

The inflow into Hjellevatn from Falkumelva and other small streams downstream of Farelva gauging station flowing into Hjellevatn were computed by taking the difference between the total inflow to Hjellevatn and Farelva readings. The average for this local inflow was computed as **368.2m^3/s**. The actual or correct average local inflow into Hjellevatn from Falkumelva and other small rivers in the local catchment of Hjellevatn was computed as **7m^3/s** from NVE Nevina website. This correct average local inflow was computed from NVE Nevina from the sum of the product of the catchment areas and the average specific runoffs for all rivers flowing into Hjellevatn except Farelva.

The total local inflow computed from the back-calculation, Farelva flow, the average flow of **368.2m^3/s** and the correct local inflow of **7.0 m^3/s** were plotted together on the same curve as shown in Figure 3-34. Appendix C shows the computation of total inflow into Hjellevatn from back-calculation.

The difference between the total local inflows and Farelva flows are too much compared to the average inflow from Falkumelva and other small stream flowing into Hjellevatn. This large flow if indeed flowed through Falkumelva and other nearby small streams would have completely flooded Falkumelva and the small streams. In September 2015 there was no report that Falkumelva or any of the small river overflowed. This suggests that this certainly was not the case. The possible explanation to why Falkumelva had such high flows is Farelva was reading lower flows than it should.

It could be seen in figure 3-34 that during the second flood in September 2015 Farelva measure more than total inflow into Hjellevatn. This result seemed impossible because there was no way Farelva flow would be more than total inflow into Hjellevatn. A relook into the Farelva flow data from NVE xhydra database revealed that that happened in the period of manual correction. This was the same period when the flow at Farelva was more than total inflow into Hjellevatn.

NVE was contacted about the accuracy of Farelva station and about why and how the manual correction was done from 16th to 20th of September. A reply from Senior Engineer and Field Hydrologist Trine Lise Sørensen from at NVE explained that during the second flood, the river level rose very high to the level of the station. This necessitated the battery to be removed from the station before the cabinet was filled up with water to destroy the station. The manual correction was done because the index was giving wrong velocities in that period, therefore, NVE workers went into the river and measured discharge in the flood event. The data measured at these times is shown in Table 3-7. According to Trine, NVE used this data in table 3-7 to correct the lost or bad data.

Table 3-7 Measured data points used for manual correction during the second flood in September 2015

Date time	Water level [m]	Q measured [m^3/s]
16.09.15 14:00-14:30	7.42	1308.84
17.09.15 19:56-20:54	8.09	1491.24
18.09.15 08:49-09:05	8.04	1589.36
18.09.15 14:15-14:40	8.05	1507.63

NVE also indicated that Farelva was a station with a long history of trouble with regards to finding a position and the method of measuring the discharge. The position of the station was changed severally in the quest of finding the right spot for taking measurements. The last spot of the station before the second September flood was believed to be a very good spot but unfortunately, that turned out not to be the case because though the station gave good data, a cable in the station was broken twice due to velocity-current in the river. The last accident happened in autumn 2015.

Farelva station has an index instrument that measures the velocity of the river and that was used to determine the discharge. Since 2014, many control measurements Acoustic Doppler Current (ADCP) were done to make a regression to use in determining the velocity. This worked quite well until suddenly it was seen that the discharge from Skotfoss Hydropower Plant increased whiles discharge at Farelva decreased. After an investigation into this, it was found that the velocity (v.1) which is used for calculating the discharge dropped down whiles the velocity (v.3) was getting higher at the same time. NVE initially thought that the vibrations from the current had loosened the nuts on the instrument but upon sending divers down into the river it was found that the nuts were as tight as when it was mounted the first time. NVE decide to send the instrument to the manufacturer in California to have it checked. As of 6th May 2015 there instrument had not returned to Norway. Figure 3-35 shows the when the lower velocities were observed.

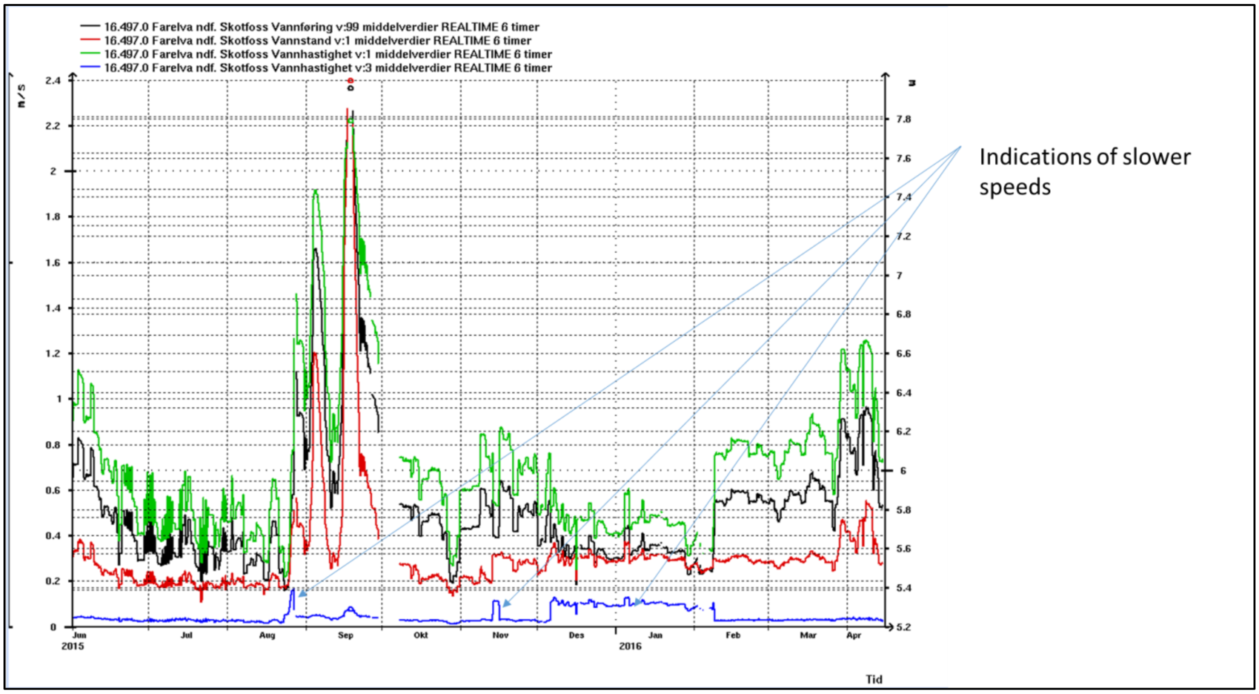

Figure 3-35 Flow measurements at Farelva ndf Skotfoss from NVE showing periods of low velocities observations

The above accounts from NVE about Farelva confirm the suspicions and explain why the negative inflows are present in Norsjo and Hjellevatn. This also contributes significantly to the discrepancies between the observed and simulated results from the FMTV at Norsjo and Hjellevatn.

In conclusion, the fault at Farelva was highly responsible for the poor model performance at Norsjo and Hjellevatn

3.3.6 Site Visitation

During the course of the master's thesis, the project site was visited in two sessions. The first visitation was held on **19th April 2016** and the second on **19th May 2016**. In both visits, Prof. Ånund Killingtveit was the guide. The details of the two visits are described below;

3.3.6.1 First Site Visit

The first visit covered Norsjo and Hjellevatn. At Hjellevatn, the complex gates and intake to Klosterfoss Hydropower plant were visited. Pictures of these place visited are shown in Appendix R1 to R4. At Norsjo, the dam and intake of Skotfoss Hydropower Plant and its complex spillway was visited. The boat lift at Norsjo was seen and pictures of it taken. This picture and others area also found in Appendices. Farelva gauging station was visited and as said earlier the position of the Farelva gauging station relative to the Farelva River was seen. No snow was found in any of the sites visited on 19th April 2016.

During a visit to the Farelva gauging station, it was seen that the gauging station Farelva was located very close to the river. A picture showing the relative position between the Farelva gauging station and the river is shown in figure 3-36.

Figure 3-36 Position of Farelva ndf Skotfoss gauging station relative to Farelva river

The lower measured flow at Farelva compared to the outlet of Norsjo suggests that the gauging station was not reading correctly during the very high flows passing through the river. Initially the location of the gauging station relative to the river seen during the site visitation was thought to strongly confirm the possibility that the water level during the high floods reached the gauging station rendering it inoperative but a separate conversation with **Frode T. grinder Haugen** from NVE revealed that the station was lifted 50cm higher after the second flood even in September 2015.

3.3.6.2 Second Site Visit

The second site visitation covered Heddalsvatn, Tinnsjoen and Mar and Mosvatn Hydropower Systems. Gauging stations Hagadrag, Omnesfoss and Kirkevol Bru. The dams of Skatfoss, Mosvatn and Tinnsjoen were also visited. The catchment Austbygdåi was seen from afar at Tinnsjoen. It was seen that Austbygdåi and some part of the Marvatn and Mostvatn region still had snow as at 19th May 2016 whiles the stretch from Reservoir Tinnsjoen all the way to Skien had no snow. It was like Tinnsjoen all the way to Skien was in summer and the upper parts were still in winter. All picture of this area can be found in Appendix S1 to S4.

3.4 EVALUATION OF SCALING IN THE EXISTING FMTV MODEL

3.4.1 Overview

The scaling in the existing FMTV model was evaluated based on a comparison between specific runoff of computed local inflow and each of the target catchment. This was done separately for each model unit in the FMTV model determines the best donor catchment for scaling. This result was then compared to the scaling the FMTV to objectively criticize the model and where necessary come up with better scaling. The following are scaling evaluation for each lake and reservoir.

3.4.2 Tinnsjo

The FMTV's scaling for Tinnsjo was verified by comparing the specific runoff between inflow series of the local catchment area of Tinnsjo to Hørte, Austbygdåi, and Kileai for September 2015. Catchment area for local Tinnsjo was found to **1403 km^2** from NVE Nevina website. The result of this analysis is shown in figure 3-37.

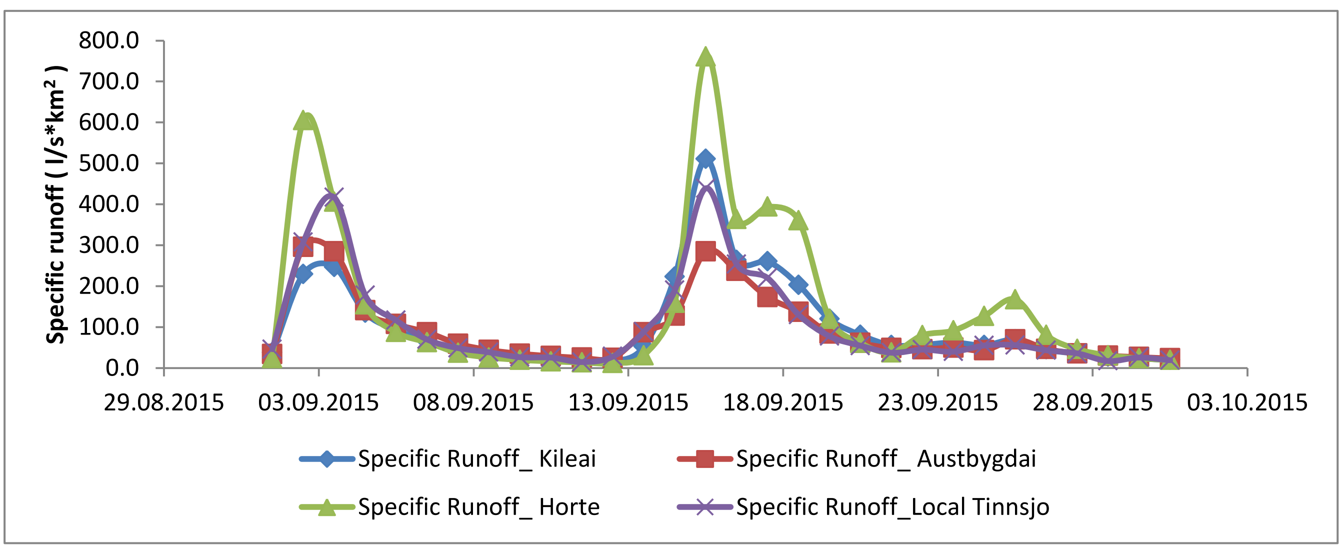

Figure 3-37 Comparing specific runoff f local Tinnsjo to specific runoff of three donor catchments

Table 3-8 shows a comparison of the correlation between specific runoff of local inflow into Tinnsjo and specific runoffs of Kileai, Austbygdåi, and Hørte respectively. It was observed from the results that correlation between local inflow Tinnsjo and Austbygdåi gave the best correlation followed by Kileai and Hørte.

Table 3-8 Correlation between specific runoff of local inflow into Tinnsjo and donor catchments

	Kileai	Austbygdåi	Horte
Local Inflow Tinnsjo	0.9259	0.9718	0.9117

Scaling constants were computed for each day in September 2016 with donor catchment Austbygdåi. The scaling constants varied from **2.30** to **6.24** with an average of **4.06**.

3.4.3 Heddalsvatn

An evaluation of the scaling of local inflow to Heddalsvatn was done by comparing the specific runoff of local inflow to Heddalsvatn and the specific runoffs of Hørte, Austbygdåi, and Kileai. The catchment area for local Heddalsvatn was found to be **732km^2**.The results of this analysis showed in the graph in figure 3-38.

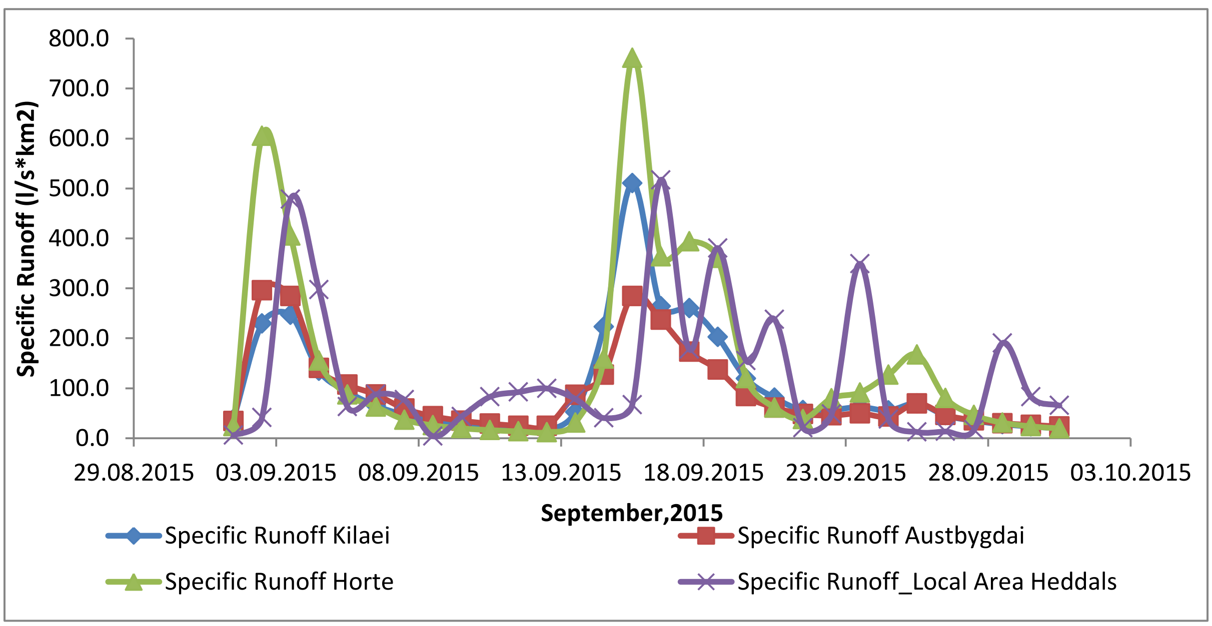

Figure 3-38 Comparing specific runoff f local Heddalsvatn to specific runoff of three donor catchments

Table 3-9 shows the correlation values between specific runoff of local inflow to Heddalsvatn to specific runoff to Hørte, Kileai, and Austbygdåi. The results of the correlations suggest that Austbygdåi is the best donor catchment for scaling local Heddalsvatn inflow. This was followed by Kileai then Hørte. Hørte and Kileai were selected as donor catchments for computing Local Heddalsvatn due to their close proximity to Local Heddalsvatn. The scaling constants for Hørte varied from **0.432** to **53.474** with an average of **12.773** whiles Kileai varied from **0.670** to **42.061** with an average of **11.478**.

Table 3-9 Correlation between specific runoff of local inflow into Heddalsvatn and donor catchments

	Kileai	**Austbygdåi**	**Hørte**
Local inflow Tinnsjo	0.37	0.4663	0.3337

3.4.4 Norsjo

The FMTV's scaling for local inflow into Norsjo with Farelva as outflow was verified by comparing the specific runoff of local inflow into Norsjo to Hørte, Austbygdai, and Kileai for September 2015. Catchment area for local Tinnsjo was found to **258 km^2** from NVE Nevina website. A comparison between the specific runoff of local inflow into Norsjo and the three donor catchments is shown in figure 3-39. The correlations between specific runoff of local Norsjo and three donor catchments are shown in Table 3-10

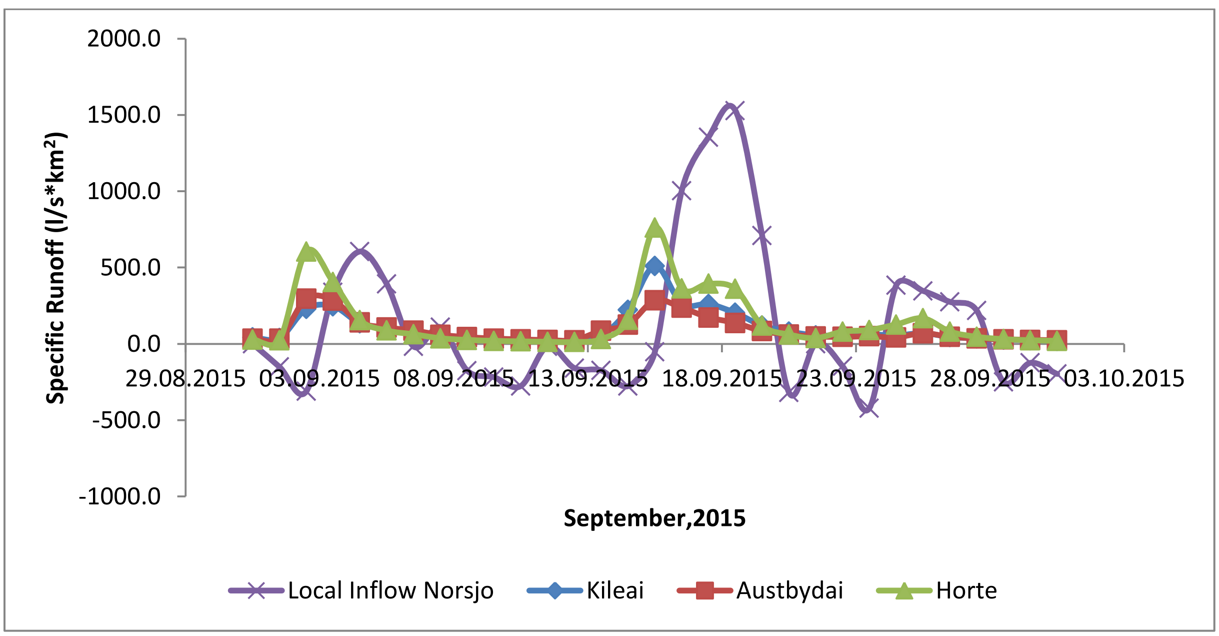

Figure 3-39 Comparing specific runoff f local Norsjo to specific runoff of three donor catchments

Table 3-10 Correlation between specific runoff of local inflow into Norsjo and donor catchments

	Kileai	Autsbygdai	Horte
Local inflow Norsjo	0.3762	0.350	0.3788

3.4.4.1 Combination of Heddalsvatn and Norsjo with Farelva as outflow

The FMTV's scaling for local inflow into Norsjo with Farelva as outflow was verified by comparing the specific runoff of local inflow into Norsjo to Horte, Austbygdåi, and Kileai for September 2015. The total catchment area for local combine Heddalsvatn and Norsjo was found simply by summing up local area for Heddalsvatn and Norsjo, thus **732km^2 +258km^2= 990 km^2**. The results of specific runoff comparison with that of donor catchments are shown in figure 3-40.

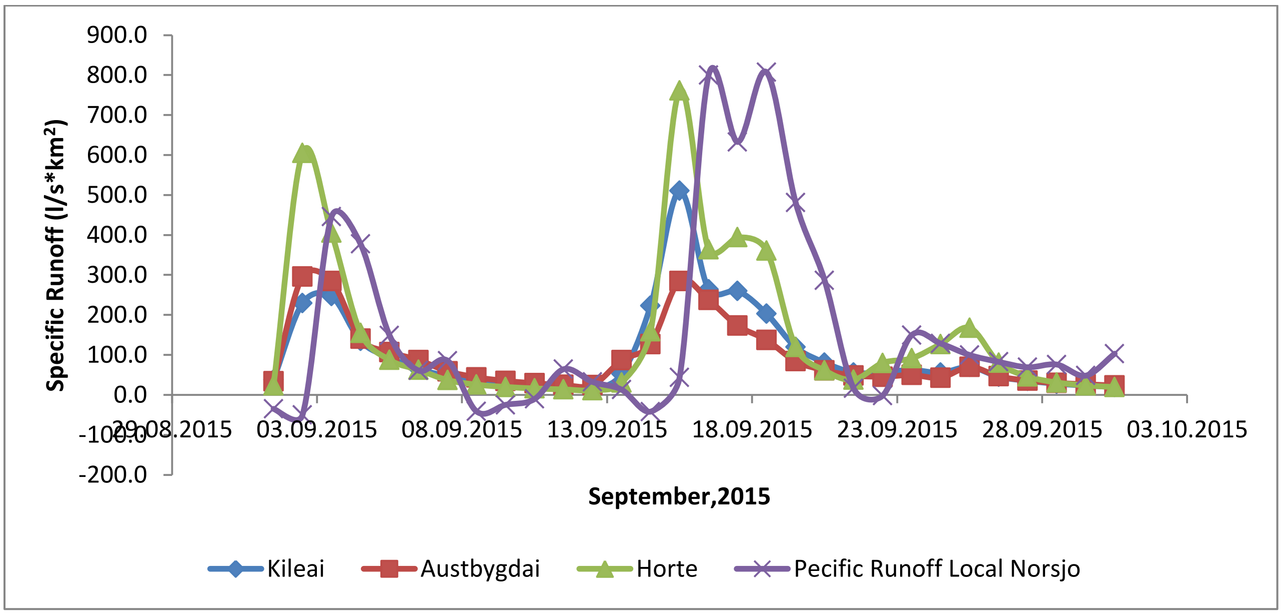

Figure 3-40 Comparison between combined specific runoff f local Heddalsvatn_Norsjo to specific runoff of three donor catchments

The correlations between specific runoff of local Heddalsvatn_Norsjo and three donor catchments are shown in Table 3-11

Table 3-11 Correlations between specific runoff of combined local Heddalsvatn_Norsjo and three donor catchments

	Kileai	Austbygdåi	Horte
Local inflow Norsjo	0.4256	0.4303	0.3863

The scaling constants for Norsjo for both scenarios for each day in September varied from -21 to 13.58. The negative scaling was due to the negative local inflows.

3.4.5 Hjellevatn

The manually computed local inflow to Hjellevatn was compared to that computed from FMTV and the three donor catchment Austbygdåi, Kileai, and Horte and plotted in the same graph as shown in figure 3-41 below.

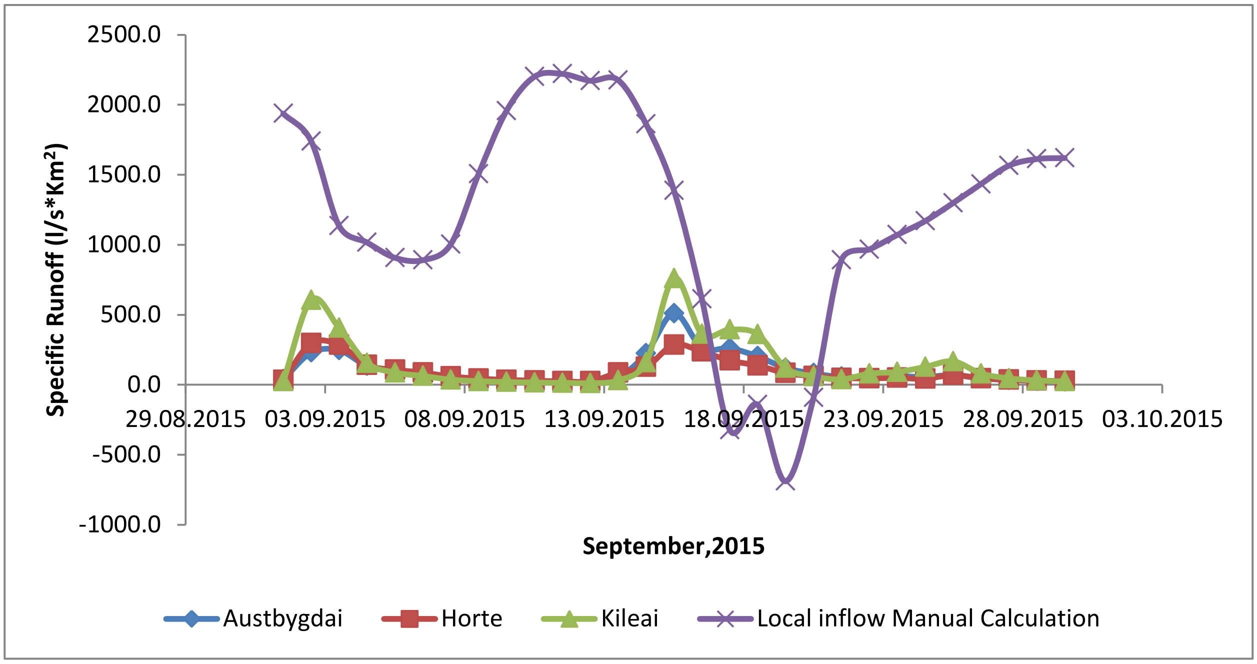

Figure 3-41 Comparing specific runoff f local Hjellevatn to specific runoff of three donor catchments

The correlations between specific runoff of local Hjellevatn and three donor catchments are shown in Table 3-12

Table 3-12 Correlation between specific runoff of local inflow into Hjellevatn and donor catchments

	Kileai	Austbygdåi	Horte
Local inflow Norsjo	-0.305	-0.235	-0.254

3.4.6 Discussion and conclusion on scaling

The very poor correlations between Local Hjellevatn and donor catchments made it difficult to calculate a specific scaling constant or constants for Local Hjellevatn and Norsjo due to Farelva gauging which was found to be faulty. In addition, the results in figure 3-41 show a clear mismatch between the manually computed local inflow and the FMTV computed inflow. The very weak correlation between the local inflow and each of the three HBV catchments and the local inflow from the FMTV showed in Table 3-12 confirms this mismatch. From figure 3-41, we see that the Local inflow does not reflect the two September 2015 floods as reflected by the three catchments Kileai, Hørte, and Austbygdåi. This could be due to the high uncertainties in the parameters of the water balance equation shown in equation (14).

Negative inflow values could be seen during the second flood in September. These negative values are unphysical and require an investigation into all the parameters involved in the water balance equation of Hjellevatn. The river flow measurements at Farelva looked suspicious as was seen in Norsjo water balance in the previous chapter. The outflow from Hjellevatn has high uncertainty because of the complexity of the eight gates and the lack of information on their actual openings during September 2015. The reservoir stage-volume curve of Hjellevatn has some uncertainties since it was made indirectly made from flood maps.

3.5 MANUAL ROUTING COMPUTATION

3.5.1 Overview

The fluctuations in each reservoir or lake level could be calculated throughout the month of September 2015 if the following information about the reservoir or lake were known(Å. Killingtveit & Sælthun, 1995)

- Initial stage of reservoir or lake
- Inflow and outflow hydrograph
- Stage-volume relationship
- Stage-outflow relationship

The Puls method for level pool routing was used to run a manual routing on reservoirs Norsjo and Hjellevatn. The level pool routing equation was developed from the continuity equation (mass balance equation) given in equation (18).

The mass

$$\frac{dS}{dt} = I(t) - Q(t) \tag{18}$$

Where $\frac{dS}{dt}$ is change in reservoir or lake storage m^3/s

I(t) is the inflow into reservoir or lake m3/s

Q(t) is the outflow from lake or reservoir m3/s

If we consider two successive time intervals with subscript 1 and 2 denoting initial and final states respectively, Eq.17 could be re-written to get equation (19)

$$\frac{I1+I2}{2} * \Delta t - \frac{Q1-Q2}{2} * \Delta t = S2 - S1 \tag{19}$$

In Eq(18) I1 and H2,Q1, and S1 are known but S2 and Q2 are not known. This makes it difficult to solve equation (19). A solution to this problem is a modification of the equation (20) where is re-arranged to get Eq.19.

$$\frac{S2}{\Delta t} + \frac{Q2}{2} = \frac{I1+I2}{2} + \left(\frac{S1}{\Delta t} + \frac{Q1}{2}\right) - Q1 \tag{20}$$

If G is substituted with $\frac{S}{\Delta t} + \frac{Q}{2}$, then equation (20) could rewritten as

$$G2 = G1 + Im - Q1 \tag{21}$$

Where $Im = 0.5 * (I2 + I1)$ (22)

The routing for two successive time intervals or time steps was computed with Eq.(21) by the procedure outlined below.

3.5.2 Routing Procedure

Step 1. The initial stage and inflow hydrograph for a reservoir or lake undergoing routing for September 2015 were determined from stage data and water balance study respectively. Im was calculated.

Step 2 a) Stage-volume relationship) G versus Q curve and c) stage-discharge relationship for the outlet were developed to compute Q1,S1

Step 2. G1 was computed from $\frac{S1}{\Delta t} + \frac{Q1}{2}$

Step 3. G2 was computed with Eq.20

Step 4. Q2 was computed by making Q2 subject of the Equation that best fit G versus Q curve and solving for Q2

Step 5. H2 (simulated water level-H_{sim}) was computed from the stage – discharge relationship for the outlet of reservoir or lake under routing.

Step 6. Final storage (**S_2**) from the stage-volume relationship with H2 (H_{sim}) found in step 5 to complete all

Step 7. Repeat steps 1 to 6 for subsequent cells as shown in Tabel 19 below. Take note that in the next time step, 2 was initial and 3 was final

Time Step	I	**Im=(I_1+I_2)/2**	S(m3)	G= S/dt +Q/2	Q	H-simulated	H-Observed
1	55	-	Step 2	Step 3	Step 2	-	-Observed
2	57	Step 1	Step 7	Step 4	Step 5	Step 6	-Observed
3	63	REPEAT	REPEAT	REPEAT	REPEAT	REPEAT	-Observed
4	-	-	-	-	-	-	-Observed
5	-	-	-	-	-	-	-Observed

Step8. Finally, the simulated reservoir or lake levels obtained through routing are compared to the observed reservoir level and LRV and HRV for assessment.

3.5.3 Routing results for Norsjo and Hjellevatn for different scenarios

3.5.3.1 Norsjo

Routing was performed for reservoir Norsjo with total inflow from Heddalsvatn, the Western catchment and local inflow for Norsjo. Two scenarios were accessed for Norsjo. The first scenario was routing with Farelva as outflow and the second was replacing Farelva with Firingsfoss as outflow. The results of the routing were compared with observed Norsjo reservoir level and HRV and LRV of Norsjo. The results of scenario 1 and 2 are shown in figure 3-42 and 3-43 respectively.

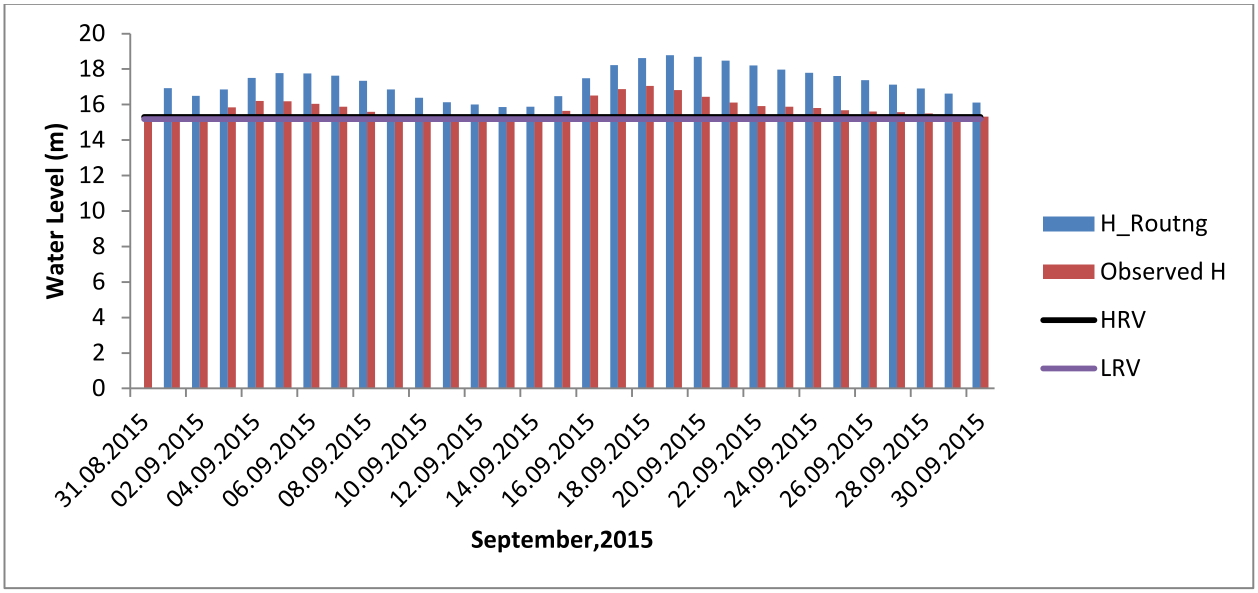

Figure 3-42 Routing results scenario 1

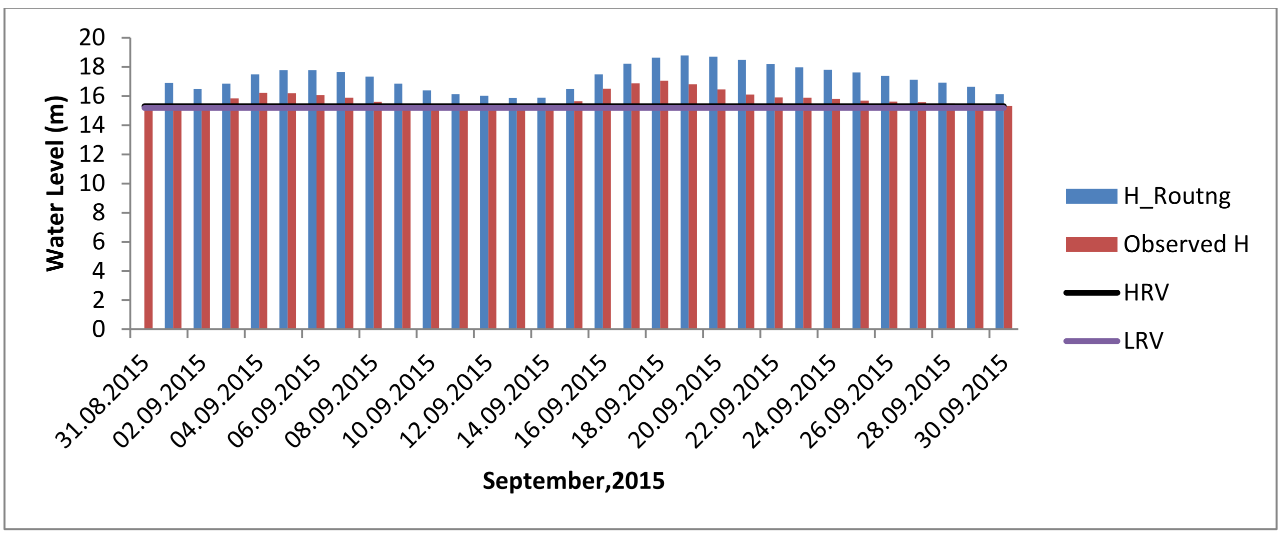

Figure 3-43 Routing results scenario 2

3.5.3.1.1 Evaluation of Norsjo's stag-volume curve with RIFA

The River and Accident Simulator (RIFA) was used to evaluate the accuracy of the stage-volume curve of the existing FMTV model. The stage-volume curve was modified based on a constant area computation. The results of the analysis could be found in figure 3-44. More about RIFA could found at (Alfredsen, 2001).The results suggest that the existing curve in the FMTV needs adjustment to get a better stage-reservoir curve for Norsjo. This would, in turn, help better the model's performance at Norsjo.

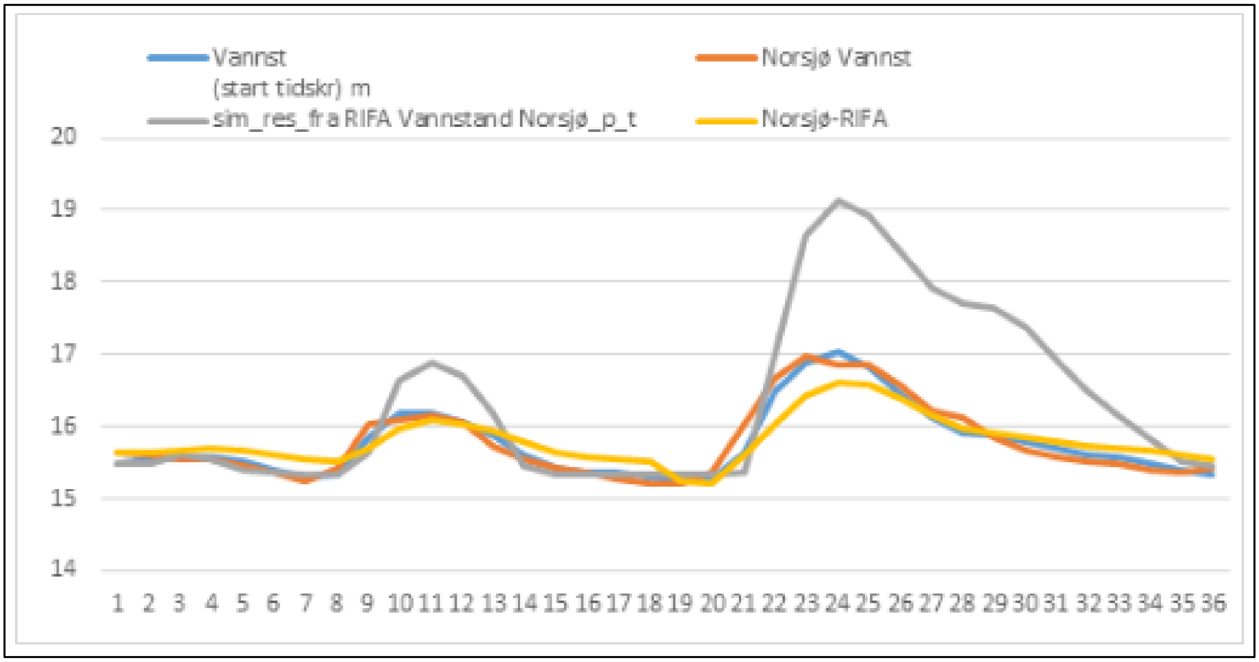

Figure 3-44 Results of Norsjo stage-volume curve with RIFA

The old stage-volume data in the existing FMTV model is shown in Table 3-13. The newly proposed data for stage volume relationship for Norsjo could be seen in Table 3-14.

Table 3-13 Data for stage-volume curve for Norsjo in existing FMTV

Old stage-volume data for Norsjo in Existing FMTV	
Stage [m]	Norsjo Volume Data in existing FMTV [m3]
15	0
15.15	0
15.24	13310000
15.36	139500000
19.3	240000000
23.3	480000000

Table 3-14 New proposed data for stage-volume curve for Norsjo yet to be implemented in the FMTV model

Newly stage-volume data for Norsjo in Existing FMTV	
Stage[m]	New Volume Curve for Norsjo [m3]
15	0
15.15	0
15.24	13222880
15.36	198432000
16	551220000
17	110240000

This new data points for computing stage-volume for Norsjo, when implemented in the FMTV model, would improve the performance of the FMTV at Norsjo.

3.5.3.2 Hjellevatn

Routing was performed for reservoir Hjellevatn with total inflow from the Norsjo and local inflow for Hjellevatn. Falkumelva forms part of the local inflow to Hjellevatn. Three scenarios were accessed for Hjellevatn. The inflow into Hjellevatn was computed by back calculating total inflow into Hjellevatn with the computed total outflow and changes in reservoir volume for each time step. This shown in equation (17) above

In the first scenario, Klosterfoss production was set at **243m3/s** throughout September 2015 whiles plant flow for combined Eidet hydropower Sytems was set also at 60m3/s except 17th to 20th September where the entire Eidet Hydropower Systems were shut down due to too much water in the reservoir.

In the second scenario, it was assumed that existing power plants were shut down during the first and second flood events in September 2015. Since plant flow data available for Eidet hydropower Systems was from 14th to September 20th September and stating explicitly that Eidet Hydropower Plants were shut down from 17th to 20th September, Eidet hydropower systems plant flows was set at **60m^3/s** from **1st to 3rd September** , **0m^3/s** from **4th to 7th September**(first flood period) , **60m^3/s** from **8th to 16th September**, **0m^3/s** from **17th to 20th of September**(second flood period), and **60m^3/s** from **21st to 30th September**. Klosterfoss was set to **243m^3/s** throughout **September 2015**.

In the third scenario, the plant flow of Eidet Hydropower Systems was maintained as it was in the second scenario and Klosterfoss was set as follows; **243m^3/s** from **1st to 3rd September**, **0m^3/s** from **4th to 7th September** (first flood period), **243m^3/s** from **8th to 16th September**, **0m^3/s** from **17th to 20th September** (second flood period) and **243m^3/s** from **21st to 30th September 2015.**

The results of the different scenarios for routing stated above were compared with observed Hjellevatn reservoir level and its HRV and LRV. This is shown in figure 3-45,46 and47 respectively

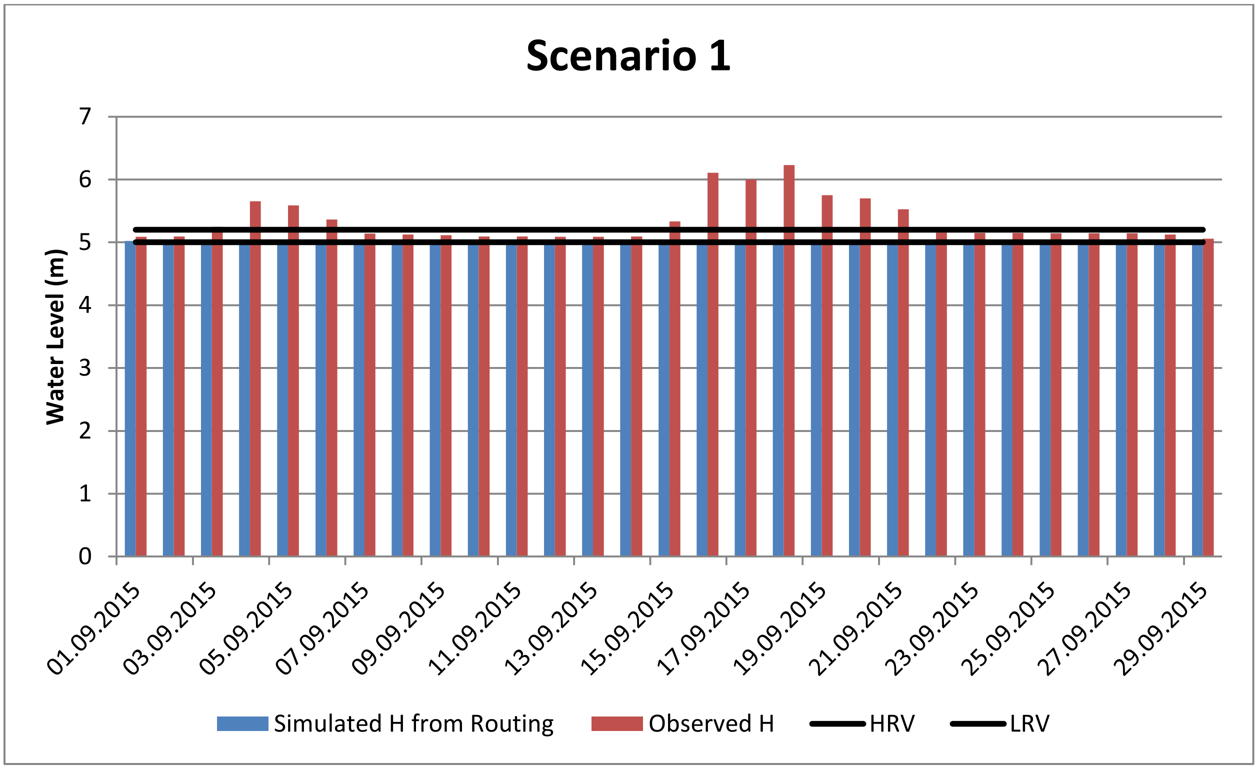

Figure 3-45 Routing results scenario 1

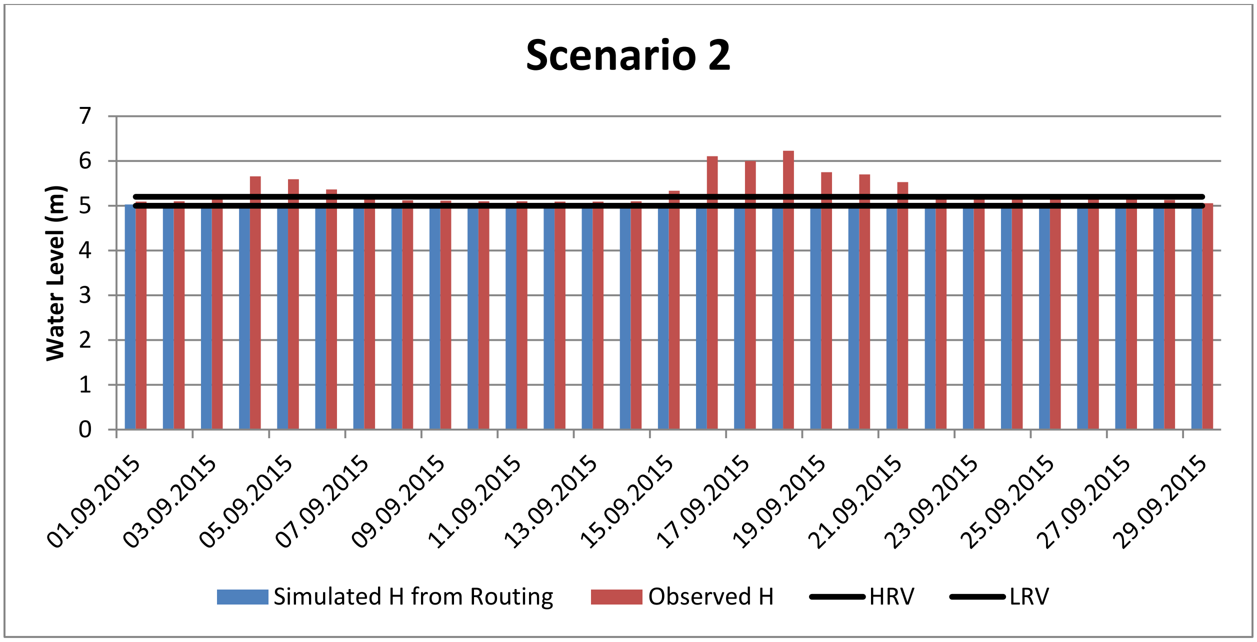

Figure 3-46 Routing results scenario 2

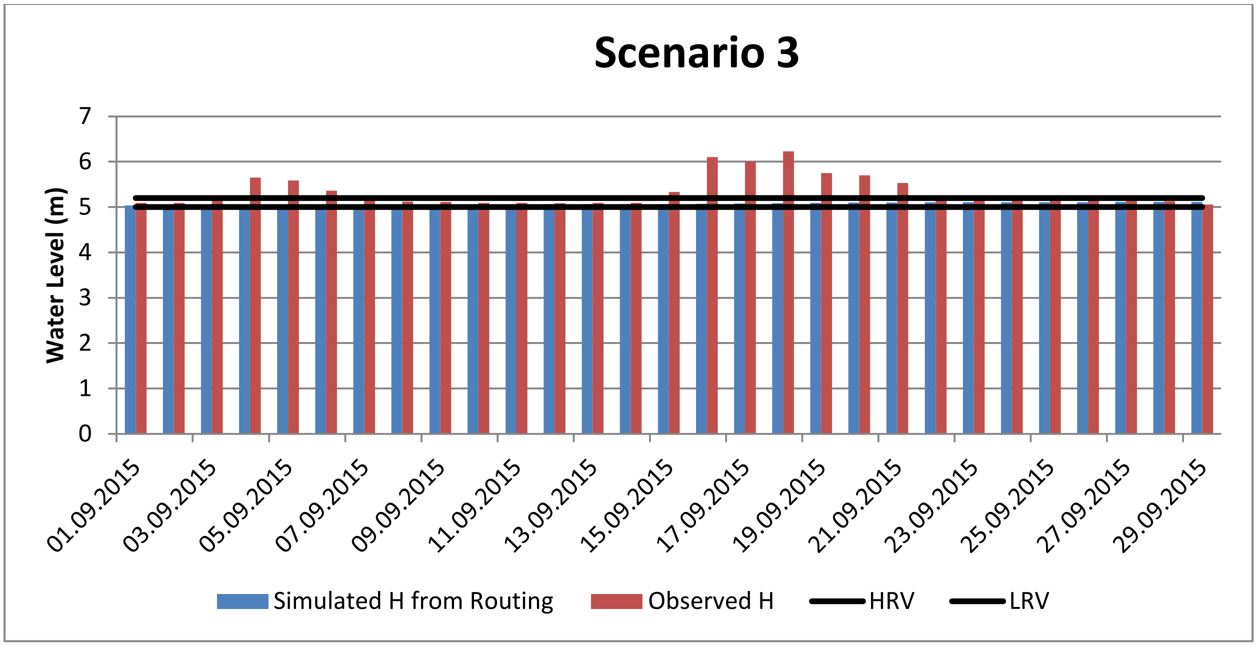

Figure 3-47 Routing results scenario 3

3.5.4 Observation and Discussion of Routing Evaluation

All three scenarios for reservoir routing at Hjellevatn gave water level the matched the observed flow except during the period of the two floods where the observed levels were higher than the simulated levels. This confirms that our assumption of the total inflow to Heddalsvatn from back-calculation is very close to right. This also suggests and confirms the earlier claim that Farelva gauging station is measuring lower flows than it should. This is because considering the total inflow that gave the results in scenarios 1, 2 and 3, the results when Farelva measurements are subtracted from the total inflow is significantly more than the expected inflow from the local Hjellevatn.

The results of routing at Norsjo showed a higher simulated level more than the observed level throughout September 2015. This is similar to the results of the existing. Since Farelva was used to compute outflow from Norsjo in the model, lower flows measured at Farelva would be interpreted by the model as more water stuck in the reservoir and hence higher levels than the observed.

Finally, it was decided to do a trial and error analysis of the scaling constants and to see their influence on the Observed and Simulated levels for each reservoir and lake to have an impression on how good the scaling was. The next sub-section describes the trial and error analysis, it results and discussions.

3.6 TRIAL AND ERROR ANALYSIS OF SCALING FACTORS

Trial and error analysis was done as another approach to accessing the scaling of the existing FMTV model. This was done by simply varying the scaling constants from the donor catchments and running the routing model to see how good the simulated water level fits the observed water level. Nash efficiency criterion was used as the criteria of goodness of fit to for each new scaling constant used in the model. The results of the trial and error analysis are shown in Table 33-15 below. The best scaling factor is shaded green in the Table 3-15. The results of the simulation in the FMTV model are shown in Appendix T to W

Table 3-15 Results of the trial and error analysis

Model	Donor Catchment	Target Catchment Austbygdai	Hørte	Kileai	Nash Eff. R2	Comment
Tinnsjoen	Local Tinnsjo	3.71	0	0	-8.7549	not ok!
	Local Tinnsjo	4	0	0	-0.5517	not ok!
	Local Tinnsjo	4.5	0	0	0.5355	not ok!
	Local Tinnsjo	5	0	0	-0.4616	not ok!
	Local Tinnsjo	5.5	0	0	0.2648	not ok!
	Local Tinnsjo	6	0	0	0.5086	not ok!
	Local Tinnsjo	0	9	0	0.6421	ok!
	Local Tinnsjo	0	7	0	-0.1005	not ok!
Heddalsvatn	Local Heddalsvatn	0	0.48	0	0.802	
	Local Heddola	0	0.35	0.65		not ok!
	Local Heddalsvatn	0	0.414	0	0.8167	not ok!

	Local Heddola	0	0	2.982		
	Local Heddalsvatn	0	0.35	2.982	0.8651	
	Local Heddola	0	0.1	0		not ok!
	Local Heddalsvatn	0	0.35	2.982	0.8664	
	Local Heddola	0	0.05	0		ok!
Norsjo	Local Norsjo	0	0	1.592	-47.6177	
	Local Boelva	0	0.754	0		not ok!
	Local Norsjo	0	0	1.5	-45.2007	
	Local Boelva	0	0.754	0		not ok!
	Local Norsjo	0	0	0.5	-23.0939	
	Local Boelva	0	0.754	0		not ok!
	Local Norsjo	0	0	0.1	-16.3662	
	Local Boelva	0	0.754	0		not ok!
Hjellevatn	Local Hjellevatn	0	0	2.082	-1.7088	not ok!
	Local Hjellevatn	0	0	3	-101.774	not ok!
	Local Hjellevatn	0	0	2.09	-1.7706	not ok!
	Local Hjellevatn	0	0	2.07	-1.6265	not ok!

4 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

4.1.1 Scaling and Scaling Adjustment

The initial scaling of the FMTV model resulted in a significant divergence between simulated and observed water levels at Tinnsjo and Heddalsvatn. It was not expected for simulated and observed of reservoir or lake levels to have a perfect match due to issues associated with scaling described by (Blöschl & Sivapalan, 1995; Gentine et al., 2012).Also, because the runoff series for the three target catchments used in scaling were generated from a hydrological model (HBV model) which linearizes the nonlinear equations describing the natural hydrological processes, the discrepancy in the observed and simulated reservoir or lake level was expected. This agrees with the statement made by Gentine et al. (2012). An adjustment in the scaling factors through ***trial and error test*** was considered to help reduce the discrepancy in the observed and simulated water levels in the FMTV model.

- **Tinnsjo.**

The correlations between the Local Tinnsjo and the donor catchment suggest that Austbygdåi is the best catchment for scaling local Tinnsjo. However, Hørte and Kileai show high correlations which suggest that Hørte and Kileai could also be used to local inflow to Tinnsjo. Austbygdåi is the closest donor catchment to local Tinnsjo and there is a higher probability of Local Tinnsjo and Austbygdåi experiencing the same precipitation compared to Kileai and Hørte. In the situation where Austbygdåi has more snow in its catchment than Tinnsjo, then Hørte or Kileai may be a suitable donor catchment than Austbygdåi.

A trial and error test which involves varying the scaling constants till a better match between the observed and simulated reservoir or lake level is attained was employed as a strategy of finding a single scaling constant for each scaling since Tinnsjo had varying scaling constants for each day.

The existing FMTV model computes local Inflow into Tinnsjo based on scaling from Austbygdåi with a scaling factor of 3.71. This gave a Nash Efficiency of -8.755. Though by physical observation the existing FMTV model showed a good match between simulated and observed reservoir level at Tinnsjo, using donor catchment Hørte with a scaling factor of 9 in the trial and error test gave the best goodness of fit with an R2 value of 0.6421.

It was observed the scaling ***9*Hørte*** gave the better goodness of fit for the two flood periods than the low flow periods. On the other hand using ***4.5*Austbygdåi*** gives a better goodness of fit outside the two flood periods. This can be seen in Appendix T-3. According to (Berglund, 2015) the September 2015flood was a 50-year flood. In view of this view, it suggested for a scaling factor of (***9*Hørte)*** if expected flood is equal to or more than 50-year flood and (***4.5*Austbygdåi)*** if expected flood is less than a 50year flood. Take note considering that the

September 2015 flood was a 50year one, low flows refer to flows lower than 50year flood and high flows are those equal to or more than 50 years flood.

Another master thesis running parallel with this focusing on spills from brook intakes and spillways from various hydropower dams in the project study area suspects that spills from brook intake at Tinnsjo and possibly other reservoirs were not included in the FMTV model. If this suspicion turns out to be true, the scaling factor for Tinnsjo would have to be modified due to the inclusion of water in each model unit due to spill. If the spills are enough to raise the simulated water level of Tinnsjo to the observed reservoir level at Tinnsjo, a modification of scaling factors may not be necessary. That will mean keeping the initial scaling and attributing the cause of the deviation at Tinnsjo to the exclusion of excess water from brook intakes when the flows exceeded their capacities.

- **Heddalsvatn**

The results from the correlations between specific runoff of local inflow to Heddalsvatn and the donor catchments Austbygdåi, Hørte and Kileai suggest Austbygdåi as the best donor catchment for scaling followed by Kileai and Hørte. The local inflows to Heddalsvatn are made up of local Heddøla and local Heddalsvatn. The scaling in the existing FMTV model for Local Heddøla and Local Heddalsvatn were (0.414*Hørte) and (2.982*Kileai) respectively. The two catchments were chosen over Austbygdåi because they were closer to the local Heddalsvatn and local Heddøla than Austbygdåi.

The trial and error analysis for lake Heddalsvatn revealed that scaling with (0.35*Hørte and 2.982*Kileai) for Local Heddalsvatn and (0.05*Hørte) for Local Heddøla gives the best goodness of fit between the simulated and observed lake levels at Heddalsvatn. The existing scaling gave a Nash Efficiency value of 0.8167 whiles the best goodness of fit gave R2 value of 0.8664. Since there were not spills in Heddalsvatn the in upgrading the model at Heddalsvatn, (***0.35*Hørte*** and ***2.982*Kileai***) for ***Local Heddalsvatn*** and (***0.05*Hørte***) for ***Local Heddøla*** are proposed. It was advised that these new scaling should be used for Heddalsvatn to see if for future events these scalings work better than the previous scaling or not.

- **Norsjo and Hjellevatn**

The correlations between the specific runoff of local Norsjo and each of the three donor catchments were very poor. This reflected in the significant mismatch between the simulated and observed reservoir level a Norsjo. The situation at Hjellevatn was similar as Norsjo had much worse correlation between Local Hjellevatn and each of the three donor catchments. The reason for these results was found to be faulty gauging station at Farelva (Farelva ndf Skotfoss). The suspicions the Farelva gauging station could be measuring lower flows was confirmed by NVE. The gauging station as off 6th May 2016 had been sent to manufacture in California for repairs.

The role of Farelva gauging station in Norsjo and Hjellevatn explains the poor correlation explained above. The simulation results showed a significantly higher simulated reservoir level at Norsjo than the observed. The explanation to this behavior by the model could be linked to the fact the Farelva measures lower flow than it should so the model sees more water in the system than it should. These small flows when fed into Hjellevatn, the simulated reservoir level at Hjellevatn will be significantly lower than its observed reservoir level.

A separate analysis on the flood routing of reservoir Norsjo from the test data files of the existing FMTV model revealed that the stage-volume curve of Norsjo was inaccurate. The implementation of the new curve from the data in table 3-14 could improve the models performance at Norsjo in future work on this project. Based on the results from the RIFA and results from figure 3-42 to 3-44, the possibility of direct errors in the routing model in FMTV is eliminated at Norsjo.

The reservoir volume curve, spillway gate openings were assumed in the worst case scenario to confirm that Farelva gauging station was faulty, thus, in reality, the reservoir volume could be smaller than what was assumed. If Farelva shows lower flows with this assumption then if the reservoir is smaller this result will be worse.

In conclusion, for a scaling to be done for the model unit at Norsjo and Hjellevatn, Farelva station must be active and working correctly. This means no proper scaling could be developed for Norsjo and Farelva until the reason of the fault at Farelva is found and corrected.

4.2 Recommendations

One of the major challenges in this master thesis was the fact that the scaling factors in the FMTV model seem to be incorrect. They were adjusted in the trial and error to find new scaling factors that gave better goodness of fit than the previous scaling factor. This could have been caused by the wrong calibration in the HBV model used to generate runoff series for the donor catchments. It will be prudent to check the calibration and where necessary corrected.

The total flow out of Hjellevatn was difficult to measure due to its complexity with three power plants, four large gates, a lock-system for ships, salmon ladders, and lack of data on the actual gate openings. Again there were no plant production data for Klosterfoss. Lastly, there were few production data for Eidet 1, Eidet and Eidet 2 Hydropower Systems. To reduce the stress and make it easier to better the model at Hjellevatn it was recommended for a gauging station to be built and positioned below Hjellevatn station to have better control of the flow out of Hjellevatn.

An electronic recording system type of gauging station is recommended for Hjellevatn due to their advantage in giving more precise timing, ability to combine high time resolution with long observation period, easy post-processing and most importantly their visual display for showing measured stage, battery status etc.(Å. Killingtveit & Sælthun, 1995). The river profile of Hjellevatn was made (figure 4-1) to help inform the decision of the most appropriate position to locate the new gauging station considering the tidal wave from the ocean into the Fjord towards Hjellevatn which courses backwater effect within the river reach shown in Appendix

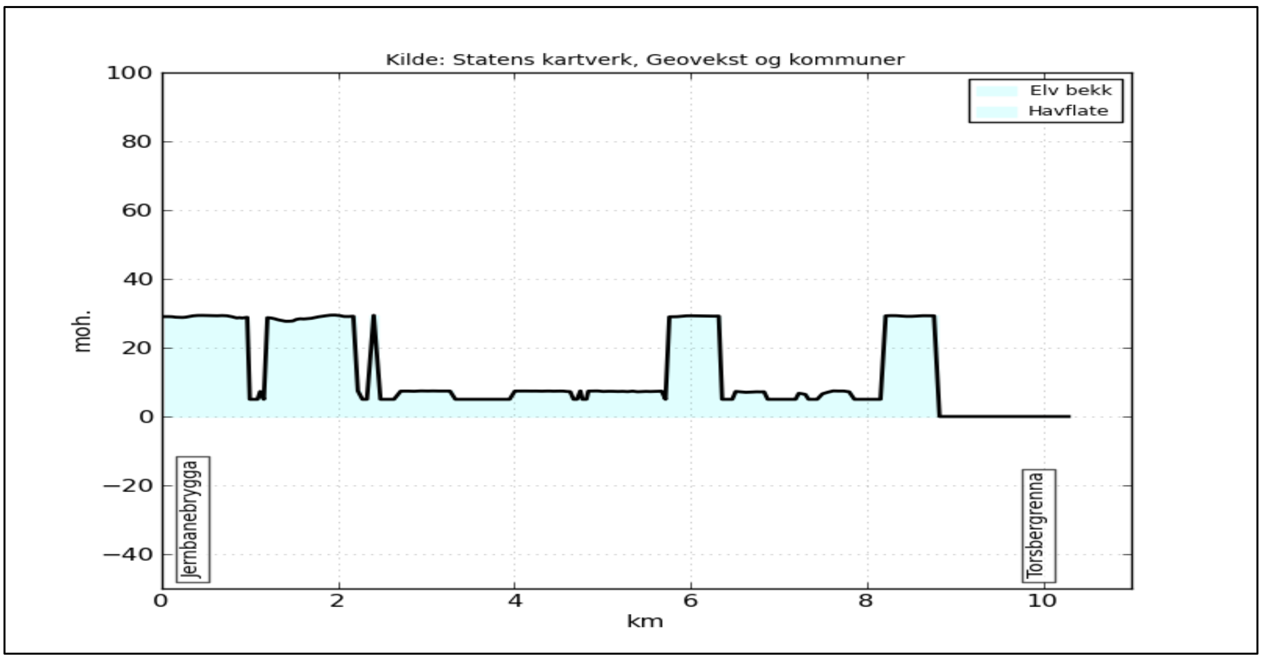

Figure 4-1River profile downstream of Hjellevatn

As seen from the river profile, there is no significant slope to avoid a backwater effect. In addition, this river flows into the ocean and therefore may experience backwater effect from tidal waves from the ocean. It is not clear the exact position to place the gauging station. It is believed that further studies with new Hjellevatn station in mind could come up with a good position for the gauging station.

It was recommended for a proper stage-discharge relationship for Hjellevatn to be developed since an indirect method was used to determine the stage-storage relationship for Hjellevatn. This would help reduce the uncertainties in the assumptions used for Hjellevatn water balance calculations in further studies.

Tapping Vestvatna denoting flow from Vrangfoss is a very important input to reservoir Norsjo if proper water balance relationship is to be developed for Norsjo. As it's the culture of power plant owner not bordering so much about taking data on the total flow out of the power system it recommended for OTB to persuade the power plant owners at Vrangfoss to measure total outflow from Vrangfoss to give a more reliable Tapping Vestvatna.

Flow out of Tinnsjo enters Arlifoss then to Gronvollfoss then to Svegfoss (a power plant located between Tinnsjo and Heddalsvatn). The gauging station Kirkevoll Bru used as inflow into Heddalsvatn is located upstream of Svegfoss and measure total flow out of Tinnsjo. We assumed that at the same time step the measured flow at Kirkevoll Bru was equal to total inflow from Tinnsjo into Heddalsvatn. This may be an overestimation if the Reservoir at Svegfoss was not too big to hold back some of the flow from Tinnsjo. It was suggested that a flow measurement (total outflow) through Tinfoss I and II should be used as inflow to Heddalvatn from Tinnsjo instead of Kirkevoll Bru

Finally, the trial and error test done for Tinnsjo and Heddalsvatn should be done for Norsjo and Hjellevatn should be repeated when Farelva is working correctly as a way to upgrade those models.

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APPENDIX

A)

Date	Sum_Volume_(Heddals+Norsjo) m3	ΔVol (Combined Volume) m3	Q_Heddola(Omnesfoss) m3/s	Q_Tinnai(Kirkevoll) m3/s	Q_Vrangfoss m3/s	Q_Hagadrag m3/s	Q_outflow_Farelva m3/s	Q_Local Inflow m3/s	FMTV_Sum_Norsjo_Heddasvatn
31.08.2015	207525008.4		30.877	124.139	213.587963	61.321	504.929		21.786
01.09.2015	200755646.5	-78.3490963	34.822	141.245	212.6049383	49.306	481.69	-34.63703457	26.319
02.09.2015	209993762.9	106.9226435	270.581	151.736	188.9866049	100.098	554.927	-49.55196142	151.05
03.09.2015	251370573	478.8982646	282.287	132.271	216.5466049	240.234	833.455	441.0146596	269.834
04.09.2015	271679126.6	235.0527037	106.34	257.417	308.3066049	222.206	1032.925	373.7080988	45.132
05.09.2015	267685497.6	-46.22255732	61.478	285.772	307.5308642	158.483	1006.707	147.2205785	28.487
06.09.2015	257481388.1	-118.1031198	52.71	274.074	300.0679012	117.268	922.419	60.195979	51.096
07.09.2015	243835434.2	-157.9392808	41.009	183.043	261.0833333	85.509	813.244	84.66038588	15.813
08.09.2015	222700264.2	-244.6200236	30.976	151.327	196.3449074	63.226	645.342	-41.15193105	9.909
09.09.2015	210763009	-138.1626755	25.567	152.25	140.837963	48.655	480.714	-24.75863843	6.946
10.09.2015	204792698.1	-69.10082072	23.291	151.102	114.3009259	38.993	386.543	-10.24474664	4.839
11.09.2015	205120614.7	3.795331395	22.432	150.005	116.3611111	32.467	381.015	63.54522028	3.329
12.09.2015	200959838.6	-48.15713079	28.64	149.26	109.7685185	28.173	395.924	31.92535069	2.423
13.09.2015	198285778.9	-30.94976505	46.381	158.761	117.3912037	29.079	395.39	12.82803125	6.88
14.09.2015	203851617	64.41942173	138.708	245.398	186.9866049	45.463	510.599	-41.53718321	68.307
15.09.2015	241008380.1	430.055129	383.113	343.953	321.8266049	115.092	777.34	43.41052403	197.614
16.09.2015	301844215.3	704.1184628	239.631	327.796	531.9466049	199.105	1386.107	791.7468579	220.191
17.09.2015	319360938	202.7398457	195.318	330.918	421.1066049	169.269	1540.202	626.3302408	186.501
18.09.2015	331839276.4	144.4252137	125.894	324.308	344.9066049	150.43	1600	798.8866087	132.941
19.09.2015	311464056.4	-235.8243056	67.311	316.051	333.7466049	113.078	1542.502	476.4910895	115.561
20.09.2015	284796488	-308.6524118	40.397	309.096	320.8666049	87.071	1349.308	283.2249832	91.106
21.09.2015	261310745.1	-271.8257289	30.673	302.005	291.1066049	70.421	981.83	15.79866616	73.545
22.09.2015	248059027.1	-153.376365	48.179	300.373	255.6266049	61.574	817.093	-2.035969985	60.63
23.09.2015	246046502.3	-23.29311195	56.074	270.202	256.5671296	58.051	811.904	147.7167584	64.308
24.09.2015	239425405.6	-76.63306351	52.518	217.296	247.5810185	54.808	776.023	127.186918	35.662
25.09.2015	231852642.8	-87.6477169	65.961	217.517	203.7466049	55.694	729.236	98.66967816	31.224
26.09.2015	227238085	-53.40923403	53.634	237.008	199.9066049	54.292	679.955	81.70516103	26.761
27.09.2015	223748781.2	-40.38546065	43.069	228.425	201.2666049	49.887	631.416	68.38293441	20.585
28.09.2015	217171376.5	-76.12736898	37.492	173.369	199.9466049	45.449	607.539	75.15502608	13.262
29.09.2015	208369639.5	-101.871956	34.426	154.225	200.3866049	41.778	580.303	47.61543904	9.208
30.09.2015	203254402.9	-59.20412731	32.509	146.259	174.6266049	38.492	553.068	101.9772677	6.933

B)

Date	Lake level_m	Volume_m3	Δ Res. Volume_m3/s	Q_Farelva_m3/s	Q_Outflow_m3/s	Eidet Power P/ m3/s	Klosterfoss Power P. m3/s	Loc_Inflow m3/s	Local Inflow FMTV_m3/s
31.08.2015	5.09	712000.00		504.93	877.97	60.00	243.00		18.96
01.09.2015	5.09	720000.00	0.09	481.69	878.26	60.00	243.00	699.67	15.04
02.09.2015	5.10	760000.00	0.46	554.93	879.73	60.00	243.00	628.27	45.18
03.09.2015	5.25	1992000.00	14.26	833.46	926.21	60.00	243.00	410.01	101.06
04.09.2015	5.65	5216000.00	37.31	1032.93	1059.79	60.00	243.00	367.18	50.27
05.09.2015	5.59	4704000.00	-5.93	1006.71	1037.35	60.00	243.00	327.72	33.90
06.09.2015	5.36	2896000.00	-20.93	922.42	961.87	60.00	243.00	321.52	24.23
07.09.2015	5.14	1120000.00	-20.56	813.24	893.07	60.00	243.00	362.27	17.28
08.09.2015	5.12	984000.00	-1.57	645.34	888.01	60.00	243.00	544.09	12.21
09.09.2015	5.11	912000.00	-0.83	480.71	885.34	60.00	243.00	706.79	8.57
10.09.2015	5.10	768000.00	-1.67	386.54	880.03	60.00	243.00	794.82	5.95
11.09.2015	5.10	768000.00	0.00	381.02	880.03	60.00	243.00	802.01	4.07
12.09.2015	5.09	712000.00	-0.65	395.92	877.97	60.00	243.00	784.40	3.04
13.09.2015	5.09	720000.00	0.09	395.39	878.26	60.00	243.00	785.97	7.03
14.09.2015	5.10	760000.00	0.46	510.60	879.73	60.00	243.00	672.60	14.26
15.09.2015	5.34	2680000.00	22.22	777.34	953.23	60.00	243.00	501.11	30.21
16.09.2015	6.11	8840000.00	71.30	1386.11	1233.07	60.00	243.00	221.26	65.52
17.09.2015	6.00	8000000.00	-9.72	1540.20	1190.54	0.00	243.00	-116.39	57.58
18.09.2015	6.23	9816000.00	21.02	1600.00	1284.40	0.00	243.00	-51.58	46.88
19.09.2015	5.75	5992000.00	-44.26	1542.50	1094.72	0.00	243.00	-249.04	38.95
20.09.2015	5.70	5608000.00	-4.44	1349.31	1077.29	0.00	243.00	-33.46	27.81
21.09.2015	5.53	4216000.00	-16.11	981.83	1016.41	60.00	243.00	321.47	19.82
22.09.2015	5.16	1240000.00	-34.44	817.09	897.56	60.00	243.00	349.02	15.31
23.09.2015	5.15	1200000.00	-0.46	811.90	896.06	60.00	243.00	386.69	16.55
24.09.2015	5.15	1184000.00	-0.19	776.02	895.46	60.00	243.00	422.25	16.23
25.09.2015	5.15	1176000.00	-0.09	729.24	895.16	60.00	243.00	468.83	14.21
26.09.2015	5.15	1168000.00	-0.09	679.96	894.86	60.00	243.00	517.81	12.18
27.09.2015	5.14	1144000.00	-0.28	631.42	893.96	60.00	243.00	565.27	8.61
28.09.2015	5.13	1000000.00	-1.67	607.54	888.60	60.00	243.00	582.40	6.04
29.09.2015	5.06	456000.00	-6.30	580.30	868.63	60.00	243.00	585.03	4.19
30.09.2015	no data	no data	No data	553.068	no data	-	-	-	-

C)

Date	Lake Level (m)	ΔVolume_Norsjo m3/s	Q_Hagadrag m3/s	Q_Vrangfoss m3/s	Q_Heddalsvatn m3/s	Q_Farelva m3/s	Q_Local Inflow m3/s
31.08.2015	15.40	-	61.32	213.59	189.00	504.42	-
01.09.2015	15.30	-68.60	49.31	212.60	190.00	481.61	-38.90
02.09.2015	15.34	29.57	100.10	188.99	375.00	554.34	-80.18
03.09.2015	15.84	324.00	240.23	216.55	610.00	829.73	86.96
04.09.2015	16.20	233.47	222.21	308.31	580.00	1032.91	155.87
05.09.2015	16.19	-9.53	158.48	307.53	430.00	1006.57	101.03
06.09.2015	16.05	-89.25	117.27	300.07	420.00	922.16	-4.43
07.09.2015	15.87	-113.16	85.51	261.08	325.00	812.89	28.14
08.09.2015	15.60	-179.86	63.23	196.34	250.00	644.33	-45.10
09.09.2015	15.43	-107.49	48.66	140.84	240.00	480.61	-56.37
10.09.2015	15.35	-54.00	38.99	114.30	250.00	386.05	-71.25
11.09.2015	15.36	8.84	32.47	116.36	245.00	380.73	-4.26
12.09.2015	15.29	-43.89	28.17	109.77	255.00	395.86	-40.97
13.09.2015	15.24	-33.69	29.08	117.39	260.00	395.22	-44.94
14.09.2015	15.26	10.81	45.46	186.99	360.00	510.28	-71.36
15.09.2015	15.65	254.12	115.09	321.83	600.00	769.45	-13.35
16.09.2015	16.50	553.32	199.11	531.95	795.00	1231.06	258.33
17.09.2015	16.87	236.24	169.27	421.11	690.00	1393.03	348.90
18.09.2015	17.06	120.58	150.43	344.91	705.00	1473.52	393.77
19.09.2015	16.81	-157.63	113.08	333.75	575.00	1362.11	182.66
20.09.2015	16.45	-237.11	87.07	320.87	595.00	1157.92	-82.12
21.09.2015	16.11	-219.55	70.42	291.11	400.00	981.14	0.06
22.09.2015	15.91	-127.06	61.57	255.63	410.00	816.28	-37.98
23.09.2015	15.88	-20.12	58.05	256.57	585.00	811.32	-108.41
24.09.2015	15.80	-49.29	54.81	247.58	325.00	775.62	98.94
25.09.2015	15.69	-75.21	55.69	203.75	305.00	728.99	89.34
26.09.2015	15.61	-49.83	54.29	199.91	304.00	678.90	70.88
27.09.2015	15.57	-29.04	49.89	201.27	295.00	631.41	56.22
28.09.2015	15.49	-46.38	45.45	199.95	380.00	607.48	-64.30
29.09.2015	15.38	-73.32	41.78	200.39	278.00	561.40	-32.09
30.09.2015	15.32	-40.68	38.49	174.63	245.00	448.00	-50.80

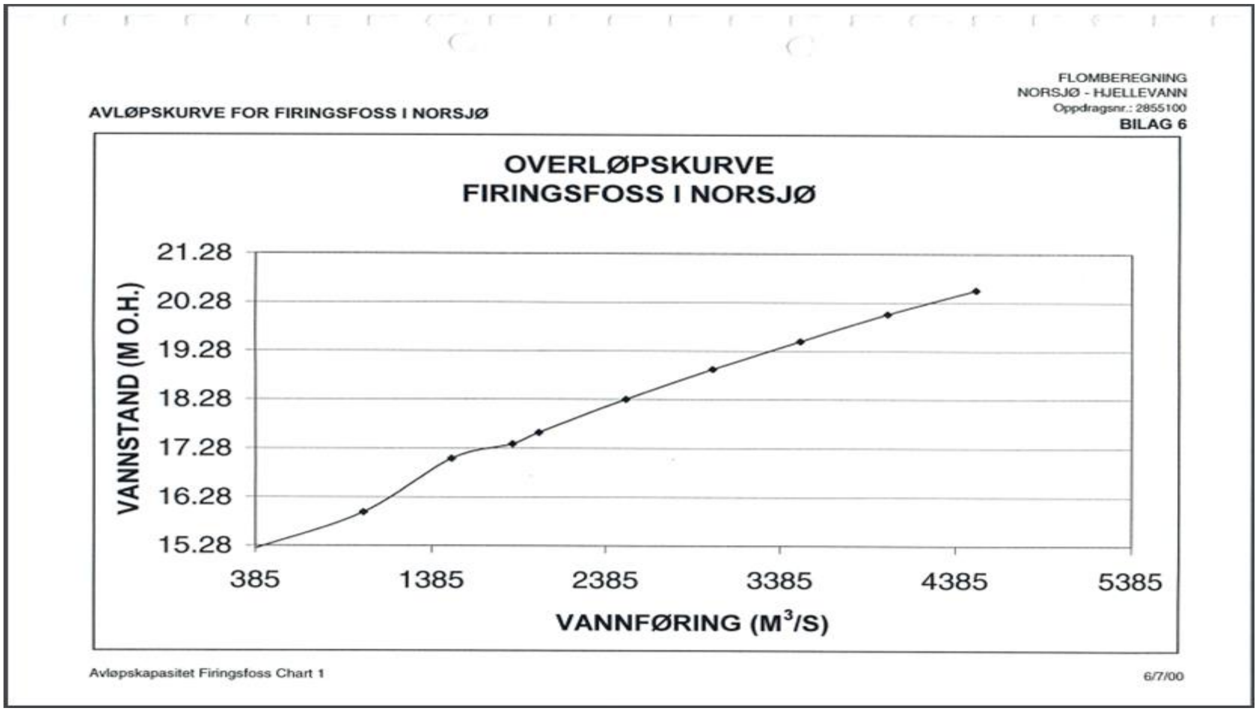
D)

Date	Δ Res. Volume_m3/s	Total Outlet_ m3/s	Total Inflow= ΔV+Total Outflow_m3/s	Q_Farelva_m3/s	Falumelva_m3/s= Total Inflow - Q_Farelva
31.08.2015		1111.970778		504.929	
01.09.2015	0.092592593	1112.264333	1112.356925	481.69	630.6669254
02.09.2015	0.462962963	1113.733579	1114.196542	554.927	559.2695422
03.09.2015	14.25925926	1160.210296	1174.469556	833.455	341.0145556
04.09.2015	37.31481481	1293.788046	1331.102861	1032.925	298.177861
05.09.2015	-5.925925926	1271.35451	1265.428584	1006.707	258.7215838
06.09.2015	-20.92592593	1195.867984	1174.942058	922.419	252.5230583
07.09.2015	-20.55555556	1127.067897	1106.512342	813.244	293.2683417
08.09.2015	-1.574074074	1122.006898	1120.432824	645.342	475.0908237
09.09.2015	-0.833333333	1119.339167	1118.505833	480.714	637.7918333
10.09.2015	-1.666666667	1114.027723	1112.361057	386.543	725.8180566
11.09.2015	0	1114.027723	1114.027723	381.015	733.0127233
12.09.2015	-0.648148148	1111.970778	1111.32263	395.924	715.3986299
13.09.2015	0.092592593	1112.264333	1112.356925	395.39	716.9669254
14.09.2015	0.462962963	1113.733579	1114.196542	510.599	603.5975422
15.09.2015	22.22222222	1187.225132	1209.447354	777.34	432.1073541
16.09.2015	71.2962963	1467.069799	1538.366095	1386.107	152.2590954
17.09.2015	-9.722222222	1364.538031	1354.815809	1540.202	-185.3861913
18.09.2015	21.01851852	1458.399677	1479.418195	1600	-120.5818045
19.09.2015	-44.25925926	1268.717164	1224.457904	1542.502	-318.0440958
20.09.2015	-4.444444444	1251.291081	1246.846636	1349.308	-102.4613636
21.09.2015	-16.11111111	1250.414697	1234.303585	981.83	252.4735854
22.09.2015	-34.44444444	1131.557433	1097.112989	817.093	280.0199887
23.09.2015	-0.462962963	1130.058419	1129.595456	811.904	317.6914561
24.09.2015	-0.185185185	1129.459515	1129.274329	776.023	353.2513295
25.09.2015	-0.092592593	1129.160213	1129.06762	729.236	399.83162
26.09.2015	-0.092592593	1128.861011	1128.768418	679.955	448.8134179
27.09.2015	-0.277777778	1127.964004	1127.686227	631.416	496.2702265
28.09.2015	-1.666666667	1122.600818	1120.934151	607.539	513.395151
29.09.2015	-6.296296296	1102.628656	1096.33236	580.303	516.0293598
30.09.2015	#VALUE!	#VALUE!	#VALUE!	553.068	#VALUE!

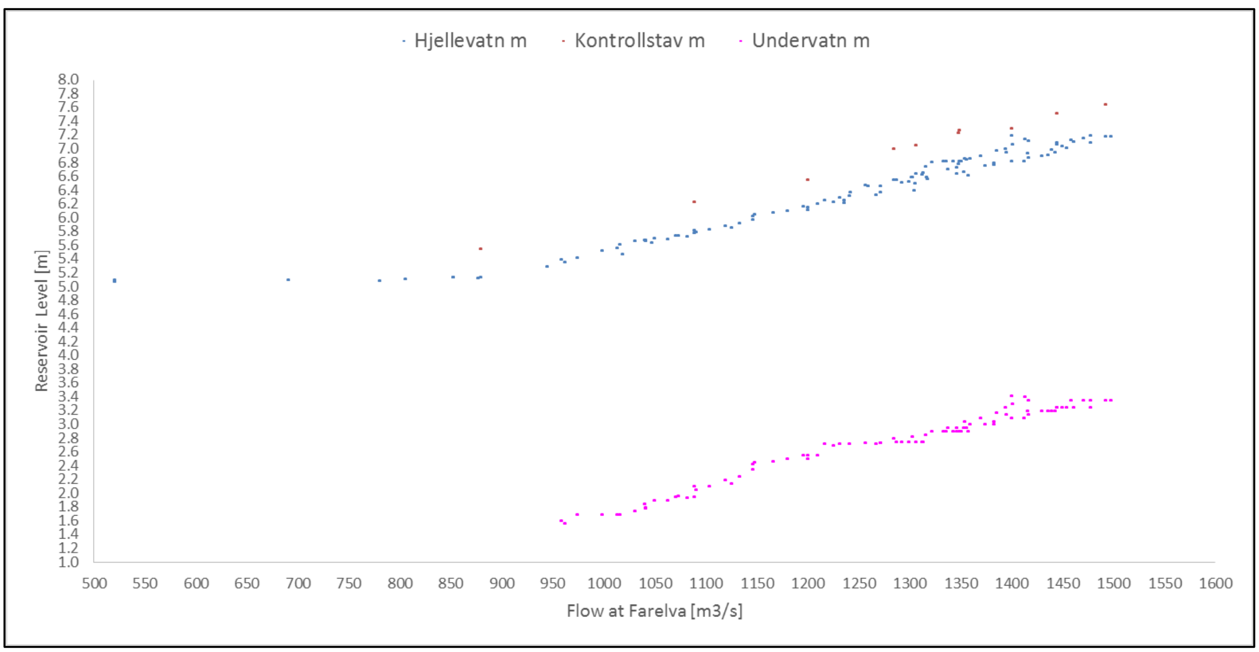
E)

Date	Lake Level (m)	ΔVolume_Norsjo m3/s	Q_Hagadrag m3/s	Q_Vrangfoss m3/s	Q_Heddalsvatn m3/s	Q_Firingsfoss m3/s	Q_Local _Inflow m3/s
31.08.2015	15.40	-	61.32	213.59	189.00	635.00	-
01.09.2015	15.30	-68.60	49.31	212.60	190.00	448.00	-72.51
02.09.2015	15.34	29.57	100.10	188.99	375.00	490.00	-144.51
03.09.2015	15.84	324.00	240.23	216.55	610.00	948.00	205.22
04.09.2015	16.20	233.47	222.21	308.31	580.00	1135.00	257.96
05.09.2015	16.19	-9.53	158.48	307.53	430.00	1051.00	145.46
06.09.2015	16.05	-89.25	117.27	300.07	420.00	1010.00	83.42
07.09.2015	15.87	-113.16	85.51	261.08	325.00	952.00	167.25
08.09.2015	15.60	-179.86	63.23	196.34	250.00	760.00	70.57
09.09.2015	15.43	-107.49	48.66	140.84	240.00	578.00	41.02
10.09.2015	15.35	-54.00	38.99	114.30	250.00	520.00	62.70
11.09.2015	15.36	8.84	32.47	116.36	245.00	528.00	143.01
12.09.2015	15.29	-43.89	28.17	109.77	255.00	445.00	8.17
13.09.2015	15.24	-33.69	29.08	117.39	260.00	380.00	-60.16
14.09.2015	15.26	10.81	45.46	186.99	360.00	384.00	-197.64
15.09.2015	15.65	254.12	115.09	321.83	600.00	790.00	7.20
16.09.2015	16.50	553.32	199.11	531.95	795.00	1260.00	287.27
17.09.2015	16.87	236.24	169.27	421.11	690.00	1385.00	340.86
18.09.2015	17.06	120.58	150.43	344.91	705.00	1510.00	430.24
19.09.2015	16.81	-157.63	113.08	333.75	575.00	1370.00	190.55
20.09.2015	16.45	-237.11	87.07	320.87	595.00	1255.00	14.96
21.09.2015	16.11	-219.55	70.42	291.11	400.00	1123.00	141.92
22.09.2015	15.91	-127.06	61.57	255.63	410.00	1118.00	263.74
23.09.2015	15.88	-20.12	58.05	256.57	585.00	1019.00	99.27
24.09.2015	15.80	-49.29	54.81	247.58	325.00	998.00	321.32
25.09.2015	15.69	-75.21	55.69	203.75	305.00	1011.00	371.35
26.09.2015	15.61	-49.83	54.29	199.91	304.00	765.00	156.98
27.09.2015	15.57	-29.04	49.89	201.27	295.00	756.00	180.81
28.09.2015	15.49	-46.38	45.45	199.95	380.00	690.00	18.23
29.09.2015	15.38	-73.32	41.78	200.39	278.00	495.00	-98.49
30.09.2015	15.32	-40.68	38.49	174.63	245.00	448.00	-50.80

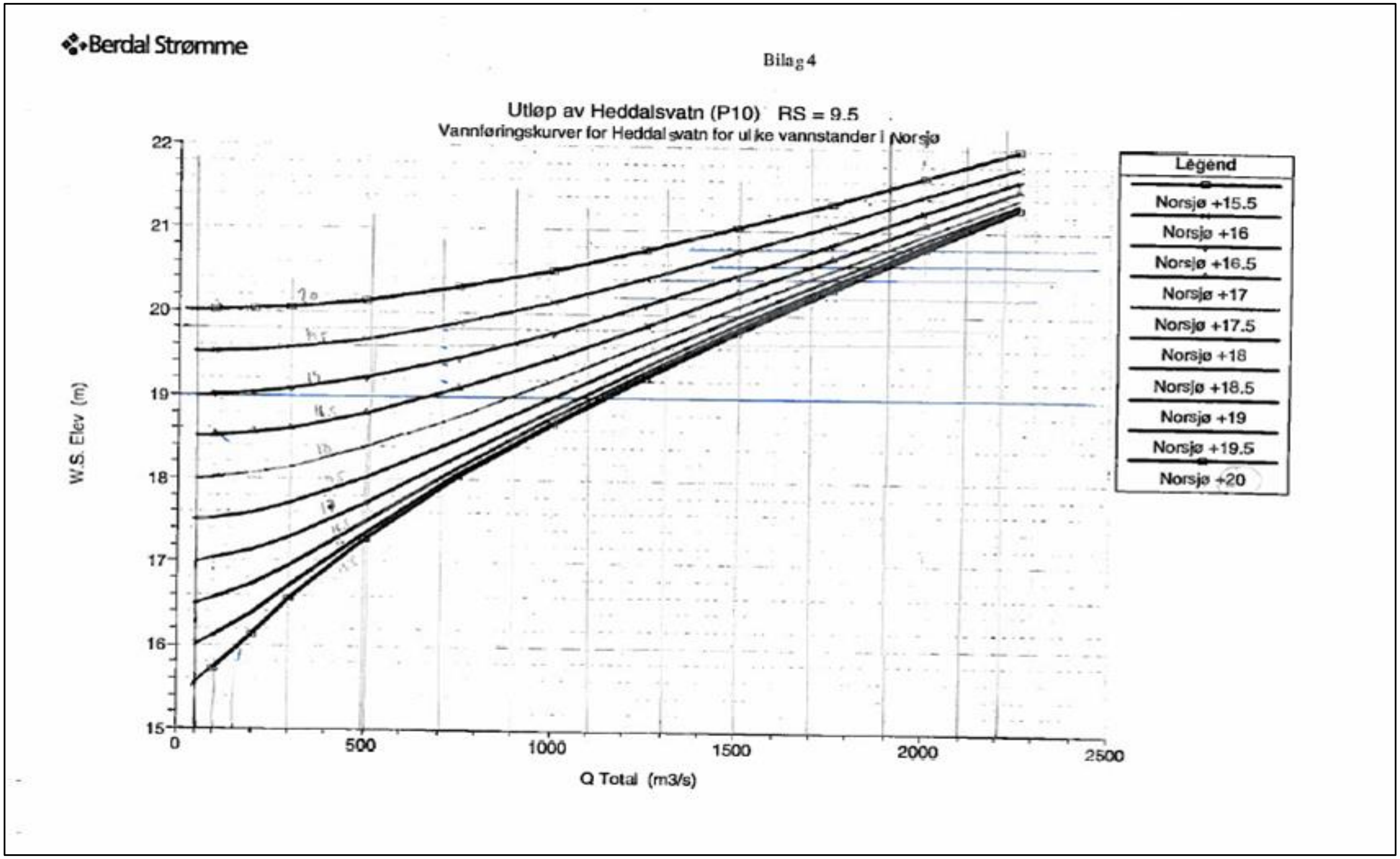
F)


FLOMBEREGNING
NORSJØ - HJELLEVANN
Oppdragsnr.: 2855100
BILAG 6
AVLØPSKURVE FOR FIRINGSFOSS I NORSJØ
OVERLØPSKURVE
FIRINGSFOSS I NORSJØ
VANNSTAND (M O.H.)
21.28
20.28
19.28
18.28
17.28
16.28
15.28
385
1385
2385
3385
4385
5385
VANNFØRING (M3/S)
Avløpskapasitet Firingsfoss Chart 1
6/7/00

G)


Hjellevatn m
Kontrollstav m
Undervatn m
Reservoir Level [m]
8.0
1.0
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
Flow at Farelva [m3/s]

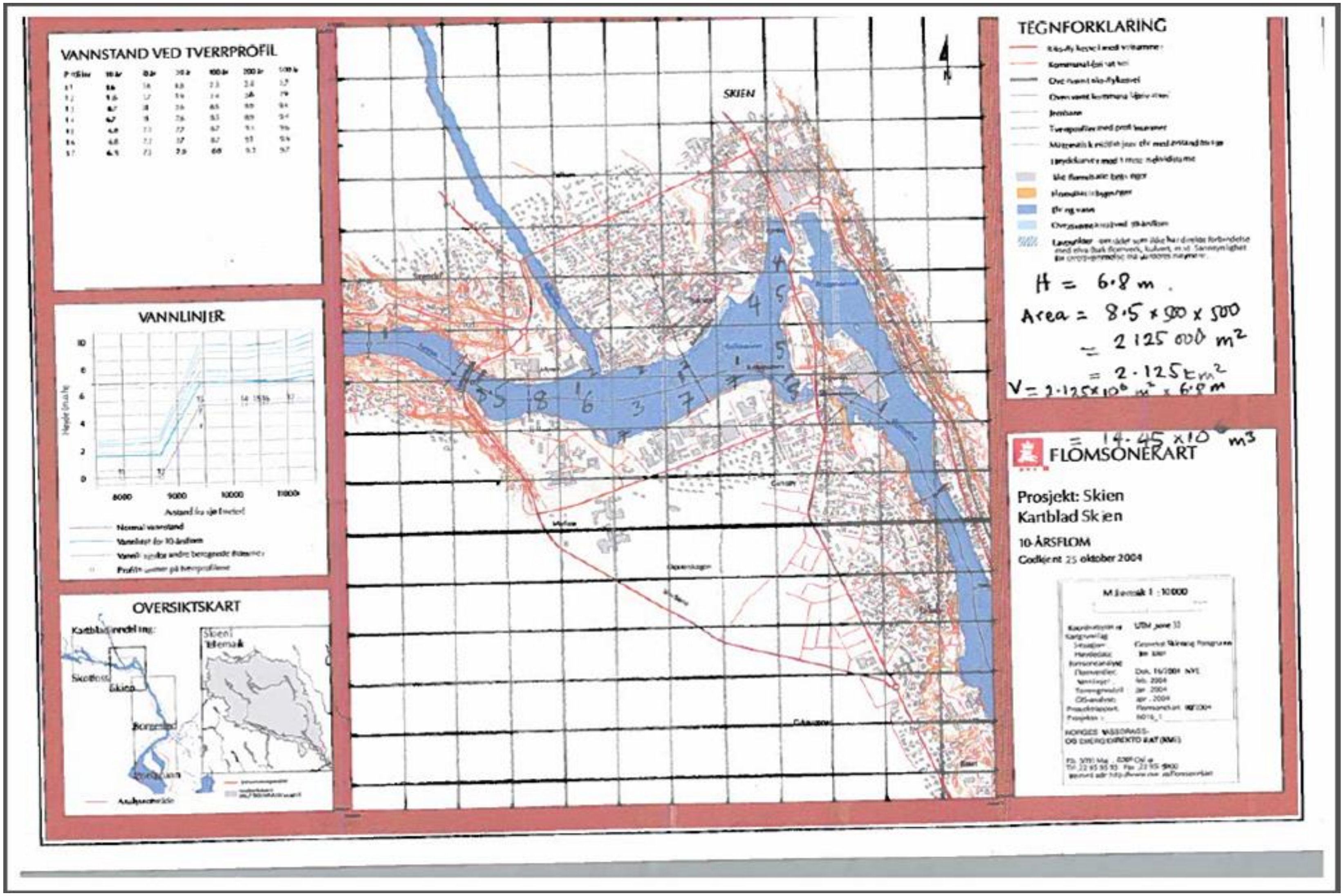
H)


Berdal Strømme
Bilag 4
Utløp av Heddalsvatn (P10) RS = 9.5
Vannføringskurver for Heddalsvatn for ulike vannstander i Norsjø
W.S. Elev (m)
Q Total (m3/s)
Legend
Norsjø +15.5
Norsjø +16
Norsjø +16.5
Norsjø +17
Norsjø +17.5
Norsjø +18
Norsjø +18.5
Norsjø +19
Norsjø +19.5
Norsjø +20

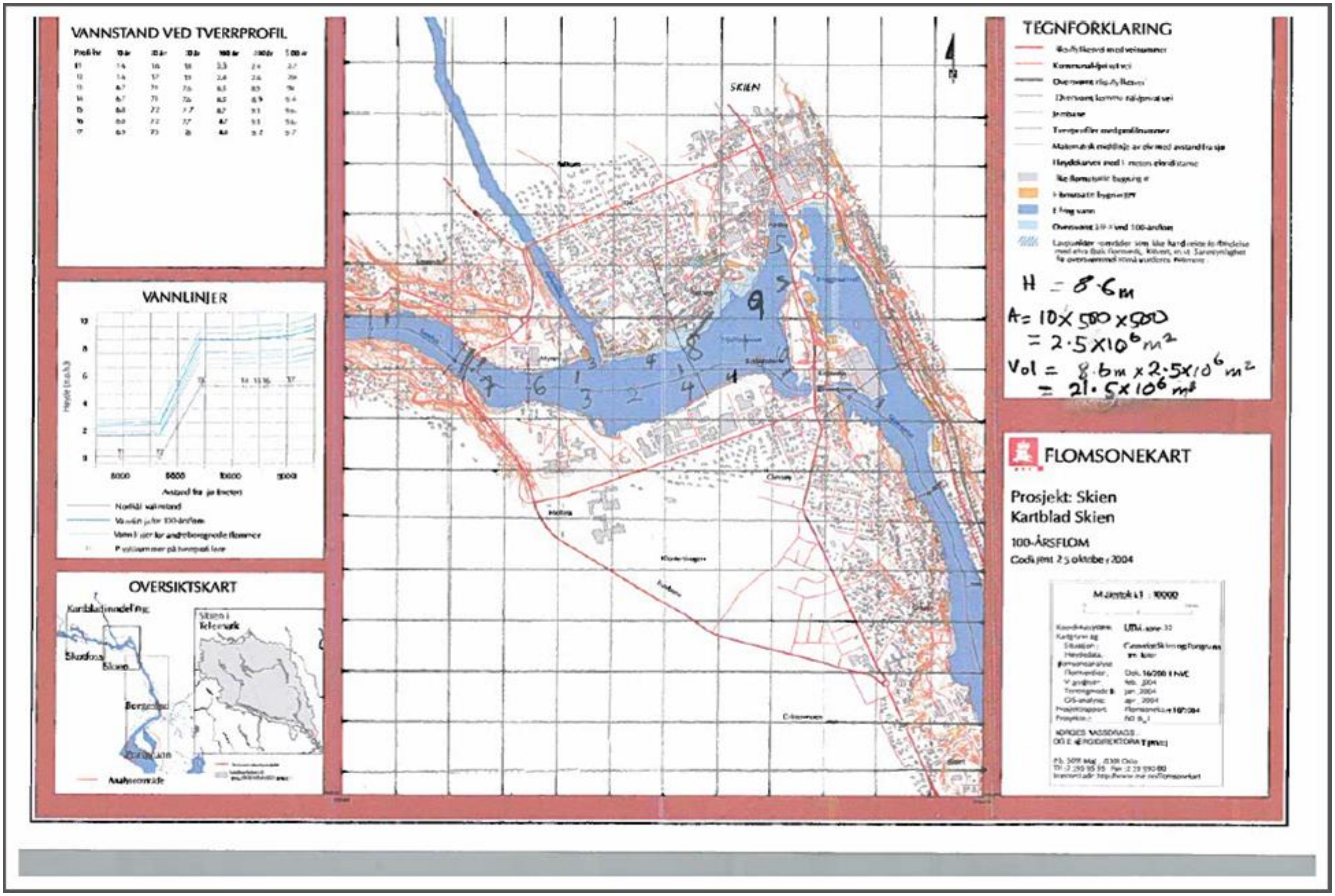
I)

Date	Vomue (m3)	ΔVolume_Heddalsvatn m3/s	Q_Tinnai(Kirkevoll Bru) m3/s	Q_Heddola (Omnefoss) m3/s	Q_Outflow_Heddalsvatn m3/s	Local Inflow_m3/s Manual Calc
31.08.2015	65763008.42	-	124.139	30.877	189	-
01.09.2015	64920646.5	-9.749559259	141.245	34.822	190	4.183
02.09.2015	71603762.9	77.35088426	151.736	270.581	375	30.034
03.09.2015	84986572.96	154.8936349	132.271	282.287	610	350.336
04.09.2015	85123126.56	1.58048151	257.417	106.34	580	217.823
05.09.2015	81952497.61	-36.69709436	285.772	61.478	430	46.053
06.09.2015	79459388.06	-28.85543458	274.074	52.71	420	64.361
07.09.2015	75590434.2	-44.77955856	183.043	41.009	325	56.168
08.09.2015	69995264.16	-64.75891253	151.327	30.976	250	2.938
09.09.2015	67345009	-30.67424954	152.25	25.567	240	31.509
10.09.2015	66040698.09	-15.09619109	151.102	23.291	250	60.511
11.09.2015	65604614.72	-5.047261198	150.005	22.432	245	67.516
12.09.2015	65235838.62	-4.268241898	149.26	28.64	255	72.832
13.09.2015	65472778.92	2.742364583	158.761	46.381	260	57.600
14.09.2015	70104616.96	53.60923655	245.398	138.708	360	29.503
15.09.2015	85305380.1	175.9347586	343.953	383.113	600	48.869
16.09.2015	98334215.29	150.7967036	327.796	239.631	795	378.370
17.09.2015	95439937.96	-33.49858021	330.918	195.318	690	130.265
18.09.2015	97500276.42	23.84650998	324.308	125.894	705	278.645
19.09.2015	90744056.42	-78.19699074	316.051	67.311	575	113.441
20.09.2015	84562488.04	-71.54593035	309.096	40.397	595	173.961
21.09.2015	80045745.06	-52.2771178	302.005	30.673	400	15.045
22.09.2015	77772027.12	-26.31617986	300.373	48.179	410	35.132
23.09.2015	77497502.25	-3.177371209	270.202	56.074	585	255.547
24.09.2015	75135405.56	-27.33908203	217.296	52.518	325	27.847
25.09.2015	74060642.82	-12.43938356	217.517	65.961	305	9.083
26.09.2015	73751085	-3.582845139	237.008	53.634	304	9.775
27.09.2015	72770781.2	-11.3461088	228.425	43.069	295	12.160
28.09.2015	70200376.52	-29.75005417	173.369	37.492	380	139.389
29.09.2015	67733639.52	-28.55019676	154.225	34.426	278	60.799
30.09.2015	66133402.92	-18.52125694	146.259	32.509	245	47.711

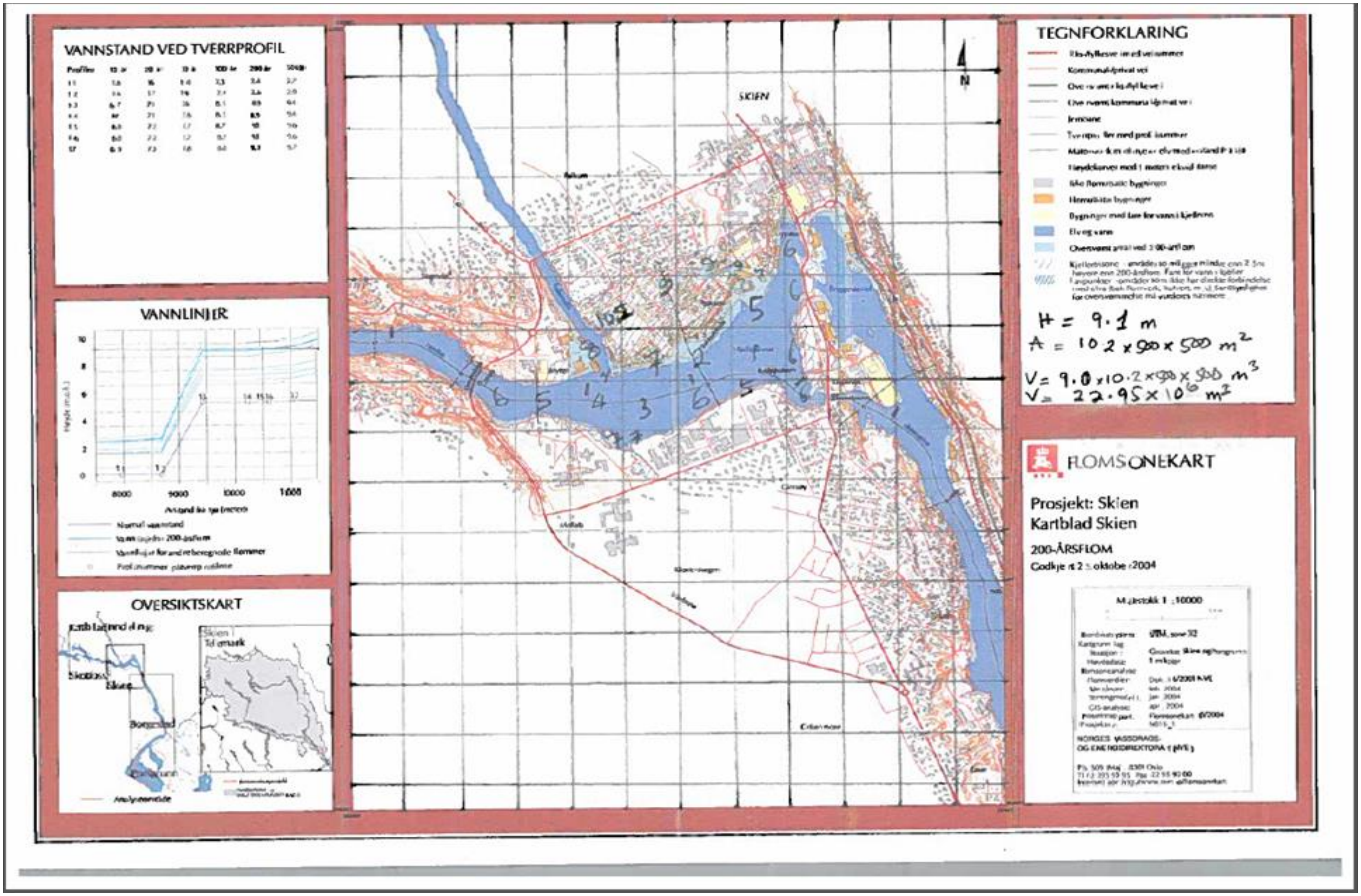
J-1. Flood map for Q10, Hjellevatn



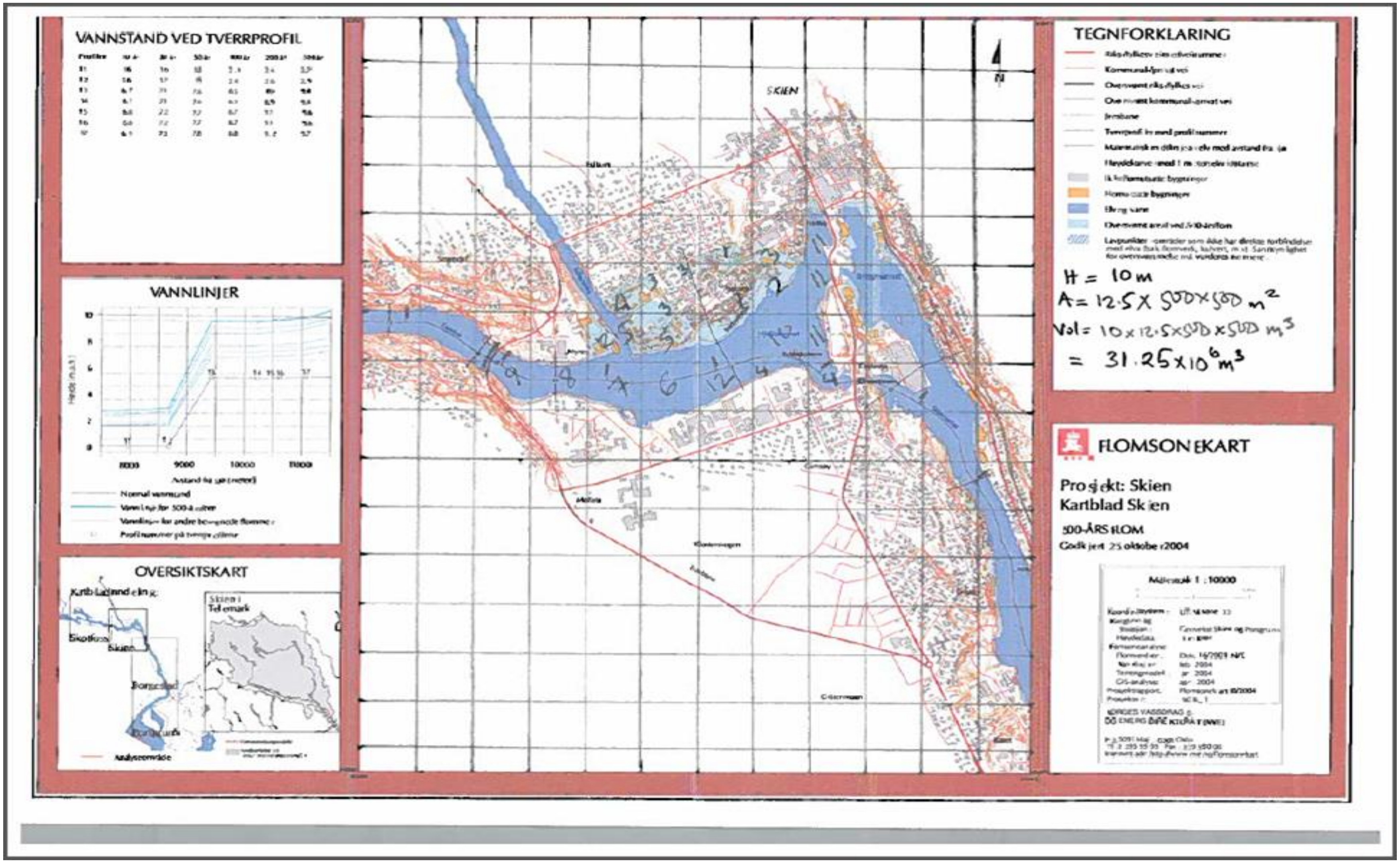
J-2 Flood map Q100, Hjellevatn



J-3 Flood map Q200, Hjellevatn



J-4 Flood map Q500, Hjellevatn

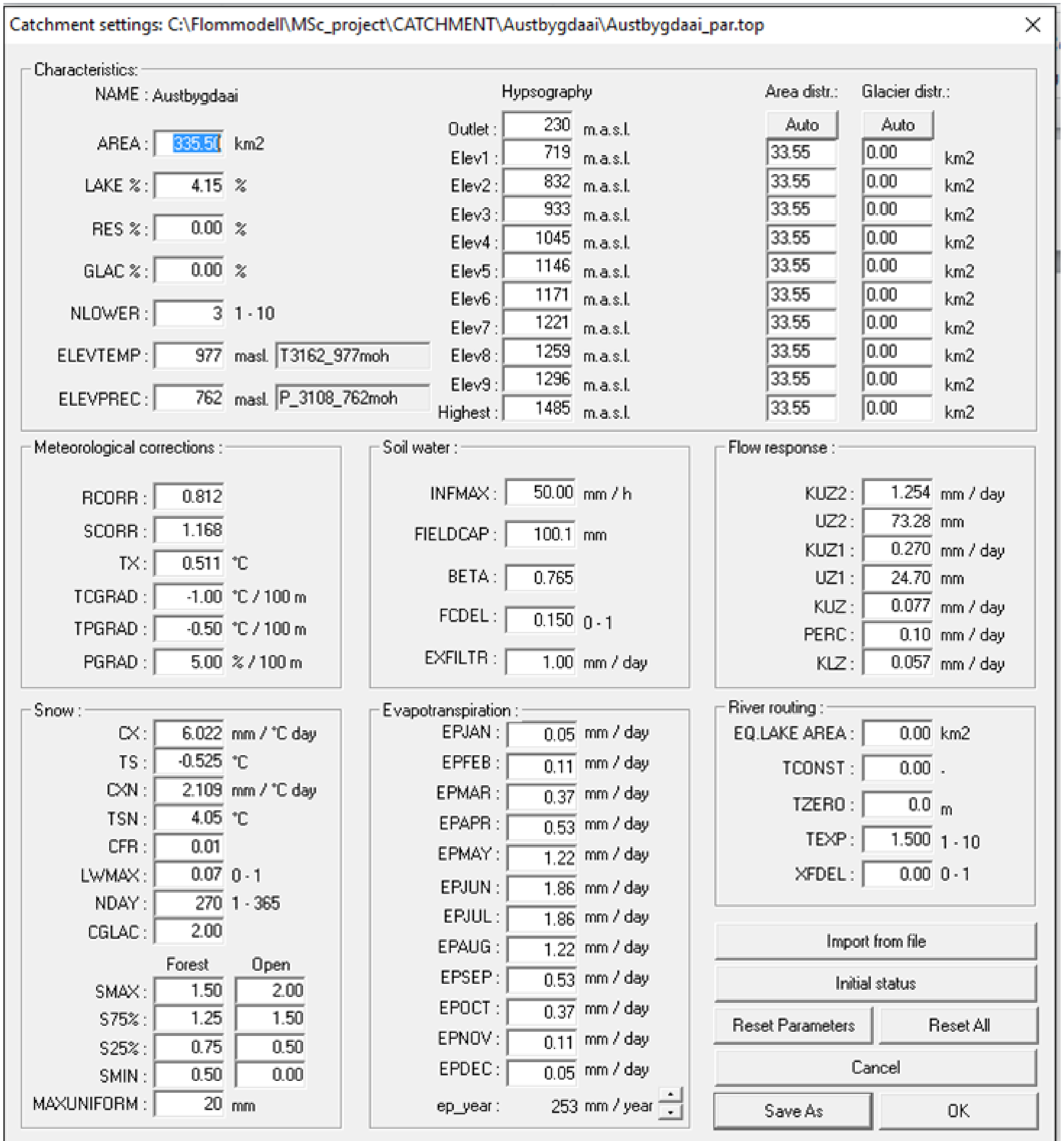


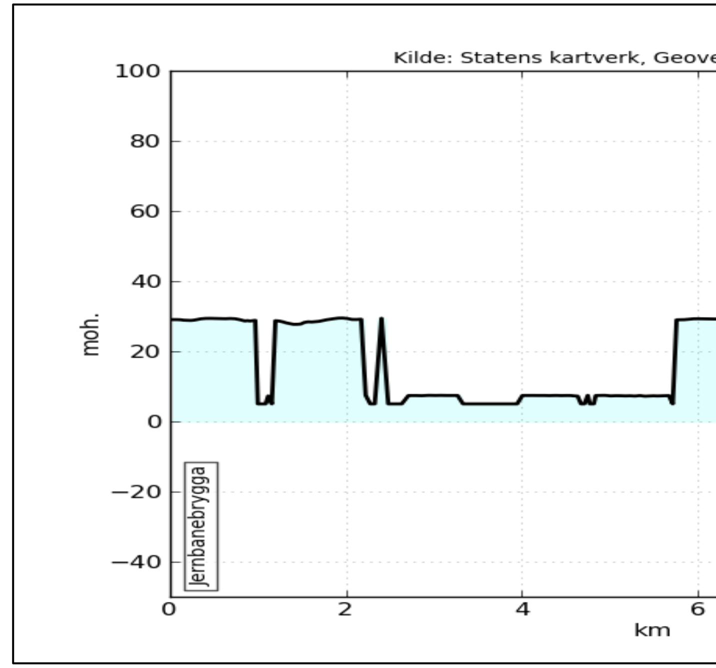
K.

Date	Inflow from Marvatnet m3/s	Inflow from Mosvatnet m3/s	Total flow to Tinsjo m3/s	Local Inflow_m3/s
01.09.2015	0.00	71.70	136.04	64.34
02.09.2015	0.00	72.86	504.05	431.19
03.09.2015	0.00	80.00	664.39	584.39
04.09.2015	0.00	79.84	328.92	249.08
05.09.2015	0.00	80.64	243.91	163.27
06.09.2015	0.00	80.98	178.62	97.64
07.09.2015	8.60	80.78	157.58	68.20
08.09.2015	11.50	80.02	145.34	53.82
09.09.2015	11.90	79.41	128.36	37.05
10.09.2015	12.10	73.54	121.24	35.60
11.09.2015	15.60	72.30	108.19	20.29
12.09.2015	13.90	72.31	125.37	39.16
13.09.2015	7.30	68.94	200.60	124.36
14.09.2015	7.30	70.27	344.07	266.50
15.09.2015	7.40	79.72	703.15	616.03
16.09.2015	7.30	60.74	423.68	355.64
17.09.2015	2.40	26.40	336.90	308.10
18.09.2015	7.70	116.50	306.41	182.21
19.09.2015	20.50	139.03	268.18	108.65
20.09.2015	21.10	133.84	231.31	76.37
21.09.2015	21.00	126.95	200.29	52.34
22.09.2015	21.10	120.72	204.70	62.88
23.09.2015	20.90	115.81	192.68	55.97
24.09.2015	21.00	111.36	209.46	77.10
25.09.2015	17.90	111.18	207.45	78.37
26.09.2015	17.30	108.71	186.62	60.61
27.09.2015	20.00	104.75	174.83	50.08
28.09.2015	21.10	101.85	146.85	23.90
29.09.2015	21.00	99.77	156.67	35.90
30.09.2015	18.70	96.81	142.13	26.62

L-1. Plan of river profile downstream of reservoir Hjellevatn (Norgeskart, 2016)

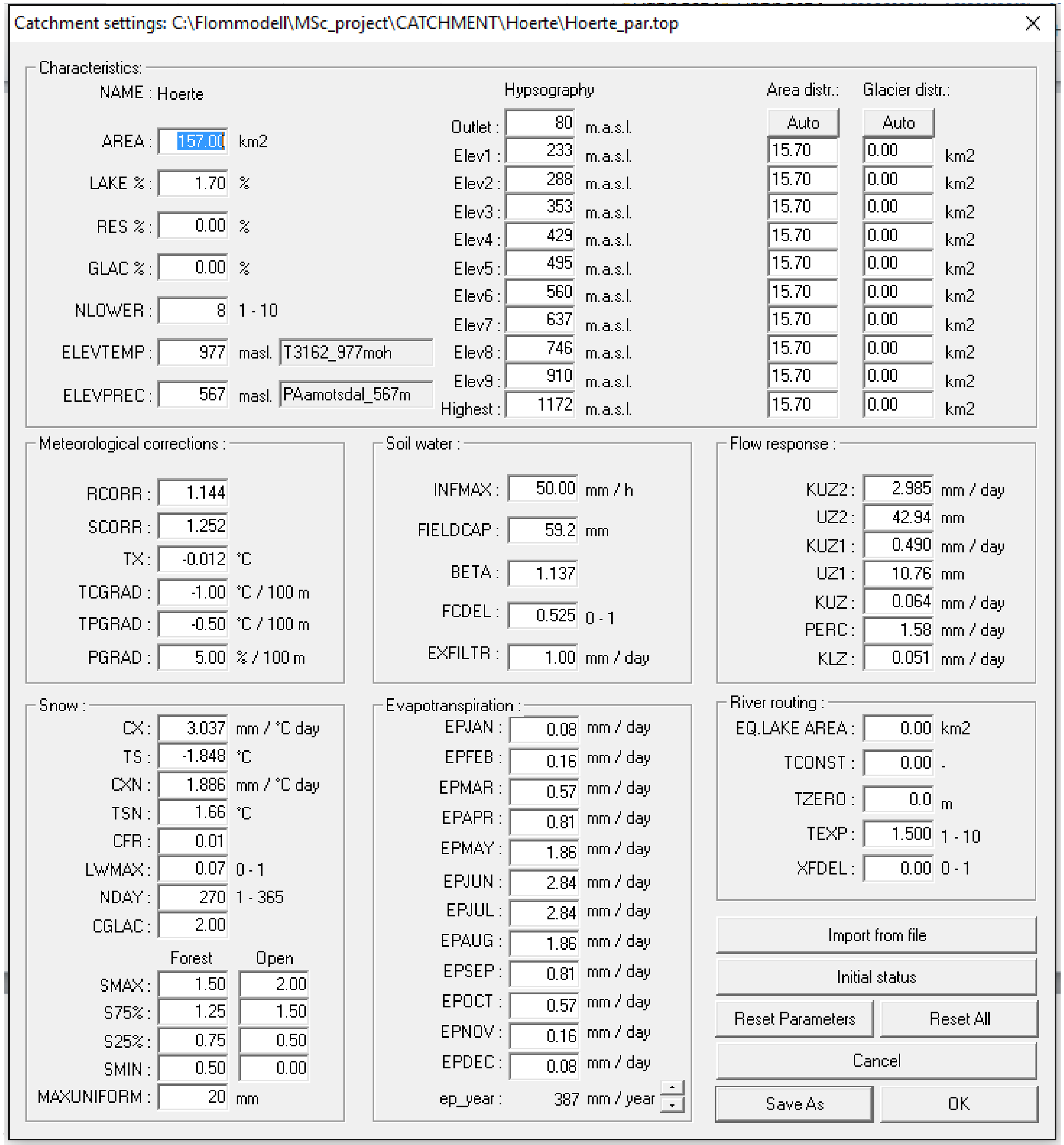
L-2. Profile of river downstream Hjellevatn





M. Results of Final Calibration for Austbygdåi in the FMTV

N. Results of Final Calibration for Horte in the FMTV


Catchment settings: C:\Flommodell\MSc_project\CATCHMENT\Hoerte\Hoerte_par.top

Characteristics:

NAME :	Hoerte		
AREA :	157.00	km2	
LAKE % :	1.70	%	
RES % :	0.00	%	
GLAC % :	0.00	%	
NLOWER :	8	1 - 10	
ELEVTEMP :	977	masl.	T3162_977moh
ELEVPREC :	567	masl.	PAamotsdal_567m

Hypsography			Area distr.:	Glacier distr.:	
			Auto	Auto	
Outlet :	80	m.a.s.l.			
Elev1 :	233	m.a.s.l.	15.70	0.00	km2
Elev2 :	288	m.a.s.l.	15.70	0.00	km2
Elev3 :	353	m.a.s.l.	15.70	0.00	km2
Elev4 :	429	m.a.s.l.	15.70	0.00	km2
Elev5 :	495	m.a.s.l.	15.70	0.00	km2
Elev6 :	560	m.a.s.l.	15.70	0.00	km2
Elev7 :	637	m.a.s.l.	15.70	0.00	km2
Elev8 :	746	m.a.s.l.	15.70	0.00	km2
Elev9 :	910	m.a.s.l.	15.70	0.00	km2
Highest :	1172	m.a.s.l.	15.70	0.00	km2

Meteorological corrections :

RCORR :	1.144	
SCORR :	1.252	
TX :	-0.012	°C
TCGRAD :	-1.00	°C / 100 m
TPGRAD :	-0.50	°C / 100 m
PGRAD :	5.00	% / 100 m

Soil water :

INFMAX :	50.00	mm / h
FIELDCAP :	59.2	mm
BETA :	1.137	
FCDEL :	0.525	0 - 1
EXFILTR :	1.00	mm / day

Flow response :

KUZ2 :	2.985	mm / day
UZ2 :	42.94	mm
KUZ1 :	0.490	mm / day
UZ1 :	10.76	mm
KUZ :	0.064	mm / day
PERC :	1.58	mm / day
KLZ :	0.051	mm / day

Snow :

CX :	3.037	mm / °C day
TS :	-1.848	°C
CXN :	1.886	mm / °C day
TSN :	1.66	°C
CFR :	0.01	
LWMAX :	0.07	0 - 1
NDAY :	270	1 - 365
CGLAC :	2.00	

	Forest	Open
SMAX :	1.50	2.00
S75% :	1.25	1.50
S25% :	0.75	0.50
SMIN :	0.50	0.00
MAXUNIFORM :	20	mm

Evapotranspiration :

EPJAN :	0.08	mm / day
EPFEB :	0.16	mm / day
EPMAR :	0.57	mm / day
EPAPR :	0.81	mm / day
EPMAY :	1.86	mm / day
EPJUN :	2.84	mm / day
EPJUL :	2.84	mm / day
EPAUG :	1.86	mm / day
EPSEP :	0.81	mm / day
EPOCT :	0.57	mm / day
EPNOV :	0.16	mm / day
EPDEC :	0.08	mm / day
ep_year :	387	mm / year

River routing :

EQ.LAKE AREA :	0.00	km2
TCONST :	0.00	-
TZERO :	0.0	m
TEXP :	1.500	1 - 10
XFDEL :	0.00	0 - 1

Import from file

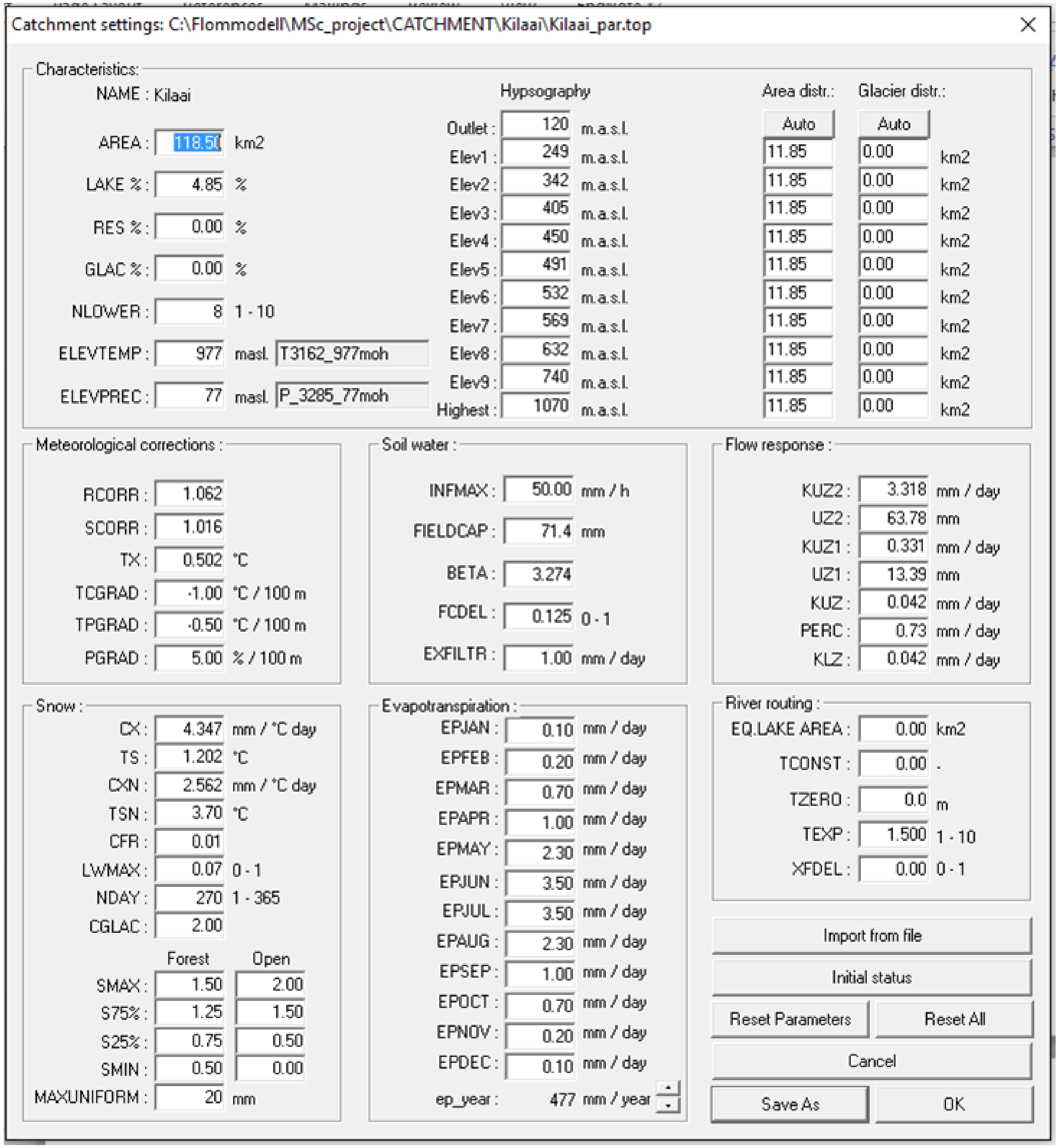
Initial status

Reset Parameters | Reset All

Cancel

Save As | OK

O. Results of Final Calibration for Kilaai in the FMTV


Catchment settings: C:\Flommodell\MSc_project\CATCHMENT\Kilaai\Kilaai_par.top
Characteristics:
NAME : Kilaai
AREA : 118.50 km2
LAKE % : 4.85 %
RES % : 0.00 %
GLAC % : 0.00 %
NLOWER : 8 1 - 10
ELEVTEMP : 977 masl. T3162_977moh
ELEVPREC : 77 masl. P_3285_77moh
Hypsography
Outlet : 120 m.a.s.l.
Elev1 : 249 m.a.s.l.
Elev2 : 342 m.a.s.l.
Elev3 : 405 m.a.s.l.
Elev4 : 450 m.a.s.l.
Elev5 : 491 m.a.s.l.
Elev6 : 532 m.a.s.l.
Elev7 : 569 m.a.s.l.
Elev8 : 632 m.a.s.l.
Elev9 : 740 m.a.s.l.
Highest : 1070 m.a.s.l.
Area distr.: Auto 11.85 11.85 11.85 11.85 11.85 11.85 11.85 11.85 11.85 11.85
Glacier distr.: Auto 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 km2
Meteorological corrections :
RCORR : 1.062
SCORR : 1.016
TX : 0.502 °C
TCGRAD : -1.00 °C / 100 m
TPGRAD : -0.50 °C / 100 m
PGRAD : 5.00 % / 100 m
Soil water :
INFMAX : 50.00 mm / h
FIELDCAP : 71.4 mm
BETA : 3.274
FCDEL : 0.125 0 - 1
EXFILTR : 1.00 mm / day
Flow response :
KUZ2 : 3.318 mm / day
UZ2 : 63.78 mm
KUZ1 : 0.331 mm / day
UZ1 : 13.39 mm
KUZ : 0.042 mm / day
PERC : 0.73 mm / day
KLZ : 0.042 mm / day
Snow :
CX : 4.347 mm / °C day
TS : 1.202 °C
CXN : 2.562 mm / °C day
TSN : 3.70 °C
CFR : 0.01
LWMAX : 0.07 0 - 1
NDAY : 270 1 - 365
CGLAC : 2.00
Forest Open
SMAX : 1.50 2.00
S75% : 1.25 1.50
S25% : 0.75 0.50
SMIN : 0.50 0.00
MAXUNIFORM : 20 mm
Evapotranspiration :
EPJAN : 0.10 mm / day
EPFEB : 0.20 mm / day
EPMAR : 0.70 mm / day
EPAPR : 1.00 mm / day
EPMAY : 2.30 mm / day
EPJUN : 3.50 mm / day
EPJUL : 3.50 mm / day
EPAUG : 2.30 mm / day
EPSEP : 1.00 mm / day
EPOCT : 0.70 mm / day
EPNOV : 0.20 mm / day
EPDEC : 0.10 mm / day
ep_year : 477 mm / year
River routing :
EQ.LAKE AREA : 0.00 km2
TCONST : 0.00 -
TZERO : 0.0 m
TEXP : 1.500 1 - 10
XFDEL : 0.00 0 - 1
Import from file
Initial status
Reset Parameters
Reset All
Cancel
Save As
OK

P)Existing FMTV

Location	Name of Target Catchment	Catchment Area (km^2)	Elevation (m.a.s.l)		Avg.Specific Runoff (l/s*km^2)	Scaling Constant K	Reference Donor Catchment
			Minimum	Maximum			
1	Kileai	118.5	120	1070	15.69	-	-
2	Hørte	115	80	1172	31.78	-	-
3	Austbygdai	347	230	1485	25.6	-	-
4	Local Tinnsjoen	1169.57	187	1420	22.6	3.71	Austbygdai
5	Local Tinnelva	344.2	150	1320	16.3	0.67	Austbygdai
6	Local Heddalsvatn	255.7	50	750	14.6	2.982	Kileai
7	Local Heddola	1000.5	40	1850	24.4	0.414	Hørte
8	Local Saua	53.2	50	800	15.8	0.36	Kileai
9	Local Norsjo	567.4	260	750	17.6	1.592	Kileai
10	Local Boelva	1052	30	1550	25.2	0.754	Hørte
11	Local Skien	115.1	20	550	18.6	0.58	Austbygdai
12	Local Hjellevatn	303.1	0	350	16.9	2.082	Kileai

Q. Vinod Thesis

Location	Name of Target Catchment	Catchment Area (km^2)	Elevation (m.a.s.l)		Specific Runoff ($l/s*km^2$)	Scaling Constant K	Reference Donor Catchment
			Minimum	Maximum			
1	Kileai	119	120	1060	19.7	-	-
2	Horte	115	80	1200	24	-	-
3	Austbygdai	347	187	1480	24.2	-	-
4	Local Tinnsjoen	1169.57	187	1420	22.6	3.16	Austbygdai
5	Local Tinnelva	344.2	150	1320	16.3	0.67	Austbygdai
6	Local Heddalsvatn	255.7	50	750	14.6	1.59	Kileai

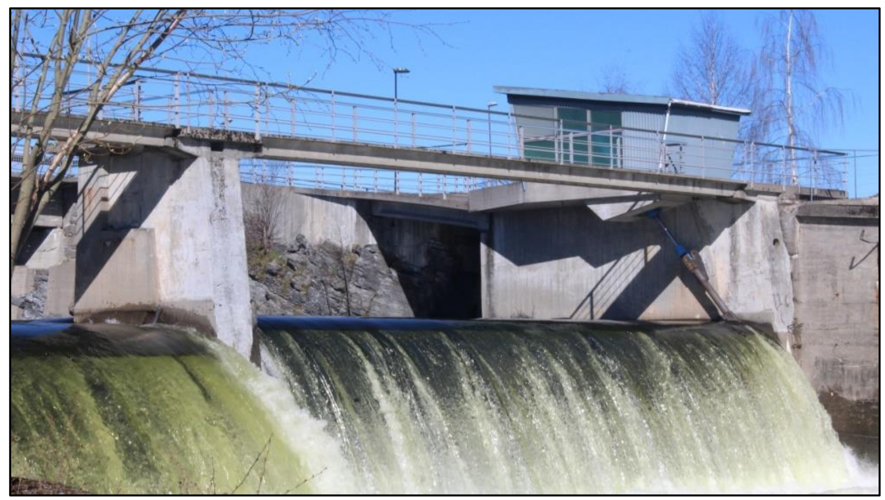
7	Local Heddola	1000.5	40	1850	24.4	2.92	Hørte
8	Local Saua	53.2	50	800	15.8	0.36	Kileai
9	Local Norsjo	567.4	260	750	17.6	4.26	Kileai
10	Local Boelva	1052	30	1550	25.2	3.18	Hørte
11	Local Skien	115.1	20	550	18.6	0.58	Austbygdai
12	Local Hjellevatn	303.1	0	350	16.9	1.38	Kileai

R-1

First site visit

Intake of Klosterofss

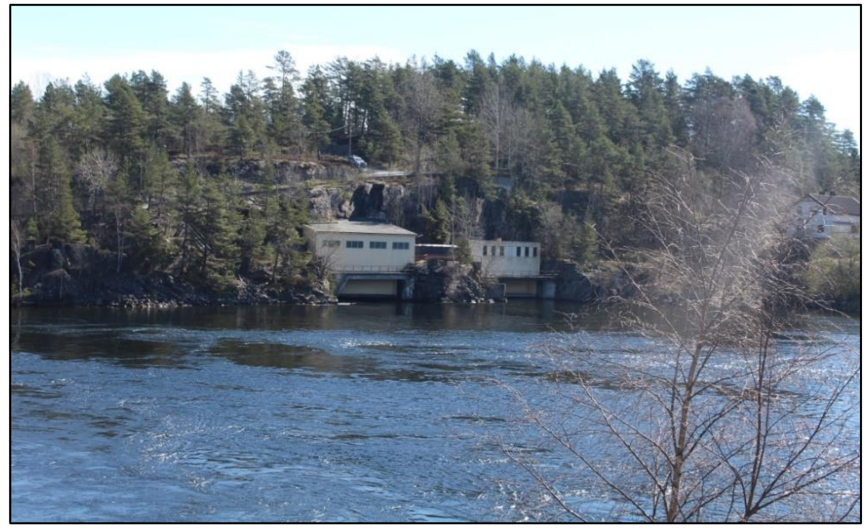
Terrain of Hjellevatn



Spillway of Hjellevatn

R-2

Boat lift at Skotfoss



Intake into Skotfoss

Farelva ndf Skotfoss gauging station

Farelva ndf skotfoss gauging station

R-3

Spillway of Vrangfoss

Intake to Vrangfoss

Tail water from

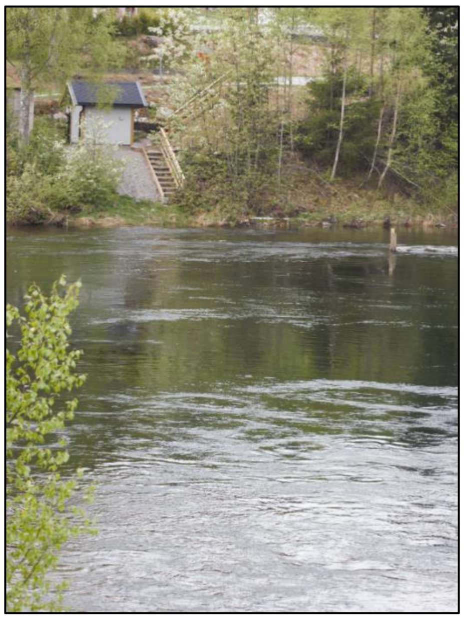
Boat lift, Spillway and tail water from Ulefoss

R-4 Level and proximity of human settlement near the banks of Hjellevatn, Skien

S-1. Second site visit

Omnesfoss gauging station

Bridge threatened by September, 2015 flood near Omnesfoss



Kirkevoll Bru gauging station

View of Austbygdåi from the banks of Tinnsjo

S-2

Skarsfoss

Outlet from Mosvatn

Reservoir of Mosvatn

S-3

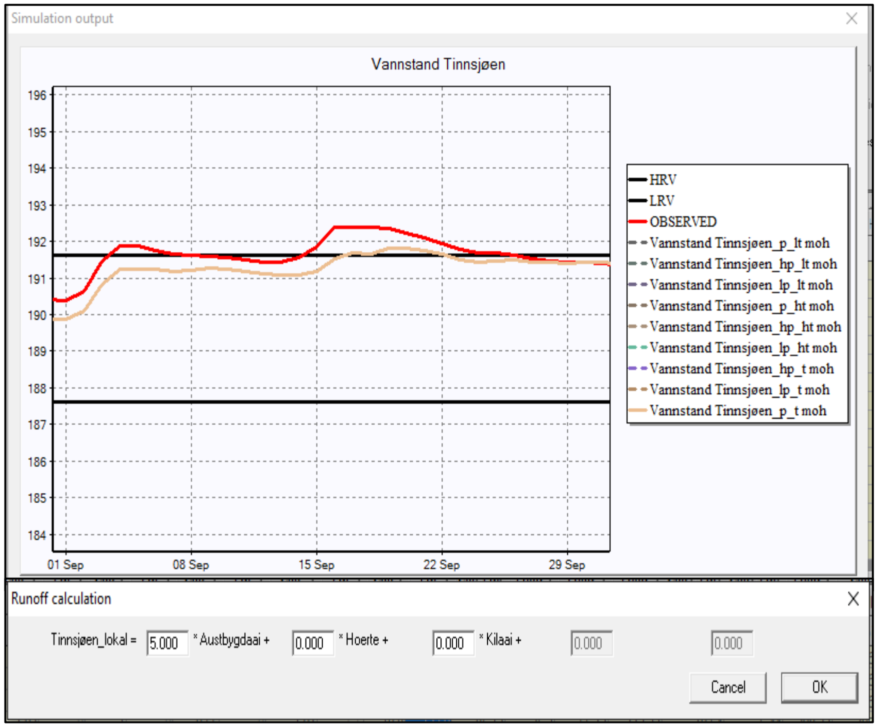
View of snow in the upstream catchment of Mosvatn

S-4

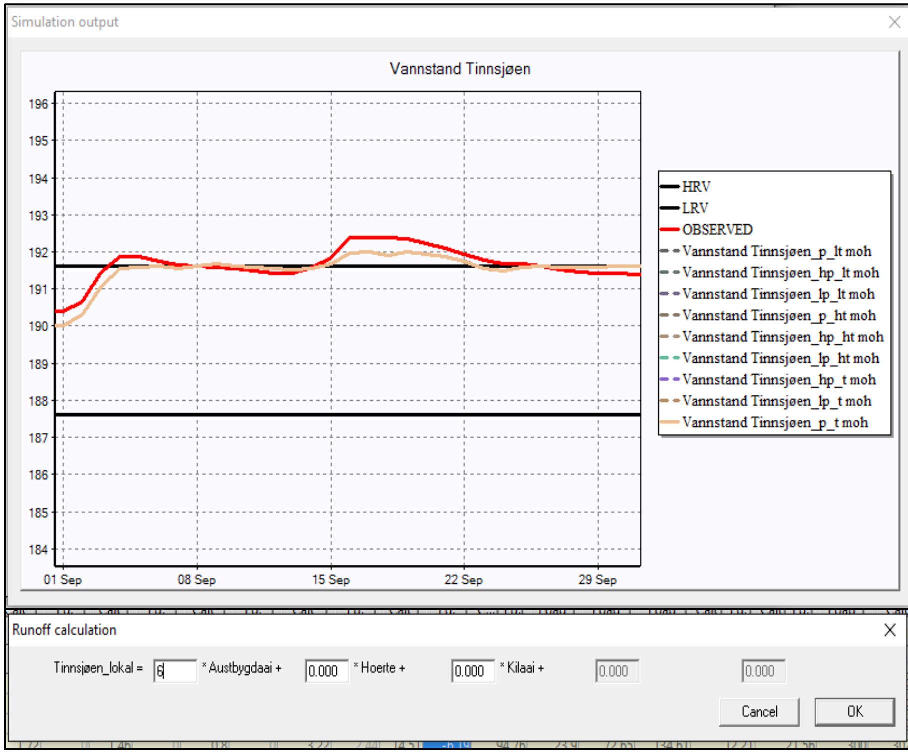
Tail water from Mar Hydropower Plant

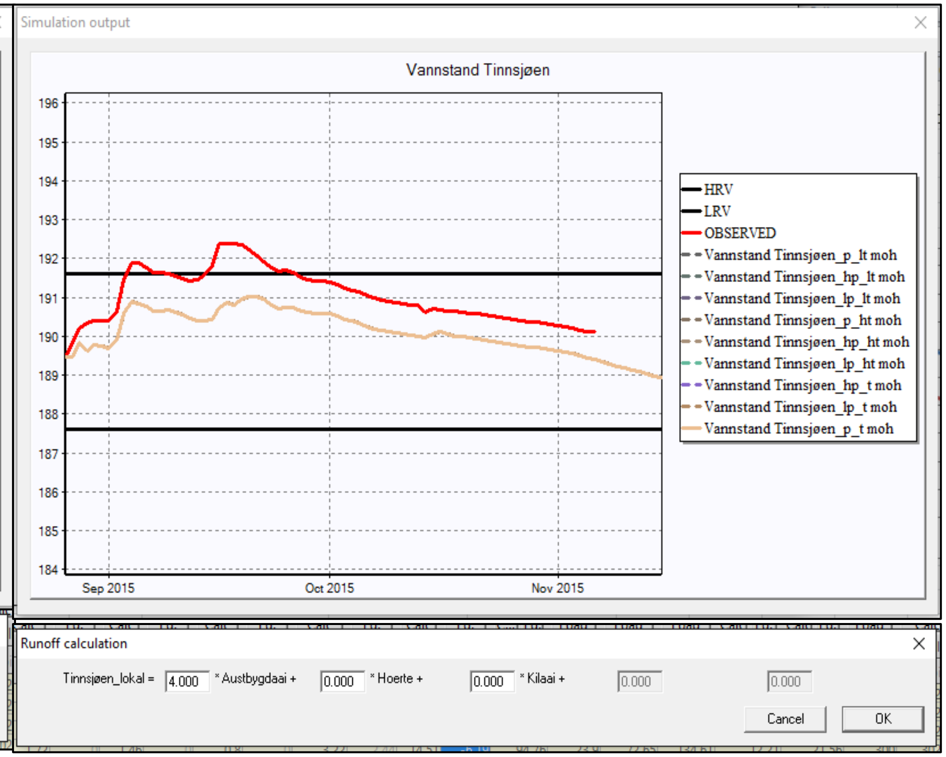
Simulation results from Trial and Error test

T-1. Tinnsjo

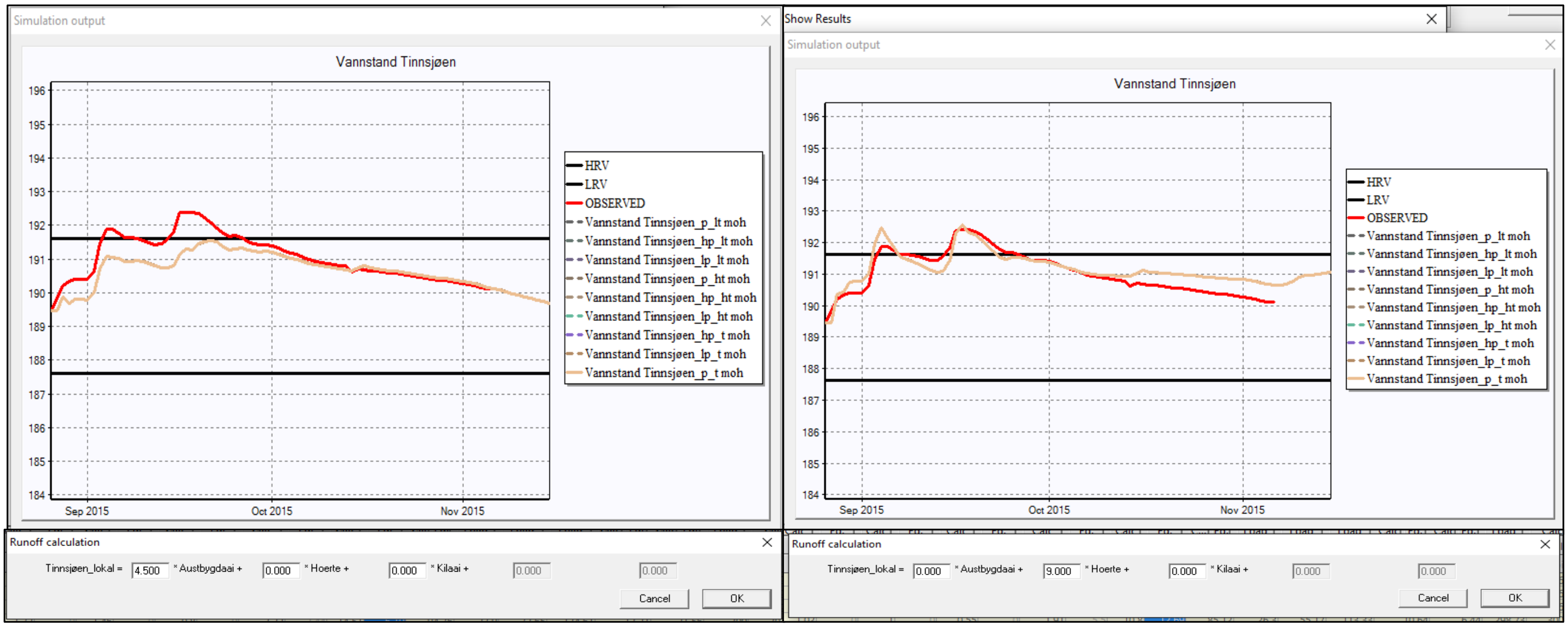


T-2

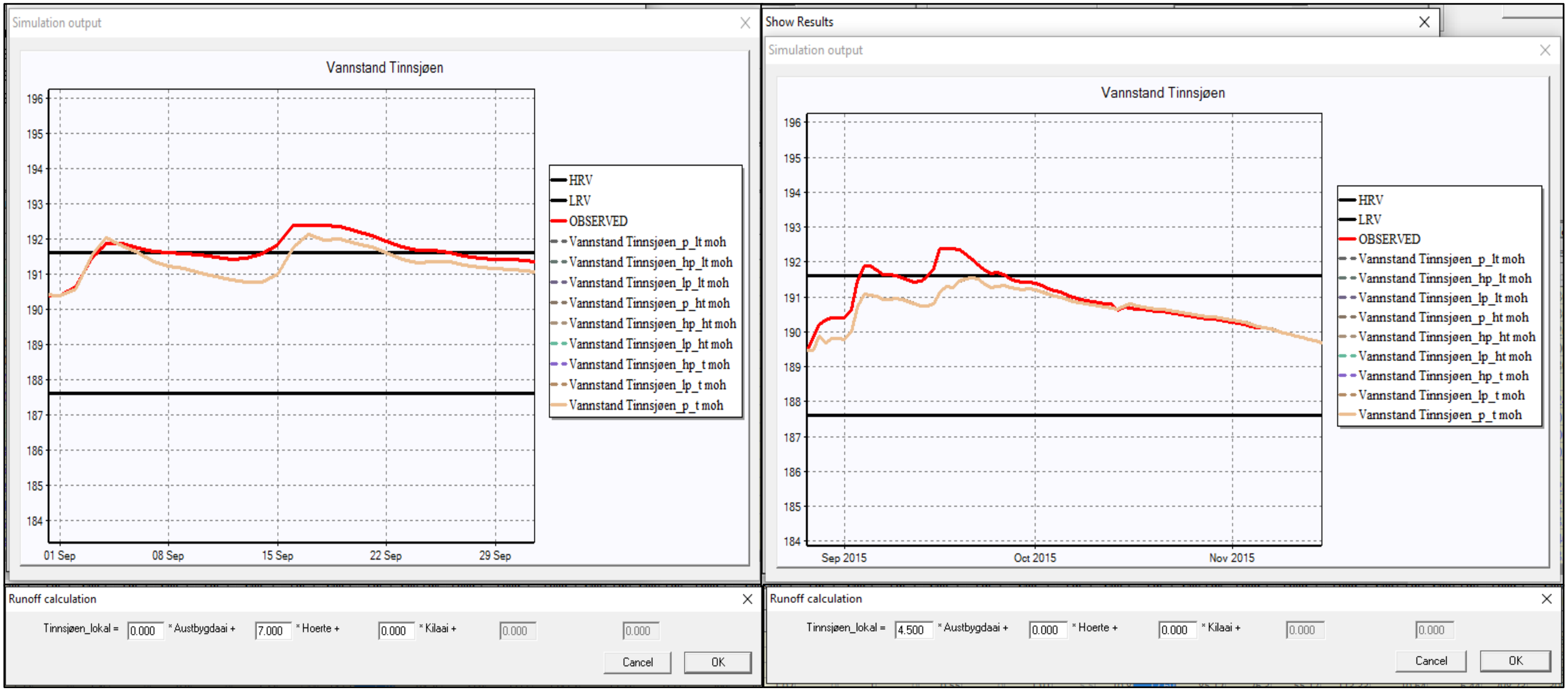

Simulation output
Vannstand Tinnsjøen
196
195
194
193
192
191
190
189
188
187
186
185
184
01 Sep
08 Sep
15 Sep
22 Sep
29 Sep
HRV
LRV
OBSERVED
Vannstand Tinnsjøen_p_lt moh
Vannstand Tinnsjøen_hp_lt moh
Vannstand Tinnsjøen_lp_lt moh
Vannstand Tinnsjøen_p_ht moh
Vannstand Tinnsjøen_hp_ht moh
Vannstand Tinnsjøen_lp_ht moh
Vannstand Tinnsjøen_hp_t moh
Vannstand Tinnsjøen_lp_t moh
Vannstand Tinnsjøen_p_t moh
Runoff calculation
Tinnsjøen_lokal =
6
* Austbygdaai +
0.000
* Hoerte +
0.000
* Kilaai +
0.000
0.000
Cancel
OK


Simulation output
Vannstand Tinnsjøen
196
195
194
193
192
191
190
189
188
187
186
185
184
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Tinnsjøen_p_lt moh
Vannstand Tinnsjøen_hp_lt moh
Vannstand Tinnsjøen_lp_lt moh
Vannstand Tinnsjøen_p_ht moh
Vannstand Tinnsjøen_hp_ht moh
Vannstand Tinnsjøen_lp_ht moh
Vannstand Tinnsjøen_hp_t moh
Vannstand Tinnsjøen_lp_t moh
Vannstand Tinnsjøen_p_t moh
Runoff calculation
Tinnsjøen_lokal =
4.000
* Austbygdaai +
0.000
* Hoerte +
0.000
* Kilaai +
0.000
0.000
Cancel
OK

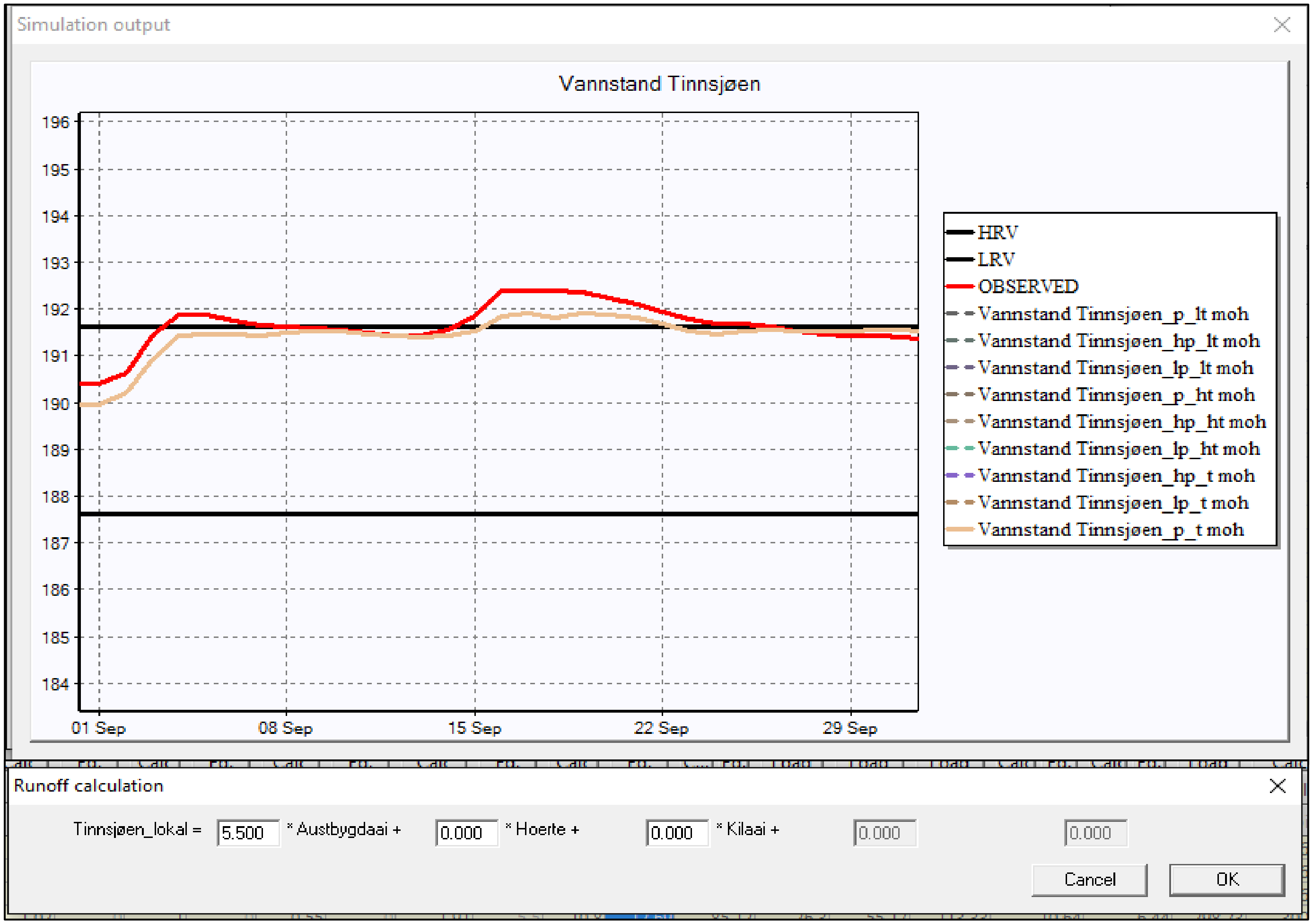
T-3


Simulation output
Vannstand Tinnsjøen
196
195
194
193
192
191
190
189
188
187
186
185
184
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Tinnsjøen_p_lt moh
Vannstand Tinnsjøen_hp_lt moh
Vannstand Tinnsjøen_lp_lt moh
Vannstand Tinnsjøen_p_ht moh
Vannstand Tinnsjøen_hp_ht moh
Vannstand Tinnsjøen_lp_ht moh
Vannstand Tinnsjøen_hp_t moh
Vannstand Tinnsjøen_lp_t moh
Vannstand Tinnsjøen_p_t moh
Runoff calculation
Tinnsjøen_lokal = 4.500 * Austbygdaai + 0.000 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK
Show Results
Simulation output
Vannstand Tinnsjøen
Runoff calculation
Tinnsjøen_lokal = 0.000 * Austbygdaai + 9.000 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK

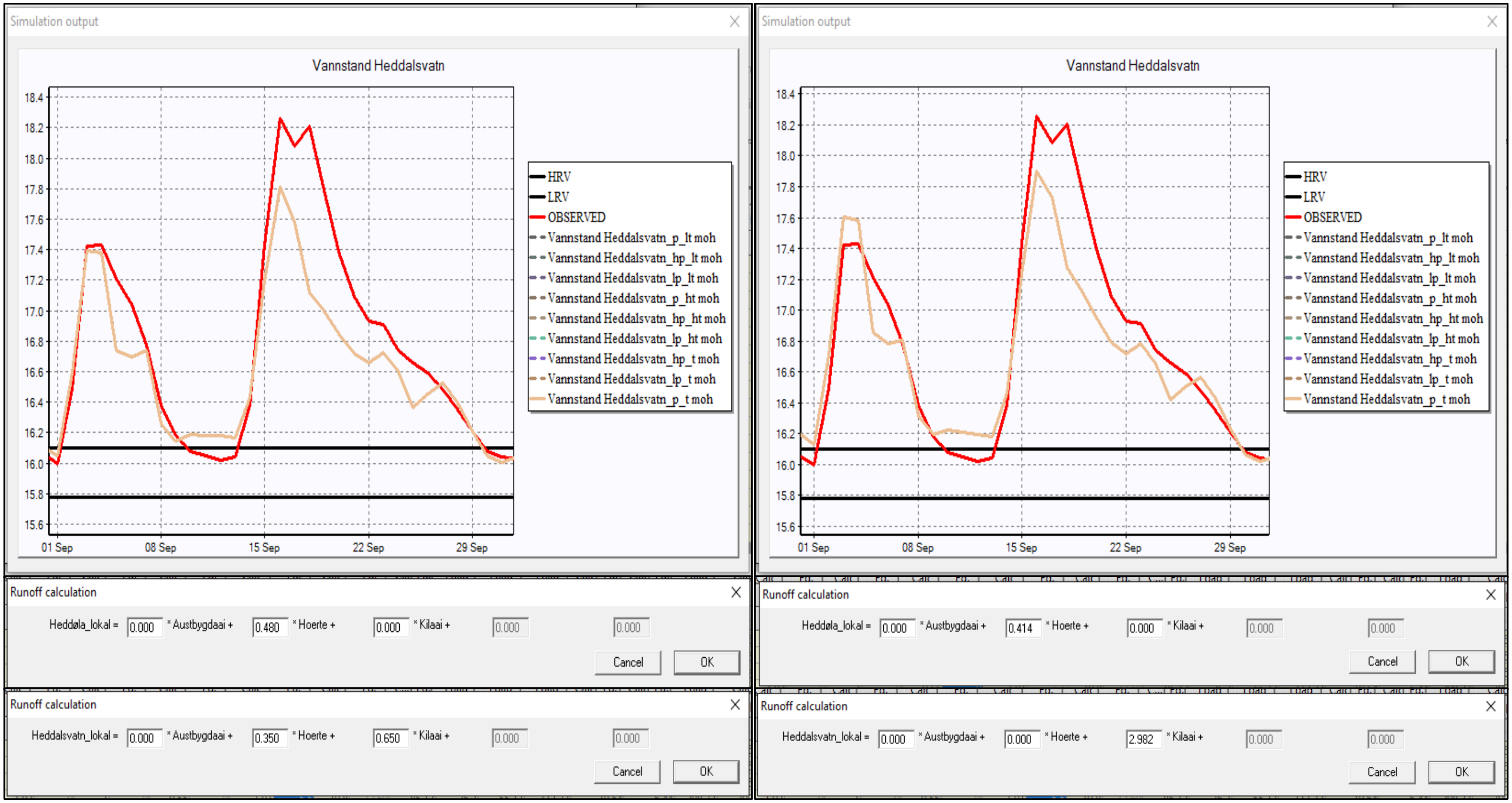
T-4


Simulation output
Vannstand Tinnsjøen
196
195
194
193
192
191
190
189
188
187
186
185
184
01 Sep
08 Sep
15 Sep
22 Sep
29 Sep
HRV
LRV
OBSERVED
Vannstand Tinnsjøen_p_lt moh
Vannstand Tinnsjøen_hp_lt moh
Vannstand Tinnsjøen_lp_lt moh
Vannstand Tinnsjøen_p_ht moh
Vannstand Tinnsjøen_hp_ht moh
Vannstand Tinnsjøen_lp_ht moh
Vannstand Tinnsjøen_hp_t moh
Vannstand Tinnsjøen_lp_t moh
Vannstand Tinnsjøen_p_t moh
Runoff calculation
Tinnsjøen_lokal = 0.000 * Austbygdaai + 7.000 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK
Show Results
Simulation output
Vannstand Tinnsjøen
Sep 2015
Oct 2015
Nov 2015
Runoff calculation
Tinnsjøen_lokal = 4.500 * Austbygdaai + 0.000 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK

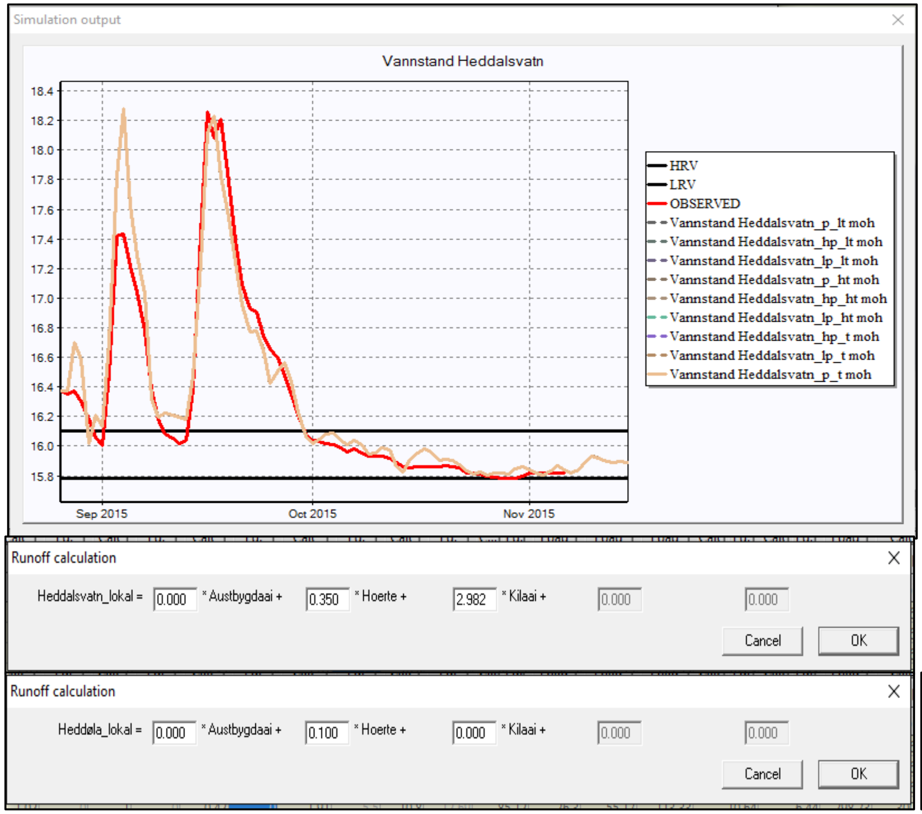
T-5

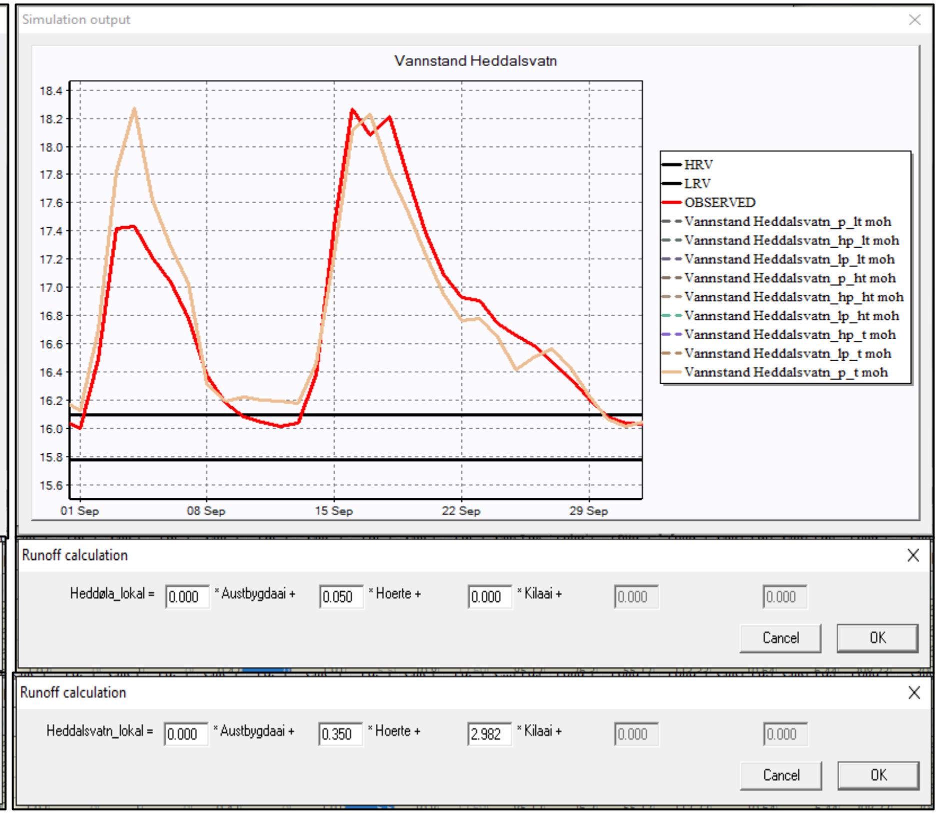

Simulation output
Vannstand Tinnsjøen
196
195
194
193
192
191
190
189
188
187
186
185
184
01 Sep
08 Sep
15 Sep
22 Sep
29 Sep
HRV
LRV
OBSERVED
Vannstand Tinnsjøen_p_lt moh
Vannstand Tinnsjøen_hp_lt moh
Vannstand Tinnsjøen_lp_lt moh
Vannstand Tinnsjøen_p_ht moh
Vannstand Tinnsjøen_hp_ht moh
Vannstand Tinnsjøen_lp_ht moh
Vannstand Tinnsjøen_hp_t moh
Vannstand Tinnsjøen_lp_t moh
Vannstand Tinnsjøen_p_t moh
Runoff calculation
Tinnsjøen_lokal = 5.500 * Austbygdaai + 0.000 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK

U-1. Heddalsvatn

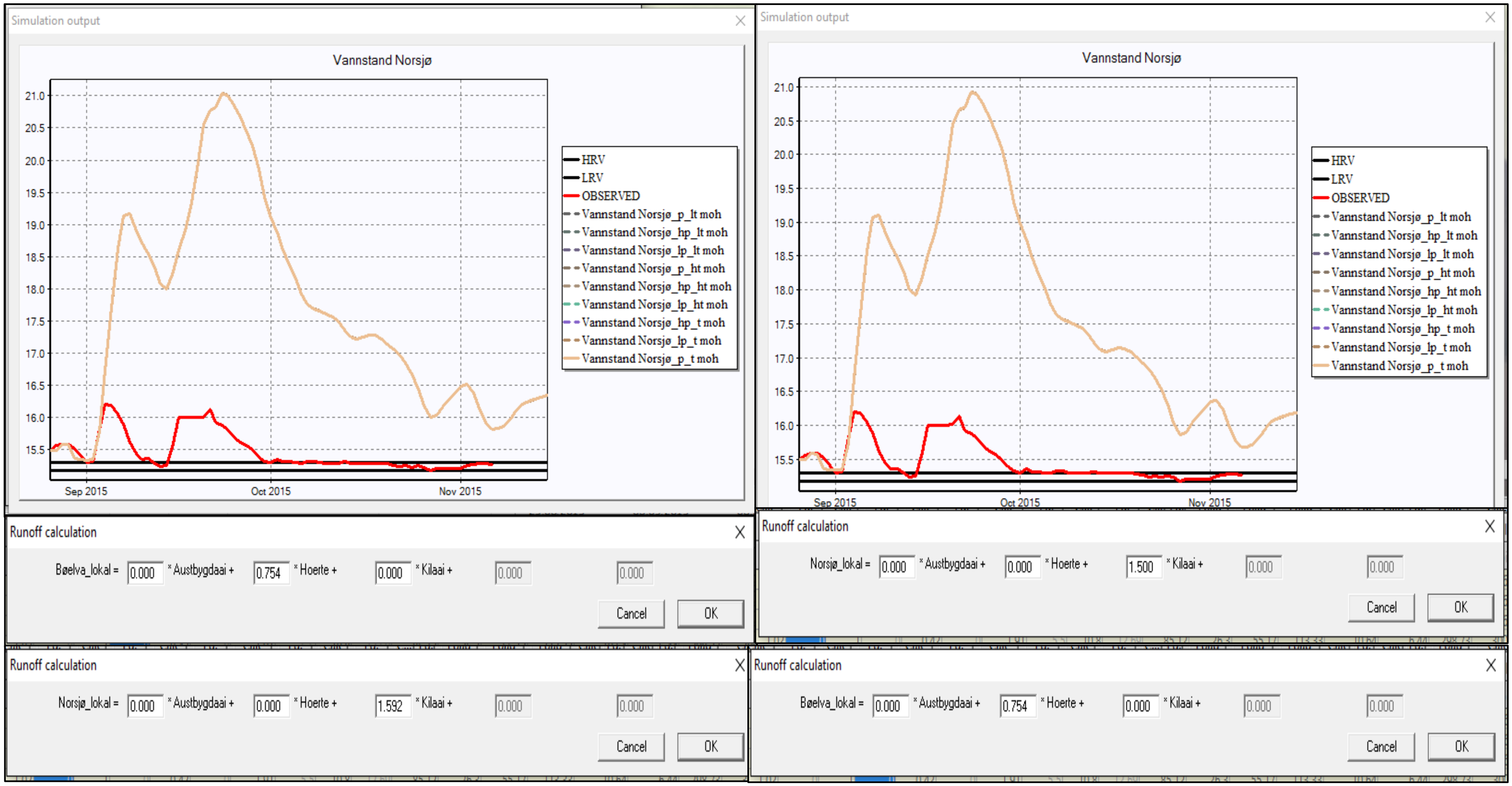


U-2

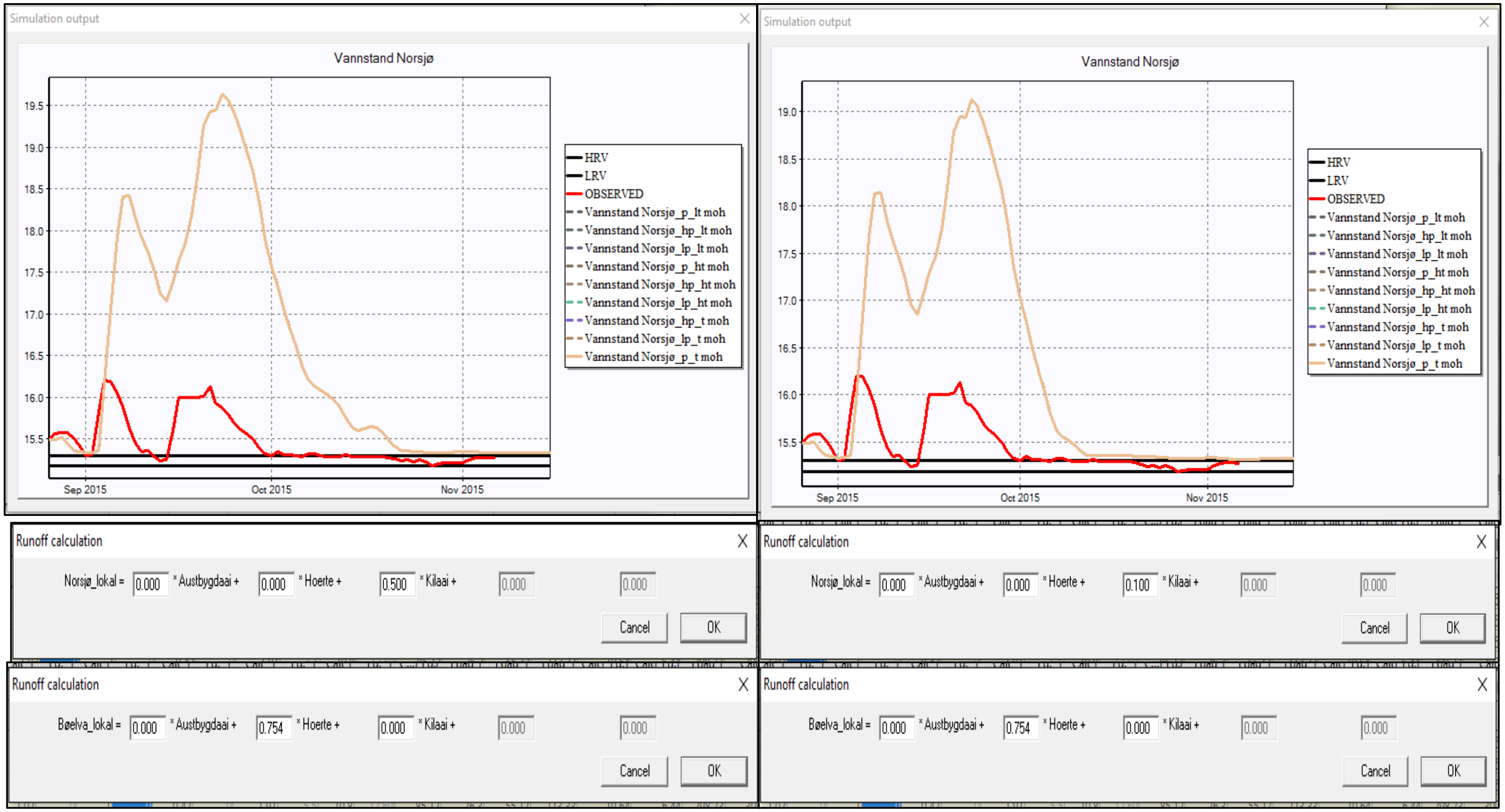

Simulation output
Vannstand Heddalsvatn
18.4
18.2
18.0
17.8
17.6
17.4
17.2
17.0
16.8
16.6
16.4
16.2
16.0
15.8
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Heddalsvatn_p_lt moh
Vannstand Heddalsvatn_hp_lt moh
Vannstand Heddalsvatn_lp_lt moh
Vannstand Heddalsvatn_p_ht moh
Vannstand Heddalsvatn_hp_ht moh
Vannstand Heddalsvatn_lp_ht moh
Vannstand Heddalsvatn_hp_t moh
Vannstand Heddalsvatn_lp_t moh
Vannstand Heddalsvatn_p_t moh
Runoff calculation
Heddalsvatn_lokal = 0.000 * Austbygdaai + 0.350 * Hoerte + 2.982 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Heddøla_lokal = 0.000 * Austbygdaai + 0.100 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK


Simulation output
Vannstand Heddalsvatn
18.4
18.2
18.0
17.8
17.6
17.4
17.2
17.0
16.8
16.6
16.4
16.2
16.0
15.8
15.6
01 Sep
08 Sep
15 Sep
22 Sep
29 Sep
HRV
LRV
OBSERVED
Vannstand Heddalsvatn_p_lt moh
Vannstand Heddalsvatn_hp_lt moh
Vannstand Heddalsvatn_lp_lt moh
Vannstand Heddalsvatn_p_ht moh
Vannstand Heddalsvatn_hp_ht moh
Vannstand Heddalsvatn_lp_ht moh
Vannstand Heddalsvatn_hp_t moh
Vannstand Heddalsvatn_lp_t moh
Vannstand Heddalsvatn_p_t moh
Runoff calculation
Heddøla_lokal = 0.000 * Austbygdaai + 0.050 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Heddalsvatn_lokal = 0.000 * Austbygdaai + 0.350 * Hoerte + 2.982 * Kilaai + 0.000 0.000
Cancel
OK

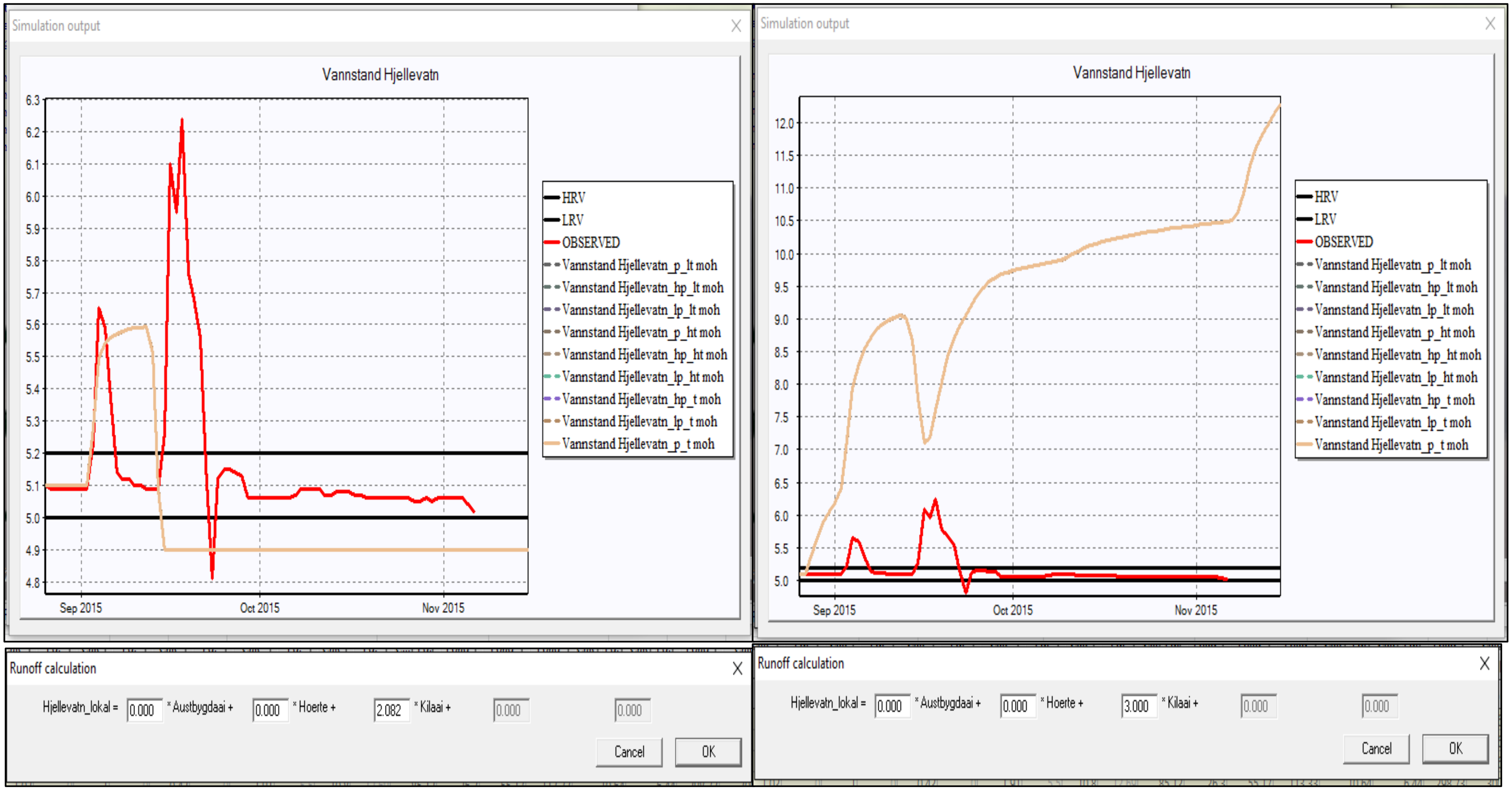
V-1 Norsjo


Simulation output
Vannstand Norsjø
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Norsjø_p_lt moh
Vannstand Norsjø_hp_lt moh
Vannstand Norsjø_lp_lt moh
Vannstand Norsjø_p_ht moh
Vannstand Norsjø_hp_ht moh
Vannstand Norsjø_lp_ht moh
Vannstand Norsjø_hp_t moh
Vannstand Norsjø_lp_t moh
Vannstand Norsjø_p_t moh
Runoff calculation
Bøelva_lokal = 0.000 * Austbygdaai + 0.754 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Norsjø_lokal = 0.000 * Austbygdaai + 0.000 * Hoerte + 1.500 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Norsjø_lokal = 0.000 * Austbygdaai + 0.000 * Hoerte + 1.592 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Bøelva_lokal = 0.000 * Austbygdaai + 0.754 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK

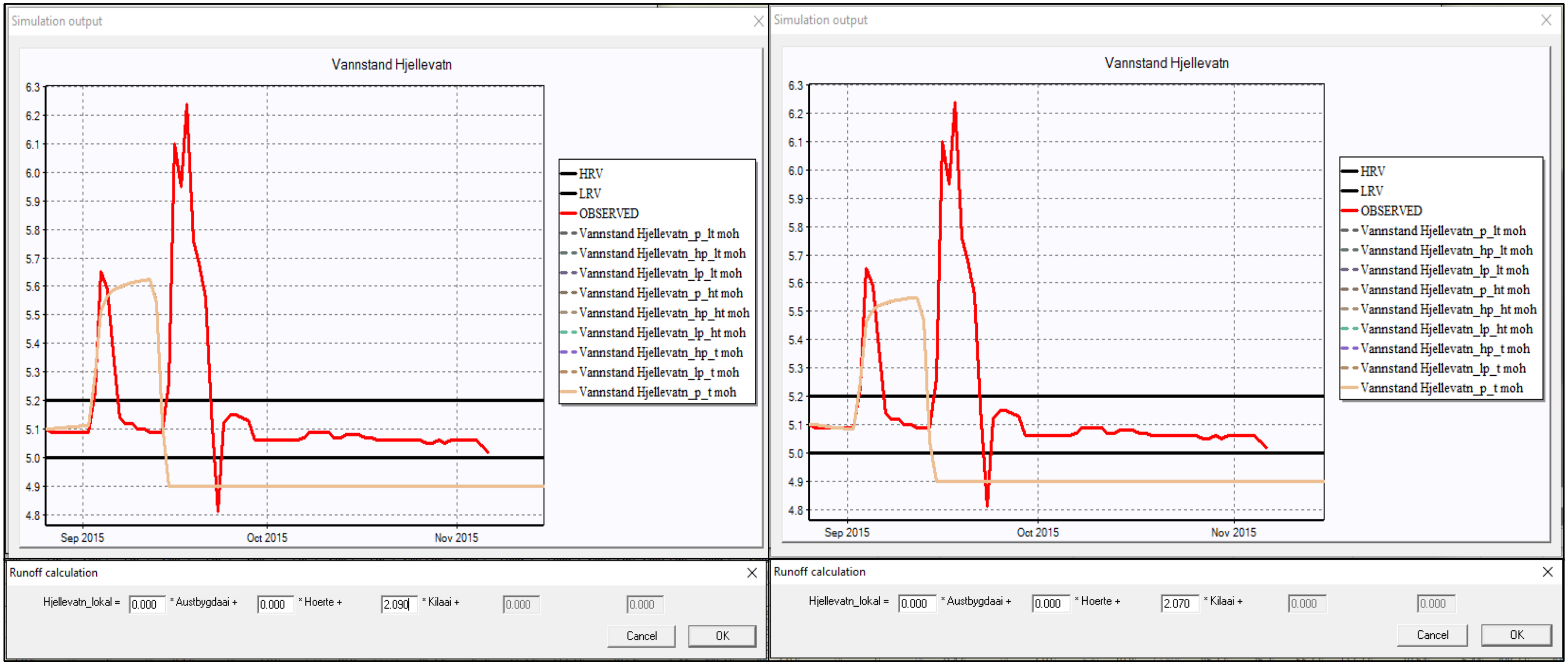
V-2


Simulation output
Vannstand Norsjø
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Norsjø_p_lt moh
Vannstand Norsjø_hp_lt moh
Vannstand Norsjø_lp_lt moh
Vannstand Norsjø_p_ht moh
Vannstand Norsjø_hp_ht moh
Vannstand Norsjø_lp_ht moh
Vannstand Norsjø_hp_t moh
Vannstand Norsjø_lp_t moh
Vannstand Norsjø_p_t moh
Simulation output
Vannstand Norsjø
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Norsjø_p_lt moh
Vannstand Norsjø_hp_lt moh
Vannstand Norsjø_lp_lt moh
Vannstand Norsjø_p_ht moh
Vannstand Norsjø_hp_ht moh
Vannstand Norsjø_lp_ht moh
Vannstand Norsjø_hp_t moh
Vannstand Norsjø_lp_t moh
Vannstand Norsjø_p_t moh
Runoff calculation
Norsjø_lokal = 0.000 * Austbygdaai + 0.000 * Hoerte + 0.500 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Norsjø_lokal = 0.000 * Austbygdaai + 0.000 * Hoerte + 0.100 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Bøelva_lokal = 0.000 * Austbygdaai + 0.754 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK
Runoff calculation
Bøelva_lokal = 0.000 * Austbygdaai + 0.754 * Hoerte + 0.000 * Kilaai + 0.000 0.000
Cancel
OK

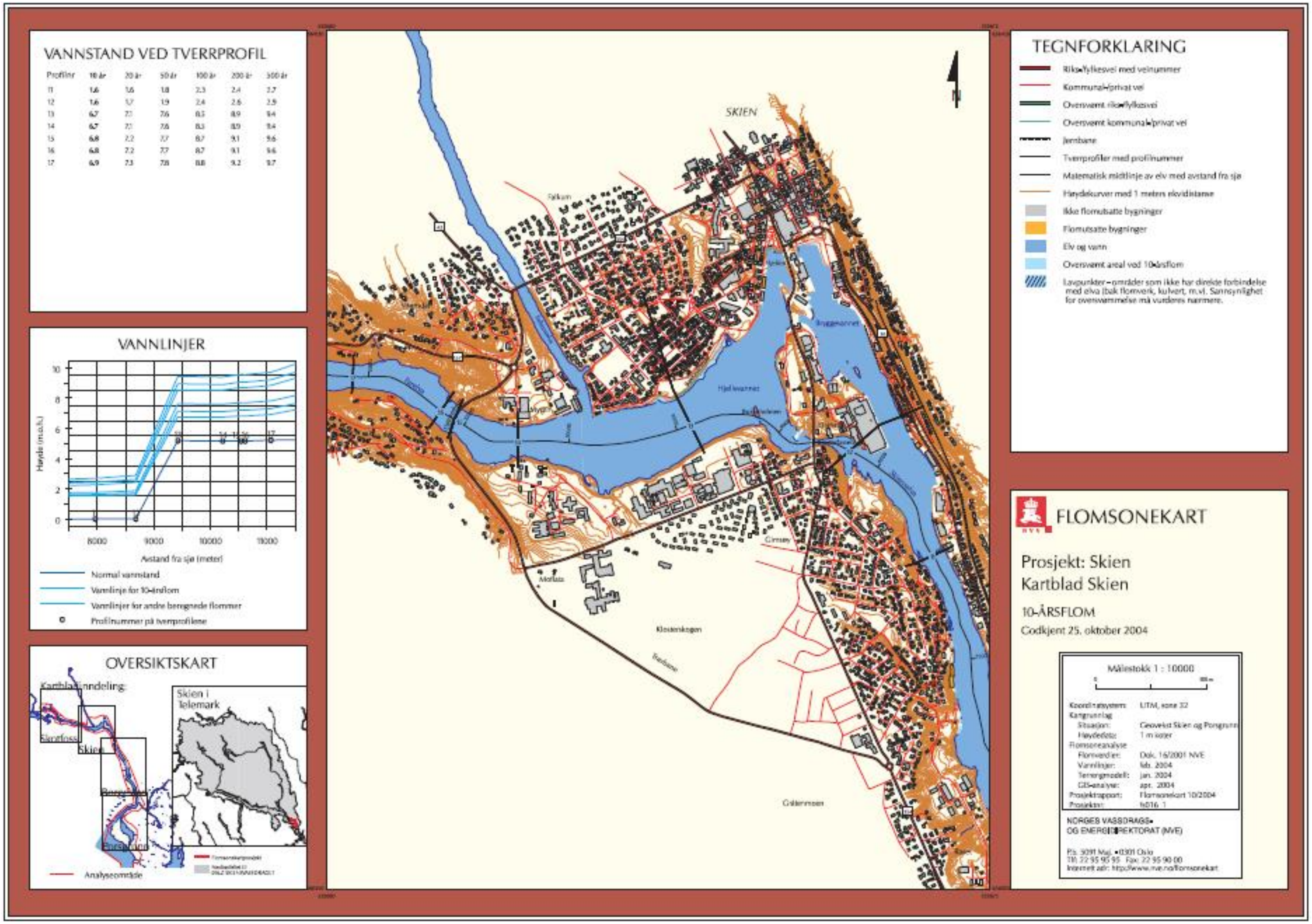
W-1 Hjellevatn



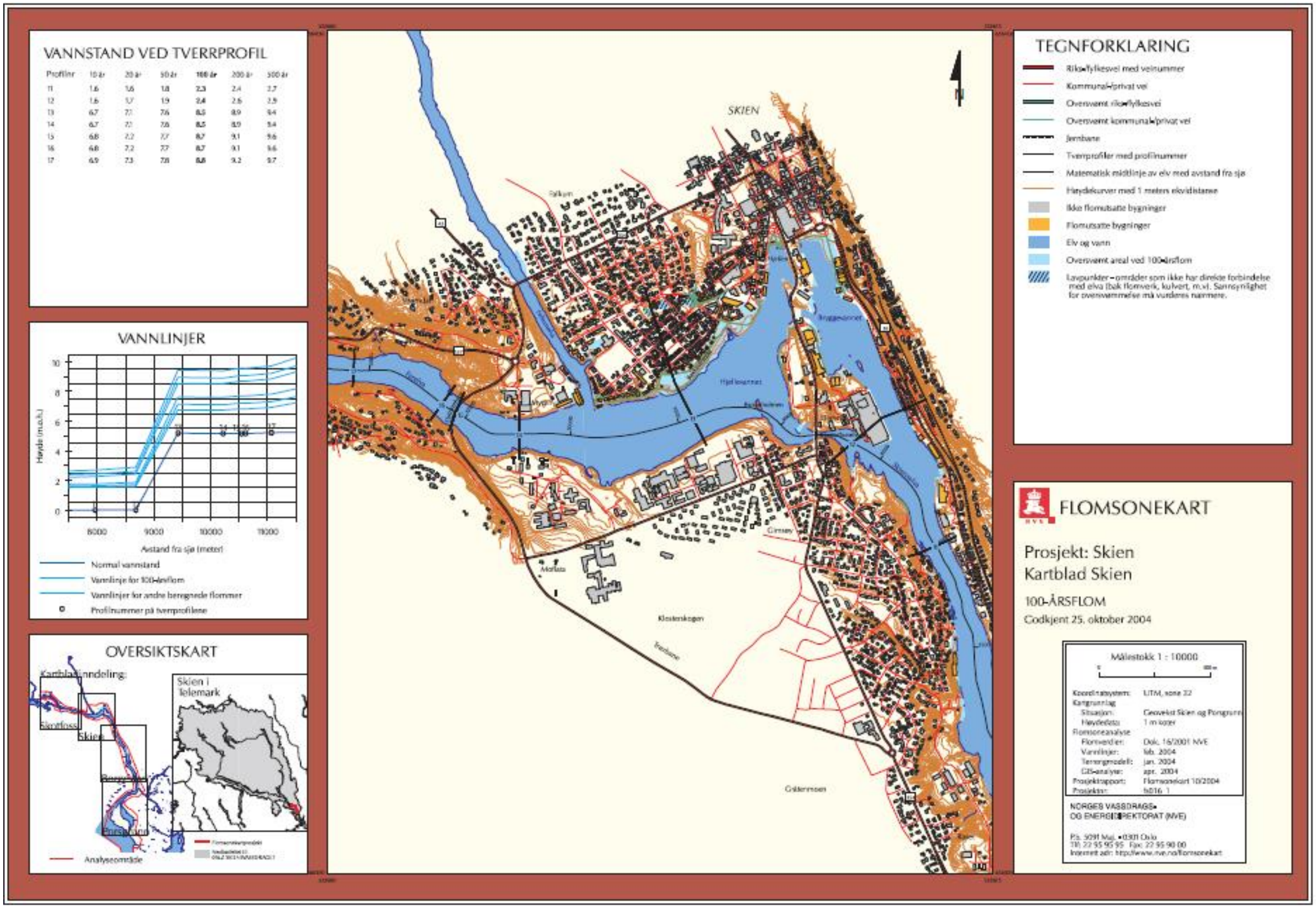
W-2


Simulation output
Vannstand Hjellevatn
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
Sep 2015
Oct 2015
Nov 2015
HRV
LRV
OBSERVED
Vannstand Hjellevatn_p_lt moh
Vannstand Hjellevatn_hp_lt moh
Vannstand Hjellevatn_lp_lt moh
Vannstand Hjellevatn_p_ht moh
Vannstand Hjellevatn_hp_ht moh
Vannstand Hjellevatn_lp_ht moh
Vannstand Hjellevatn_hp_t moh
Vannstand Hjellevatn_lp_t moh
Vannstand Hjellevatn_p_t moh
Runoff calculation
Hjellevatn_lokal = 0.000 * Austbygdaai + 0.000 * Hoerte + 2.090 * Kilaai + 0.000 0.000
Cancel
OK
Simulation output
Vannstand Hjellevatn
Runoff calculation
Hjellevatn_lokal = 0.000 * Austbygdaai + 0.000 * Hoerte + 2.070 * Kilaai + 0.000 0.000
Cancel
OK

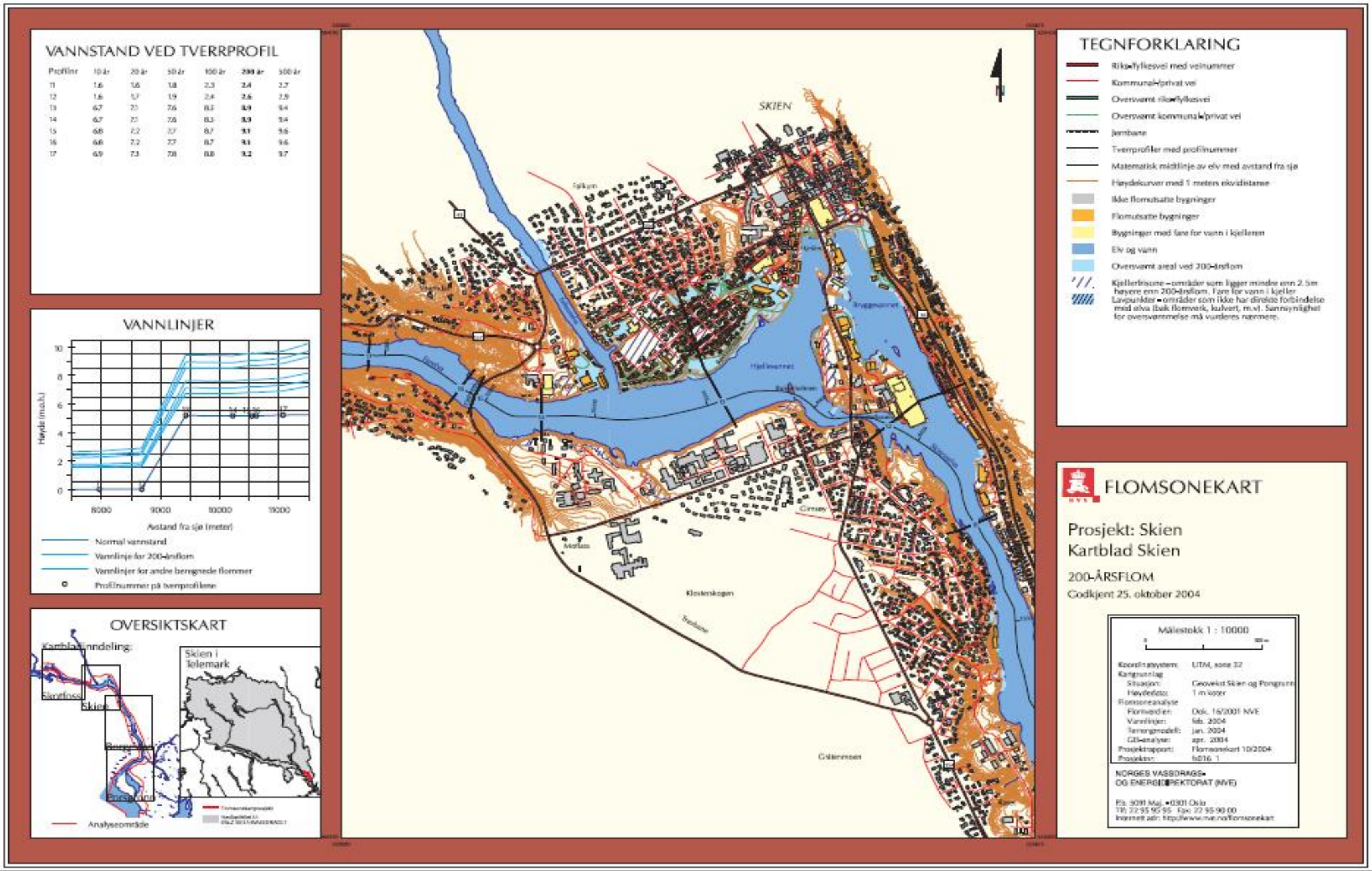
Y-1. 10 year flood at Hjellevatn



Y-2. 100 year flood at Hjellevatn



Y-3. 200 year flood at Hjellevatn



Y- 4. 500year floodat Hjellevatn