NTNU
Det skapende universitet

Improvement of flood forecasting simulations with the Telemark Flood Forecasting Model

David Maharjan

Hydropower Development
Innlevert: juni 2016
Hovedveileder: Trond Rinde, IVM
Medveileder: Ånund Killingtveit, IVM

Norges teknisk-naturvitenskapelige universitet
Institutt for vann- og miljøteknikk

David Maharjan

Improvement of Flood Forecasting Simulations with the Telemark Flood Forecasting Model

Master’s Thesis in Hydropower Development
Trondheim, July 2016
Supervisor: Trond Rinde
Co-Supervisor: Ånund Killingtveit

Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of
Science and Technology

Faculty of Engineering
Science and Technology
Department of Hydraulic and
Environmental Engineering

M.Sc. THESIS IN
HYDROPOWER DEVELOPMENT

Candidate: **David Maharjan**

Title: **Improvement of flood forecasting simulations with the Telemark Flood Forecasting Model**

1 BACKGROUND

The flood forecasting model for the Telemark River System (FlomModell for Telemarks-Vassdraget, FMTV) was developed in 2003 and has later been improved in 2008 and 2015. The model consists of an inflow module describing runoff from unregulated drainage areas and release from hydropower plants, and a routing module describing the development in water levels and outflow from the four major lakes downstream in the river system. Although comprehensive, the model still contains simplifications that introduce errors when simulating large flood events. One such simplification is that flood spill from intakes along headrace tunnels and diversions is not considered in the model. For smaller flood events this is of no consequence since the intakes will have sufficient capacity to capture all inflow, but for larger floods it is likely that flood spill from the intakes becomes a significant addition to lake inflow which is not accounted for in the model.

The objective of this thesis is to test out if inclusion of flood spill along headrace tunnels and diversions in the FMTV-model, can improve the simulation of large flood events in the Telemark River System.

2 SUGGESTED MAIN QUESTIONS FOR THE THESIS

It is suggested that the thesis should cover, though not necessarily be limited to, main questions as listed below. The final content will, however, have to be decided on basis of the hydro-meteorological data that can be found from the watershed, and the information about the river system that can be made available.

Suggested main questions:

- Acquire detailed knowledge of the Telemark River Flood Forecasting Model (FMTV), and describe its structure, working principles, and way of use.

1) Establish a database with model input data for a set of both small, medium and large flood events that have been recorded in the river system. Data must here be collected from NVE (HYDRA-II), MET.NO (Eklima), ØTB, and from power companies operating in the river (Statkraft, Hydro Energi, Skagerak Kraft, Akershus Energi).

2) Perform flood simulations with the existing FMTV-model, and evaluate to what extent unregulated lake inflow becomes underestimated during large events compared to small and medium events.

3) Collect information on the capacities of intakes along tunnels and diversions in the Telemark River System where flood spill during large flood events may become significant additions to lake inflow.

4) Suggest a method for including such flood spills in the FMTV-model.

5) Modify the FMTV-model (by help of external assistance) to take account for such flood spills in its simulation.

6) Re-simulate the flood events with the modified FMTV-model, and evaluate if improvements in flood simulations can be achieved.

3 SUPERVISION, DATA AND INFORMATION INPUT

Associate Professor Trond Rinde will supervise the thesis work and assist the candidate to make relevant information available. Professor Ånund Killingtveit will assist as co-supervisor.

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 Telemark River Flood Forecasting Model is selected as a study object.

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 summary shall not contain more than 450 words and it shall be prepared for electronic reporting to SIU. The entire thesis will be published through the DAIM system at NTNU. The candidate shall provide a copy of the thesis (as complete as possible) in digital format (.pdf) in addition to a A4 paper report for printing.

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

Trondheim 12th of January 2016

Trond Rinde

Trond Rinde
Associate Professor
Department of Hydraulic and

FOREWORD

This thesis, which is entitled “Improvement of flood forecasting simulations with the Telemark Flood Forecasting Model”, is submitted to the Department of Hydraulic and Environmental Engineering at Norwegian University of Science and Technology as a partial fulfillment of the requirements for the Master of Science in Hydropower Development.
This thesis was carried out from January 2016 to June 2016 at Norwegian University of Science and Technology, Trondheim under the supervision of Prof. Trond Rinde. The thesis with this title is done by me, and Mr. Louis Addo where we are studying different aspects for improvement of flood forecasting simulations.

I hereby declare that the work presented here is my own, and outside inputs are acknowledged appropriately.

David Maharjan,
June 2016,
Trondheim, Norway

ACKNOWLEDGEMENT

I would like to express gratitude to my supervisor, Professor Rinde Trond, Department of Hydraulic and Environmental Engineering, Norwegian University of Science and Technology (NTNU), for his continuous guidance and support. His advice, suggestions, classes on software and data provided have been very helpful in developing this report. I am delighted to have him as the supervisor.

I submit the heartiest gratitude to my co-supervisor, Professor Ånund Killingtveit for his guidance and encourage during difficult phases of the thesis. Besides, his organized field trip made it possible to visit all the reservoirs, lakes, hydropower and location of gauging stations, which provided much-needed insight to progress the work with more confidence and knowledge.

Moreover, I am ineffably indebted to Professor Knut Alfredson for his conscientious guidance to accomplish this thesis throughout the period. His suggestions and support in the absence of my supervisor were much appreciated.

Furthermore, I like to thank Mr. Louis Addo for working with me and helping me in various aspects of the thesis.

Finally, I would like to thank and acknowledge all friends, seniors, and juniors who have helped me directly or indirectly in developing this thesis.

ABSTRACT

Flood is the most common environmental hazard worldwide and can have an devastating consequences affecting the economy, environment, and people. The causes and nature of flood may be different, but it is important to control all of them. The typical cause of flood in Norway is a combination of heavy rainfall and snowmelt which results in an unexpected increase in runoff. This flash flood has been a serious threat to many communities in the lower reach of Skienselva river in Telemark county of Norway from past and control measures have been taken to control this.

Telemark flood forecasting model (FMTV) is the outcome seen as the controlling measure for the ever occurring flood problem in the region. FMTV consist of a hydrological model and a reservoir routing model for simulating inflow and provide operational decisions on water levels of the four reservoirs in the area. The operation of these reservoirs plays a critical role in the management of large flood. The model since its operation in 2003 has been functioning well until 2015 when two big flood events occurred when reservoirs were almost full.

After these floods in 2015, it was considered the necessity to improve flood forecasting simulation with the model. It was clear that the model introduces errors when simulating large flood events. Out of various possible possibilities that introduce errors, this study is focused on flood spill from intakes along headrace tunnels as these are not considered in the model. For this, data necessary to run the model were collected from different sources. Consistency and reliability of these data were studied.

The model was run for the historic flood events, small, medium and large flood events and checked how model simulated during these flood events for various years. The spill data were collected for reservoirs and added to the model for respective large flood events. In addition to this, capacities of brook intakes located in the tunnel on the way to hydropower plant were calculated. These missing values were added to the model and simulation was conducted for large flood events during various years.

In conclusion, this study has been successful in identifying a key issue related to the low performance of FMTV model during large flood events. The inclusion of flood spills is a major addition to improvement of flood forecasting simulation. Further improvement in the flood forecasting simulation can be achieved by modifying the prevailing scaling factor used to compute inflow from the local catchment of the reservoirs used in the flood computation.

Table of Contents

LIST OF FIGURES xvii

LIST OF TABLES xxiii

ABBREVIATIONS xxv

1. INTRODUCTION 1

1.1 Background 1

1.1.1 General 1

1.2. Flood Prone Areas in Telemark 2

1.2.1 Tinnsjø 3

1.2.2. Heddalsvatn 3

1.2.3. Norsjø 4

1.2.4. Hjellevatn 5

1.3 Objective of Study 5

1.4 Scope of Study 5

1.5. Structure of Thesis 6

1.6. LIMITATIONS 7

2. STUDY AREA 9

2.1. Background 9

2.2. RESERVOIRS 10

2.2.1. Tinnsjø 10

2.2.2. Heddalsvatn 10

2.2.3. Norsjø 10

2.2.4. Hjellevatn 11

2.3. Regulated flow 11

2.3.1. Møsvatn Hydropower System 11

2.3.2. Mår Hydropower System 11

2.3.3. Tokke-Vinje Hydropower System. 12
2.4. Unregulated Flow 13
2.4.1. Austbygdåi 13
2.4.2. Hørte 14
2.4.3. Kileåi 14
3. DATA ACQUISITION AND CONTROL 15
3.1. Acquisition of Meteorological Data 15
3.1.1. Precipitation data Analysis 15
3.1.2. Temperature Data Analysis 18
3.2. Acquisition of Hydrological Data 20
3.2.1. Runoff Data Analysis 20
3.2.2. Flood Spill Data Analysis 24
3.3. Filling of Missing Data 25
3.4. Data Quality Check 27
3.4.1. Visual Inspection 27
3.4.2. Double Mass Curve 27
3.4. Field Visit of Study Area 27
4. FLOOD SPILL DATA PREPARATION 31
4.1. Flood Spill from Dam 31
4.1.1. Data collection for Spill from Dam 32
4.1.2. Cross Check for the data received 35
4.1.3. Inclusion of Flood Spill from Dam in the FMTV Model 36
4.2. Flood Spill from Brook Intake 36
4.2.1. Calculation of Flood Spill from Brook Intakes 37
4.2.2. Inclusion of Capacity of Brook Intakes in the FMTV Model 40
4.3. Spill and Diversion from other regulated flows 41

5. LOCAL INFLOWS 43

5.1. Scaling Method. 43

5.2. Water Balance Equation. 43

6. TELEMARK FLOOD FORECASTING MODEL (FMTV) 45

6.1. Model Introduction 45

6.2. System Structure 46

6.3. Model Setup and Operation 47

6.3.1. System Model 47

6.3.2. Inflow Computations 48

7. FMTV MODELLING TOOLS 51

7.1. HBV model 51

7.1.1. Model Introduction: 51

7.1.2. Model Structure 51

7.1.3. Model Setup 52

7.3. Runoff Forecasting 53

7.3.1. Long Term Forecast 54

7.3.2. Short-term Forecast 54

7.2. KORTFLOM 55

7.2.1. Model Components 56

8. MODEL SIMULATION UNDER DIFFERENT HISTORICAL FLOOD EVENTS...61

8.1. Background and Input Data 61

8.2. Simulation result provided by present used dataset. 62

8.2.1. Small Flood Events 63

8.2.2. Medium Flood Event 67

8.2.3. Large Flood Event 71

8.3. Simulation results by replacing Møsvatn with Skarsfoss 74

8.3. Simulation results by considering spill and intake capacity......77

8.3.1. Tinnsjø......78

8.3.2 Norsjø......81

8.4. Discussion:......82

8.4.1. Tinnsjø......82

8.4.2. Heddalsvatn......83

8.4.3. Norsjø......83

8.4.4. Hjellevatn......86

9. Manual Calculation of Local Inflows......87

10. CONCLUSION AND RECOMMENDATION......91

10.1. Conclusion......91

10.2. Recommendations......92

REFERENCES......93

APPENDICES......1

Appendix A: Volume and Outlet Curve for Norsjø, and Gauging Stations......1

Appendix B: Runoff Calculation......3

Appendix C: Brook Intakes......4

Appendix D: Procedure to use FMTV and Dataset for FMTV......9

Appendix E: Simulation results for different flood events with FMTV......5

Appendix F: Manual Routing of water level for Norsjø......14

Appendix G: Manual calculation of local Inflow......15

LIST OF FIGURES

Figure 1-1: 1000 years flood zone for Tinnsjø (Atlas 2016)..3

Figure 1-2: 1000 years flood zone for Heddalsvatn (Atlas 2016)..4

Figure 1-3: 1000 year flood zone for Norsjø (Atlas 2016)..4

Figure 1-4: 1000 years flood zone for Hjellevatn (Atlas 2016) 5

Figure 2-1: Telemark with 19 County...9

Figure 2-2: Tinnsjø with Møsvatn and Mår Power System (NVE 2016) 12

Figure 2-3: Heddalsvatn, Norsjø and Hjellevatn (NVE 2016)...13

Figure 3-1: Graphs of Annual Rainfall data for catchment Austbygdåi 15

Figure 3-2: Graph of Precipitation data for catchment Austbygdåi 16

Figure 3-3: Graph for Annual Rainfall Data for Hørte 16

Figure 3-4: Graph for Precipitation Data for Hørte...16

Figure 3-5: Graph for Annual Rainfall Data for Kileåi...17

Figure 3-6: Graph for Precipitation Data for Kileåi..17

Figure 3-7: Austbygdåi with Selected Precipitation Station and Average Precipitation 17

Figure 3-8: Hørte and Kileåi with selected Precipitation Station and Average Precipitation 18

Figure 3-9: Graph for Daily Temperature Data for Austbygdåi, Hørte, and Kileåi.............19

Figure 3-10: Graph of Annual Average Temperature for Austbygdåi, Hørte, and Kileåi 19

Figure 3-11: Austbygdåi, Hørte, and Kileåi with Selected Temperature Station and Average Temperature from 1971-2000 19

Figure 3-12: Daily flow series recorded in Austbygdåi 20

Figure 3-13: Daily flow series recorded in Hørte 20

Figure 3-14: Daily flow series recorded in Kileåi...21

Figure 3-15: Daily flow series from Møsvatn as Production Flow to Frøystul Power Plant 21

Figure 3-16: Daily flow series from Skarsfoss as Production Flow to Vemork Power Plant 21

Figure 3-17: Daily flow series recorded from Mårvatn to Mår Power Plant 22

Figure 3-18: Daily flow series recorded at Kirkevoll Bru 22

Figure 3-19: Daily flow Series recorded at Skotfoss 22

Figure 3-20: Daily flow Series recorded at Farelva 23

Figure 3-21: Daily flow series recorded at Omnesfoss 23

Figure 3-22: Daily flow series recorded at Hagadrag 23

Figure 3-23: Daily Production Flow series recorded at Vrangfoss 24

Figure 3-24: Comparison of data recorded for Mår and Strengen for 2015 25

Figure 3-25: Comparison of data recorded for Mår and Strengen for 2015 25

Figure 3-26: Comparison of Runoff recorded at Farelva and Skotfoss plus Falkumelva for 2014 26

Figure 3-27: Comparison of Runoff recorded at Farelva and Skotfoss plus Falkumelva for 2015 26

Figure 3-28: Double Mass Curve 27

Figure 3-29: Møsvatn on 17 May 2016 28

Figure 3-30: Hjellevatn on 19 April 2016 29

Figure 4-1: Skarsfoss Dam 31

Figure 4-2: Gated Spillway in Vrangfoss Dam 32

Figure 4-3: Daily Spill from Skarsfoss dam 32

Figure 4-4: Daily Spill series recorded at Møsvatn Langhol 33

Figure 4-5: Daily Spill Series recorded at Vrangfoss 33

Figure 4-6: Production flow and Spill from Skarsfoss and Møsvatn during large flood event in 2014 33

Figure 4-7: Production flow and Spill from Skarsfoss and Møsvatn during large flood event in 2015 34

Figure 4-8: Production Flow and Spill from Vrangfoss during large flood event in 2014 ...34

Figure 4-9: Production Flow and Spill from Vrangfoss during Large Flood Event in 2015 34

Figure 4-10: Spillway Curve for Skarsfoss Dam 35

Figure 4-11: Daily Specific Runoff of Local Catchments, Tinnsjø, and Austbygdåi (2014 and 2015)...38

Figure 4-12: Intake Capacity of Brook Intakes along Tunnel from Møsvatn from 2013-2015 39

Figure 4-13: Daily Intake Capacity of Brook Intakes along Tunnel from Mårvatn from 2013-2015 39

Figure 4-14: Production Flow and Spill from Brook Intakes in Tunnel from Møsvatn during Large Flood event in 2015 40

Figure 4-15: Production Flow and Spill from Brook Intakes in Tunnel from Mår during Large Flood event in 2015...40

Figure 6-1: The model representation of the Skien watercourse (catchment symbol represents undeveloped parts of the river system that are not treated in detail in the model)...............45

Figure 6-2: Structure of FMTV (Alfredsen, Killingtveit et al. 2008) 46

Figure 6-3: The Catchment of Skien Watercourse..47

Figure 6-4: Components in FMTV...48

Figure 7-1: Structure of HBV model (Bergström and Forsman 1973) 51

Figure 7-2: Simulated and Observed Runoff for Austbygdåi obtained from HBV model ...52

Figure 7-3: Simulated and Observed runoff for Hørte obtained from HBV model.............52

Figure 7-4: Simulated and Observed Runoff for Kileåi obtained from HBV model...........53

Figure 7-5: Hierarchy of Structural Components (Booch 1996)..56

Figure 7-6: Computational Element (Alfredsen and Sæther 2000)......................................57

Figure 8-1: FMTV simulation result for a small flood period for Tinnsjø in 2013 63

Figure 8-2: FMTV simulation result for a small flood period for Tinnsjø in 2014 63

Figure 8-3: FMTV simulation result for a small flood period for Tinnsjø in 2015 64

Figure 8-4: FMTV simulation result for a small flood period for Heddalsvatn in 2015.......65

Figure 8-5: FMTV simulation result for a small flood period for Norsjø in 2015................66

Figure 8-6: FMTV simulation result for a small flood period for Hjellevatn in 2015..........66

Figure 8-7: FMTV simulation result for a medium flood period for Tinnsjø in 2013..........67

Figure 8-8: FMTV simulation result for a medium flood period for Tinnsjø in 2014..........68

Figure 8-9: FMTV simulation result for a medium flood period for Tinnsjø in 2015..........68

Figure 8-10: FMTV simulation result for a medium flood period for Heddalsvatn in 2013 69

Figure 8-11: FMTV simulation result for a medium flood period for Norsjø in 2015 70

Figure 8-12: FMTV simulation result for a medium flood period for Hjellevatn in 2015 ...70

Figure 8-13: FMTV simulation result for a Large flood period for Tinnsjø in 2013...........71

Figure 8-14: FMTV simulation result for a Large flood period for Tinnsjø in 2014...........71

Figure 8-15: FMTV simulation result for a Large flood period for Tinnsjø in 2015...........72

Figure 8-16: FMTV simulation result for a Large flood period for Heddalsvatn for 2015 ..73

Figure 8-17: FMTV simulation result for a Large flood period for Norsjø for 2015...........73

Figure 8-18: FMTV simulation result for a Large flood period for Hjellevatn for 2015......74

Figure 8-19: FMTV simulation using Skarsfoss outlet for a small flood period in 2013.....75

Figure 8-20: FMTV simulation using Skarsfoss outlet for a medium flood period in 2014.75

Figure 8-21: FMTV simulation using Skarsfoss outlet for a Large flood period in 2013 76

Figure 8-22: FMTV simulation using Skarsfoss outlet for a Large flood period in 2014 76

Figure 8-23: FMTV simulation using Skarsfoss outlet for a large flood period in 2015......77

Figure 8-24: FMTV simulation considering spill from Skarsfoss and Brook intake capacity for medium flood event in 2014...78

Figure 8-25: FMTV simulation result considering spill from Skarsfoss and Brook intake capacity for large flood event in 2013...79

Figure 8-26: FMTV simulation result considering spill from Skarsfoss and Brook intake capacity for large flood event in 2014...79

Figure 8-27: FMTV simulation results considering spill from Skarsfoss and Brook intake capacity for large flood event in 2015 80

Figure 8-28: FMTV simulation result for Norsjø after considering Spill from Vrangfoss in 2015 81

Figure 8-29: FMTV simulation result for Norsjø after including Spill from Vrangfoss in 2014 81

Figure 8-30: Simulation result from FMTV and manual calculation in 2015 84

Figure 8-31: Simulation result from FMTV and manual calculation for large flood event in 2014 85

Figure 8-32: Simulation result from FMTV and manual calculation for large flood event in 2014 85

Figure 9-1: Local Inflow provided by Manual Calculation and FMTV model for a large flood event in 2014 87

Figure 9-2: Local Inflow provided by Manual Calculation and FMTV model for a large flood event in 2014 88

Figure 9-3: Local Inflow Provided by Manual Calculation and Norsjø during large flood in 2014 89

Figure 9-4: Local Inflow Provided by Manual Calculation and Norsjø during large flood in 2015 89

LIST OF TABLES

Table 3-1: Detail of Selected Precipitation and Temperature Stations 18

Table 4-1: Hourly Spill from Skarsfoss in 2014.10.30 35

Table 4-2: Intakes along Headrace Tunnel from Mår 36

Table 4-3: Intakes along Tunnel from Møsvatn to Moflåt Power Plant 37

Table 4-4: Annual Specific Runoff in l/s.km^2...38

Table 5-1: Scaling factor used by Local Catchments used in FMTV 43

Table 7-1: Correction applied to Correlate Observed and Simulated Runoff for Austbygdåi 53

Table 8-1: Intake Capacity of Brook Intakes in Mår and Møsvatn Hydropower System during large floods 62

ABBREVIATIONS

^oC	Degree Celsius
FMTV	Flood Forecasting Model for Telemark River System
LRWL	Low Reservoir Water Level
$l/s.km^2$	Liter per Second per Square Kilometer
HBV	Hydrologiske Byrån Vattenbalans
HRWL	High Reservoir Water Level
Km^2	Square Kilometer
m	Meter
m.a.s.l	Meters above sea level
mm	Millimeter
m^3	cubic meter
m^2	Square Meter
m^3/s	Cubic Meter per Second
NVE	Norwegian Water Resources and Energy Directorate
PP	Precipitation
Q	Discharge
RIFA	River Flood and Accident Simulator
ØTB	Øst Telemark Regulatory Association

1. INTRODUCTION

1.1 Background

1.1.1. General

Flood remains one of the most frequent and devastating natural hazards worldwide. Flood poses a widely distributed risk to lives, whereas other natural disasters such as avalanches, landslides, earthquakes and volcanic activities are more local or regional in their distribution (Samuels 1999). Flood also causes an impact on society that goes beyond economical cost and facilities, including impacts such as family and community disruptions, dislocation, injuries and unemployment. Floods are news, almost every year major flood events hit some parts of the earth. (Shreedhar 2004)

In Norway, it is common to have spring floods due to snowmelt. Some of biggest floods in Norway have been due to a combination of snow melt and rain floods. One of the examples of this kind of flood is Vesleofsen flood in 1995. Norway has more than 364 reservoirs used for power production. These reservoirs can be used for flood control also, as spring floods can be used for filling these reservoirs which will maximize the power production. These spring floods are used to fill up power plant reservoirs after winter drawdown. Spring floods are not always beneficial; they are common to invite destruction also.

Most power plants in Norway use reservoir simulation model to find a balance between optimum operation water level and lowest possible level to reduce and store flood. It is necessary to forecast flood so that balance between pre-release and other reservoir regulation during a critical stage of flood peak to reduce risk and damage. It is costly to build a model for flood forecasting purpose only as damage producing floods are rare events, so hydrological models for runoff forecasting is combined with routing models for flood routing through reservoirs.,

Telemark has long experienced floods with various methods used throughout history to try to control it. Series of historical flood events in past has occurred and to control flood in Telemark water course; a project is established by Øst Telemark Regulatory along with NTNU, Skagerak Energy, and NVE. Telemark Flood Forecasting Model was created to forecast flood in 2003 and have been in operation since then.

FMTV is the flood forecasting model designed to forecast flood in Telemark water system. The model is the combination of HBV rainfall-runoff model and KORTFLOM routing model to forecast runoff. The runoff from regulated reservoirs is provided by different concerned power companies. Quantitative rainfall forecast produced by Norwegian Meteorological Institute is the input to HBV rainfall-runoff model to generate runoff. The unregulated catchments Austbygdåi, Hørte, and Kileå, are used to scale runoff from other unregulated catchments. These inputs and other data received from the various sources are inserted into routing model to simulate flood and forecast flood.

The model was studied in 2006 by Vinod Mahat titled "Flood Forecasting Model for Telemark Water Couse". The calibration results of HBV model showed good ability to simulate runoff from three catchments even though there was variation between observed and simulated runoff during large rainfalls (Mahat 2006). It was also concluded that the reservoir stage computed by the model was close to the observed result.

The model has been operational for about ten years, but in summer 2015, the exceptional flood occurred when reservoirs were almost full. The poor performance of FMTV model during large flood event can be due to inflow to the reservoirs not being complete. The one clearly visible lacking inflow is spill from reservoirs and additional runoff from brook intakes along headrace tunnel. This thesis is thus approaching to improve FMTV model. The study is mostly focused in upper parts of Skien river system with the belief that the correct operation of the reservoirs in the upper parts can help to reduce or completely avoid flood damage in the downstream area.

In the study, 'Modelling Uncertainty in Flood Forecasting Systems' by Shreedhar Maskey (Shreedhar 2004), it is described that despite the increasing advancement in the development of flood forecasting models and techniques, uncertainty in flood forecast remains unavoidable and therefore it is important to admit the existence of uncertainty. It is also concluded that various benefits of estimating uncertainty in flood forecasting has been identified, which include the rational basis for flood warning systems. He also recommends that it is essential to have an uncertainty assessment for all forecasting system as an integral component.

1.2. Flood Prone Areas in Telemark

In the East-Telemark water course, people have been experiencing a damaging flood in regular intervals. In this area, there are 15 large hydropower stations producing 1200MW of electricity. The regulated flow through several hydropower schemes from Møsvatn-Mår system flow into Tinnsjø with other unregulated flows. The flow is regulated from Tinnsjø to Hjellevatn and then to Norsjø and finally to Heddalsvatn. Being in downstream Norsjø and Hjellevatn are affected most by the occurrence of the flood. The economic impact due to flood is high in downstream especially Notodden with inhabitant 13000 and Skien with inhabitant 54000 than in upstream around Tinnsjø.

There are four reservoirs whose proper operation can reduce the flood damage or can neutralize large flood. These flood prone areas of these four reservoirs is shown below.

1.2.1. Tinnsjø

The main feeders to the lake are lakes Mår and Møsvatn. It is the upper part of the watercourse. The inflow to the lake is controlled mostly by power stations upstream to the lake. The areas around this reservoir can be seen within the flood zone. The population in this area is not dense, so NVE mostly tries to hold water during large floods in Tinnsjø. The result is flooding the area around Tinnsjø.

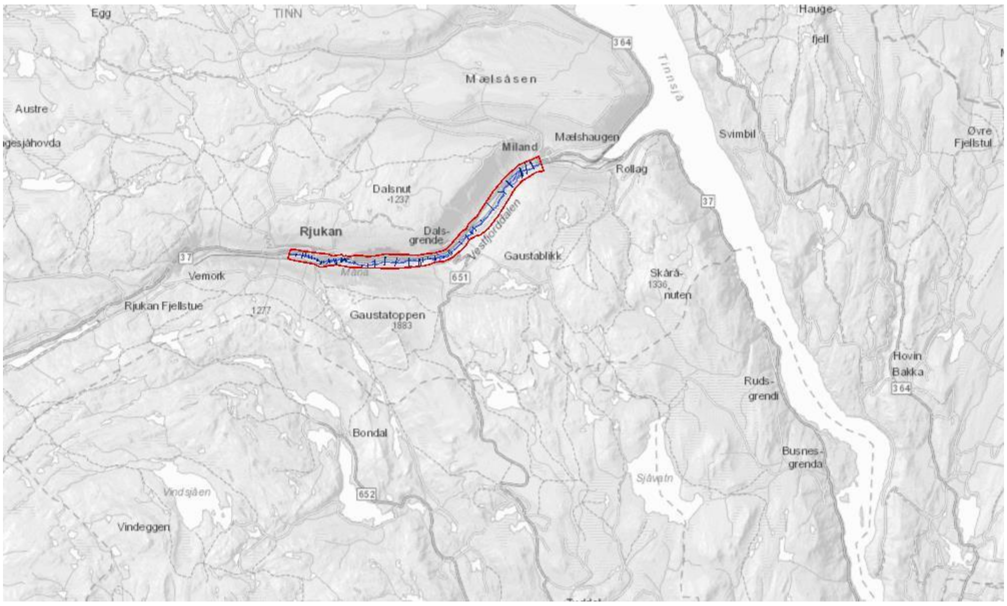


Figure 1-1: 1000 years flood zone for Tinnsjø (Atlas 2016)

1.2.2. Heddalsvatn

The feeders to this lake are Tinnsjø flowing through Tinnelva River and Heddøla River. It has no control of outflow downstream as it is a natural lake without any regulation towards Norsjø. Notodden located at the periphery of this lake has a risk of damage during a flood. There are many shopping centers in the flood prone areas which make this area necessary to protect during the large flood.

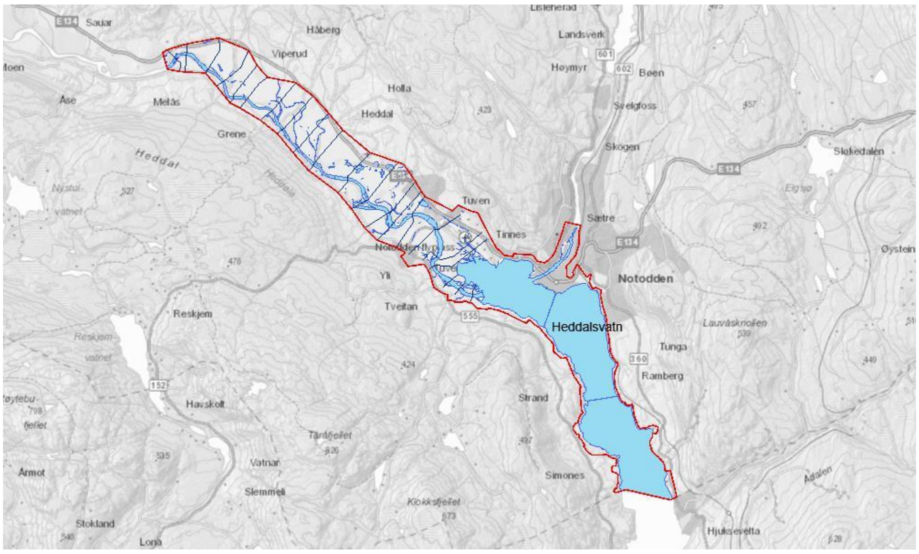


Figure 1-2: 1000 years flood zone for Heddalsvatn (Atlas 2016)

1.2.3. Norsjø

The main feeders to this lake are river Sauherad, which carries water from Heddalsvatn, Vestfelta river which carries water from west and Bøelva river. Along with these, it has local inflow from catchments around it which are unregulated. River Bøelva is also unregulated. Flooding in Skien area is affected by discharge from Norsjø. The flooding area around Norsjø is shown below.

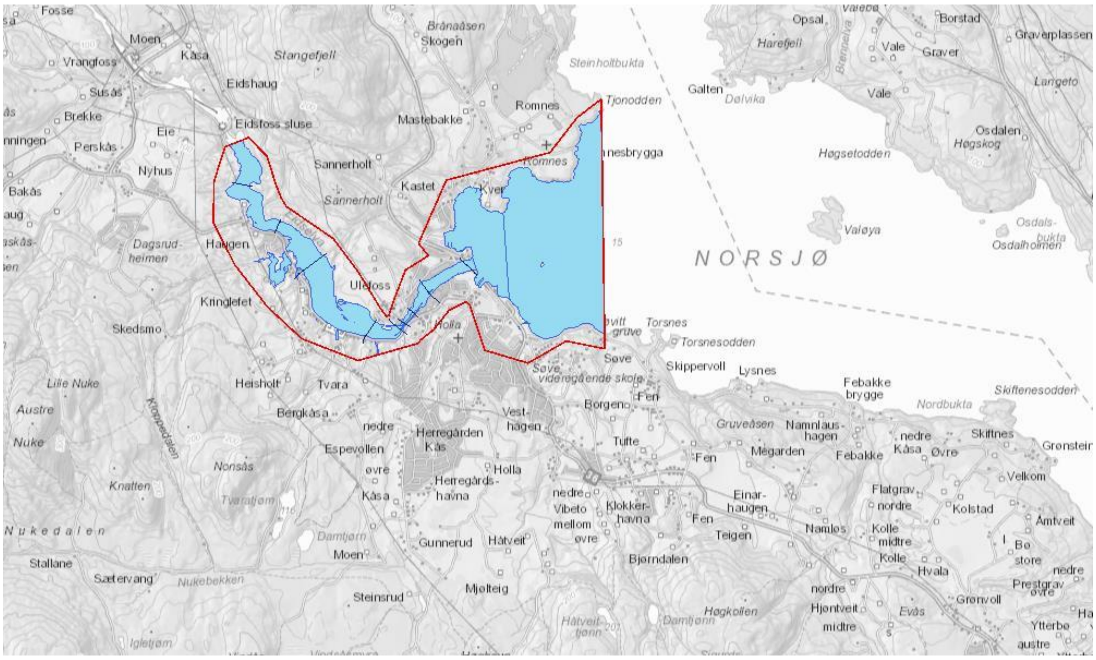


Figure 1-3: 1000 year flood zone for Norsjø (Atlas 2016)

1.2.4. Hjellevatn

It is the lowermost reservoir. The inflow to the lake is regulated from Norsjø. The river Skienelva carries water from Norsjø and other catchments to Hjellevatn. The area around Hjellevatn is densely populated. The rise in water level seems to have a serious threat to people living in Skien.

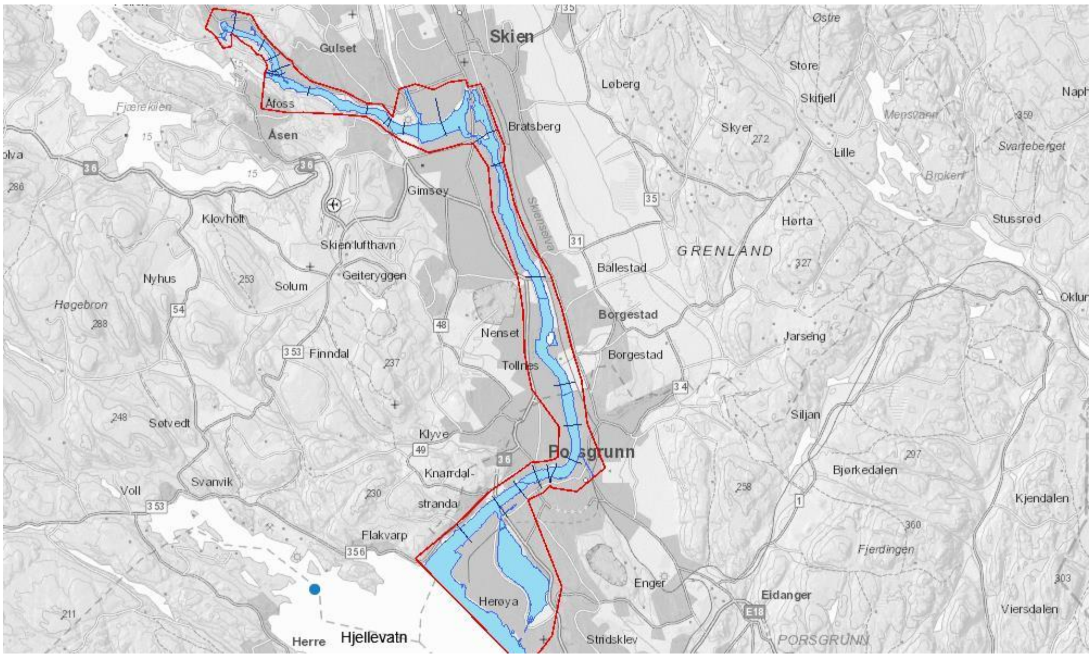


Figure 1-4: 1000 years flood zone for Hjellevatn (Atlas 2016)

1.3. Objective of Study

The main objective of this thesis is to test out if the inclusion of spill along headrace tunnels and diversions in the FMTV-model can improve the simulation of large flood events in the Telemark River System.

1.4. Scope of Study

The study aims to fulfill the objective through following steps followed in order.

1. Describing structure, working principles and way of use of Telemark River Flood Forecasting model.
2. A collection of Rainfall-Runoff data and establish a database with model input data for a set of small, medium and large flood events.
3. Performing flood simulation with existing FMTV-model, and evaluate to what extent unregulated lake inflow has been underestimated during large flood events compared to small and medium events.

4. Collecting information on the capacities of intakes along tunnels and diversions in Telemark River System where flood spill during large flood events may become significant additions to lake inflow.
5. Suggest a method for including such flood spills in FMTV-model.
6. Check whether replacement of Møsvatn outlet to Vemork outlet will improve simulation results.
7. Re-simulate the flood events with spill from dam and intakes, and evaluate if improvements in flood simulations can be achieved.

1.5. Structure of Thesis

This report tries to cover all the necessary tasks required. The structure of thesis provides an overview of each chapter for easy reference. Different chapters are assigned to describe the various sub-tasks.

Chapter 1 provides a brief introduction of thesis title, a general overview of flooding areas, objective of study, structure of thesis followed by limitations of the study.

Chapter 2 introduces study area, a general overview of reservoirs, and hydropower system, and overview of precipitation, temperature and gauging stations.

Chapter 3 introduces data processing, analysis of hydrological and meteorological data used for different stations, analysis of data for flood spill, filling of missing data and quality control.

Chapter 4 provides detail description about flood spill and capacities of intakes along with data preparation for the inclusion of spill in FMTV model.

Chapter 5 describes different methods to calculate runoff from local catchments.

Chapter 6 provides detailed description about Telemark Flood Forecasting Model (FMTV) along with its structure and working principle.

Chapter 7 describes in detail about tools used to form FMTV with their way of use during the process of the study.

Chapter 8 presents simulation results by FMTV model with present data being used for calculation and after inclusion of spill and changing Møsvatn tapping to Skarsfoss tapping.

Chapter 9 presents the manual computation of local inflows to show to what extent the model is underestimating local inflows to the reservoirs even after inclusion of spills from headrace tunnels.

Chapter 10 includes conclusion and recommendations made for further study in related topics.

1.6. LIMITATIONS

Limited data were available with some data missing for years. There is no gauging station downstream of Hjellevatn, which makes impossible to calculate exact outflow from Hjellevatn. This study is carried out focusing on one aspect which is believed to be introducing error in FMTV model during simulating large flood events. The study is carried out by assuming there is no problem in prevailing scaling factor being used in FMTV model to compute inflow from the local catchments of the reservoirs used in the flood computation. Therefore, there are sufficient aspects available for more work to improve flood forecasting simulation and can be used to modify the model if necessary.

2. STUDY AREA

2.1. Background

Norway comprises the western part of Scandinavia in Northern Europe. Norway lies between latitudes 57^0 and 81^0 N, and longitudes 4^0 and 32^0E. Norway experiences higher temperature and more precipitation than expected at such northern latitudes. The southern and western parts of Norway are fully exposed to Atlantic storm fronts and experience more precipitation and milder winter than the eastern and far northern areas. Areas to the east of coastal mountains are in a rain shadow. So these areas receive lower rain and snow than the west.

Telemark, with area 15,299 km^2 is the tenth biggest county of Norway out of 19 counties. Telemark is located in southeastern part of Norway and is also called ‘Norway in miniature.' It extends from the ocean on the South to Hardangervidda plateau in the North. It has a dynamic landscape of mountains, valleys, lakes, and rivers (Council 2016)

Figure 2-1: Telemark with 19 County

Telemark has large hydropower resources due to favorable topography and climate. It consists more than 40 hydropower plants. Many reservoirs are constructed for the purpose of water transportation to power stations. Our study area, Skien water system is located in southern Telemark and has a total catchment area of 10772 km^2 and annual runoff of 274 m^3/s. It consists of four reservoirs, Tinnsjø, Heddalsvatn, Norsjø, and Hjellevatn. The remainder of the catchments is divided into Tokke-Vinje hydropower system, Møsvatn hydropower system, and Mår hydropower system. There are six power plants located in Møsvatn and Mår hydropower system.

2.2. RESERVOIRS

2.2.1. Tinnsjø

Tinnsjø is the deepest lake in Norway with the depth of 460m which is 271 m below sea level. The lake lies in Tinn and Notodden municipalities in Telemark. The largest tributaries are Måna, coming from Møsvatn and Rjukan in the west, and Mår coming from lakes Mårvatn and Kalhovd Fjord in the north. The lake covers an area of 51.38 km^2 with a catchment area of 3775.23 km^2. The inflow is from Asses Raua, Skirva, Urdalsåe, Digeråi, Gjuvåi, Rollagåe, Måna, Austbygdåe, Gøyst, and Mår. Måna and Mår are regulated flows to Tinnsjø and rest other inflows are unregulated flows. The outflow is Tinnelva to the south and down to Heddalsvatnet. The outflow from Tinnsjø is recorded in Kirkevoll bru (16.23.0) downstream, where minimum flow registered is 12.3 m^3/s, and the maximum is 850 m^3/s. The volume of the reservoir is 204.1 million m^3/s. The regulation height is from 191.2 m to 187.2 m (NVE 2016).

2.2.2. Heddalsvatn

Heddalsvatn covers an area of 13.2 km^2 with a catchment area of 5,380.47 km^2. The lake lies in Notodden and Sauherad municipalities in Telemark. The main inflow to the lake is Tinne and Heddøla, which are regulated and flow from upstream, is recorded at gauging station Omnesfoss (16.10.0). The other inflows are fjukseelva, Klevaråo, and Tveitåa. The outlet to the lake is river Sauarelva, which flows down to Norsjø (NVE 2016).

2.2.3. Norsjø

Norsjø covers an area of 55.18 km^2 with a catchment area of 10,388.16 km^2. The lake lies in Skien, Nome and Sauherad municipalities in Telemark. The regulation height is 15.3 To 15.15 m. The inflow to the lake are Eidselva, Gvarv Elva, Saua and the outlet is Farelva. The flow from Gvarv is recorded at Hagadrag (16.51.0) and Eidselva flow out to Vrangfoss. It is regulated by the pond at Skotfoss to an altitude of 15.3 m (NVE 2016) and flow is recorded at Skotfoss (16.133.0). (NVE 2016)

2.2.4. Hjellevatn

Hjellevatn is the lower water basin in Telemark watercourse. The lake covers an area of 0.45 km^2 and is located in Skien municipality. The inflow is from Farelva and Falkumelva recorded at station Farelva (16.497.0), and outlet is to Skien river. The water drop between Hjellevatn and Skien river is utilized for power production by Eidet power plants and Klosterfoss power system (NVE 2016).

2.3. Regulated flow

2.3.1. Møsvatn Hydropower System

Møsvatn is Telemark's largest lake and the twelfth largest in Norway. The area of the lake is 78.44 km^2 located at the most part in Vinje municipality and about 5.5 km^2 in Tinn municipality. The catchment area of the lake is 1,510.26 km^2. The inflow into the lake is from Kvenna, Hellegjuvbekken, Tommåi, Skinåi, Laksåi, Grytåe, Tangeåi, Hondle. The high reservoir water level is 918.5m, and low reservoir water level is 900m. Møsvatn is dammed by Møsvassdammen and Torvehovdammen and is the main reservoir for Frøytsul power plant. The water from Møsvatn is also regulated at Skarsfoss dam. The water from Møsvatn flows through five power plants (Frøytsul, Vemork, Såheim, Moflåt, and Mæl) before it flows into Tinnsjø. The capacity of the reservoir is 1.066 billion m^3. (NVE 2016)

2.3.2. Mår Hydropower System

Mårvatn is a lake located in the municipalities of Tinn in Telemark and Nore and Uvdal in Buskerud. The area of the lake is 20.56 km^2 with a catchment area of 273.08 km^2. The inflow in the lake is from Uppnesåi, syvra, Grytekilbekken, Skjorteåe, Kosadalsåe, Hetteåe. The high reservoir water level is 1121.28m, and low reservoir water level is 1100m. The natural outlet of the lake is through Kalhovd Fjord and river Mår to Tinnsjø. The Stegaros power plant uses flow from Mårvatn to Kalhovd. The lake is regulated as a reservoir for power plants further down Skien river. The capacity of the reservoir is 321 million m^3.

Gøystavatnet is a lake located in Tinn municipality. The area of the lake is 11 km^2 with a catchment area of 72.56 km^2. The inflow to the lake is from Gøyståi and Våbekken. After construction of the power plants, the lake was dammed to the same level as Kalhovd Fjord. Kalhovd Fjord is 20.39 km^2 with a catchment area of 588.97 km^2 where inflow is from Mårvatn, Butjønnåi, and Hola. The regulation height is 1086.61 to 1075 m. The combined capacity of the reservoir is 256.4 million m^3. The two lakes in combine also include

Strengetjønnan, Kilsfjorden, Sprogen, Geitebufjorden, Grytefjorden, and Viervatnet. The natural outlet is towards east to Nysetdøla and Gøyst down to Tinnsjø. The lake is regulated as a reservoir for Mår power plant as water flow from Gøystavatnet through the tunnel from Grotte Tjønn. (NVE 2016)

2.3.3. Tokke-Vinje Hydropower System.

The power plants in Tokke-Vinje regulation utilize inflow into watercourses mainly located in Tokke and Vinje municipalities. There are seven power plants in the waterway, and the total annual power production is 4.5 TWh. The regulation zone in Tokke-Vinje include following reservoirs: Songa, Totak, Ståvatn, Kjelavatn, Vesle Kjelavatn, Førsvatn, Langesæ, Bordalsvatn, Byrtevatn, Langeidvatn, Våmarvatn, Bitdalsvatn, Venemo, Vinjevatn, Hyljelihyl, Vatjern, and Botnedalsvatn. Reservoirs and power plants are connected by about 108 km transmission tunnels and 32 dams. All the water from upstream regulated hydropower system ends up in Norsjø with a final point for discharge before Norsjø through Vrangfoss.(NVE 2016)

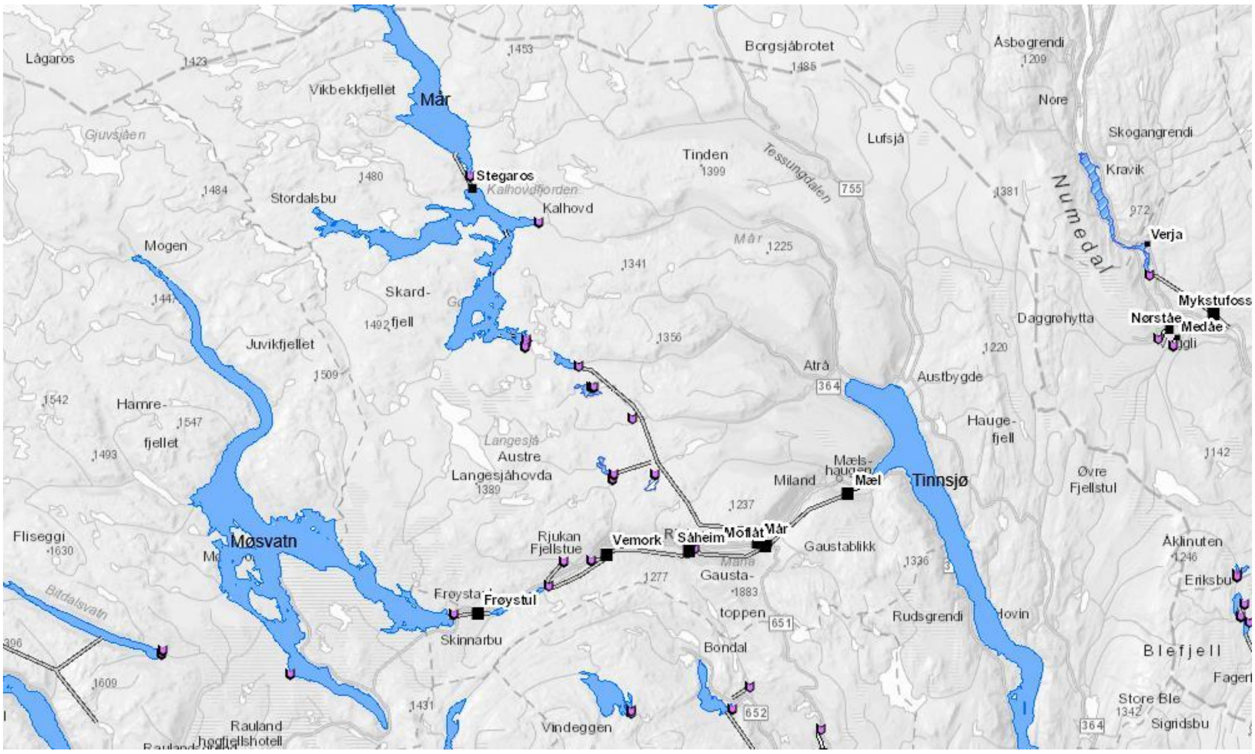


Figure 2-2: Tinnsjø with Møsvatn and Mår Power System (NVE 2016)

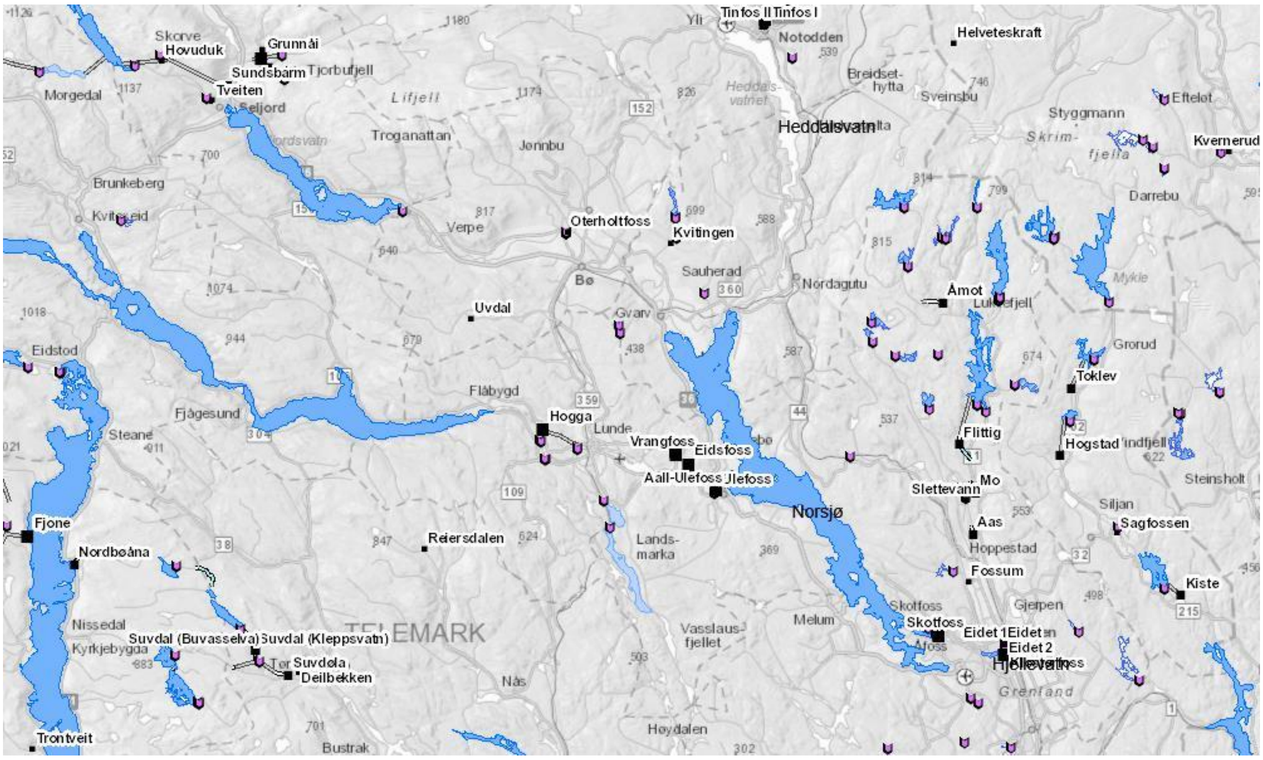


Figure 2-3: Heddalsvatn, Norsjø and Hjellevatn (NVE 2016)

2.4. Unregulated Flow

Unregulated flows are natural flows which are not controlled. Sometimes it is hard to predict flow from unregulated catchments as it is not possible to provide gauging stations in every catchment. Same is the case in Skien Water System. Thus, flow from local catchments is computed from three gauged catchments using a scaling factor based on area and specific runoff. These flows from local catchments are described as local inflows to reservoirs. Three gauged catchments are described below in detail.

2.4.1. Austbygdåi

Austbygdåi is a river that flows through Sandset valley and Tessungdalen, where it is called Tessungåe, before it empties into Austbygde, at the northern end of Tinnsjø. It has the catchment area of 344.6 km^2 which mostly lies in Tinn, and other small portion lies in Nore and Uvdal commune. The elevation within the catchment varies from 1480 masl to 180 masl with high mountains in the north. (NVE 2015)

The precipitation station P3108, Tessungdalen located at the boundary of catchment and temperature station T3162 Møsstrand 2 close to catchment are used. The annual precipitation varies for from 700 mm to 1100 mm and temperature recorded ranges from -29^o C to 27^o C.

The gauging station for Austbygdåi river is located at the outlet of the catchment, where data for daily mean flow are recorded. The maximum runoff recorded is 124.87 m^3/s.

2.4.2. Hørte

Hørte is a river formed by joining two big streams, Lonåa and Aaeåa. It flows downstream to join Bøelva and finally drains to Lake Norsjø. It has the catchment area of 155 km^2 which mostly lies in Bø, and a small portion lies in Sauherad and Notodden communes. It is located in relatively lower part representing a plain area of the watercourse and elevation varying from 80 masl to 1200 masl. (NVE 2015)

The precipitation station P3220 Lifjell located in the vicinity of the catchment is used for model calibration. The temperature station used is T3162 Møsstrand 2 for obtaining data on temperature. The annual precipitation varies from 700mm to 1050mm with temperature variation from -29^{o}C to 27^{o}C. The gauging station provided at catchment outlet provides daily flow record. The maximum runoff measured is 113 m^3/s.

2.4.3. Kileåi

Kileåi is a river formed by joining the rivers, Homflåtjønn and Dalsåi and flows downstream to join Flåvatn and finally drains to Norsjø. It has the catchment area of 119 km^2 which lies in Seljord and Nome communes. It is located in the middle part of Telemark representing a hilly area with elevation variation of 120 masl to 1060 masl. (NVE 2015)

The precipitation station P3285 Kviteseid and temperature station Møsstrand 2 located close to catchment are used for model calibration. The annual precipitation varies from 700mm to 1050mm with temperature variation from -29^{o}C to 27^{o}C. The gauging station provided at catchment outlet provides daily flow record. The maximum runoff measured is 70 m^3/s.

3. DATA ACQUISITION AND CONTROL

The result of the hydrological model depends on data achieved for setup. Data were collected from different sources depending on nature of data required.

- Daily meteorological data, precipitation, and temperature were obtained from eklima and viewed in senorge.
- Discharge data were obtained mostly from NVE whereas data for Mår hydropower system and Møsvatn hydropower system and other power systems were obtained from Statkraft and Hydro Power Company.

3.1. Acquisition of Meteorological Data

The daily meteorological data is found in Eklima. Precipitation and air temperature stations in and around catchment were extracted and was used in the model for forecasting runoff of three unregulated catchments.

3.1.1. Precipitation data Analysis

Graphs for daily series and annual precipitation for each catchment represented by the respective station are plotted.

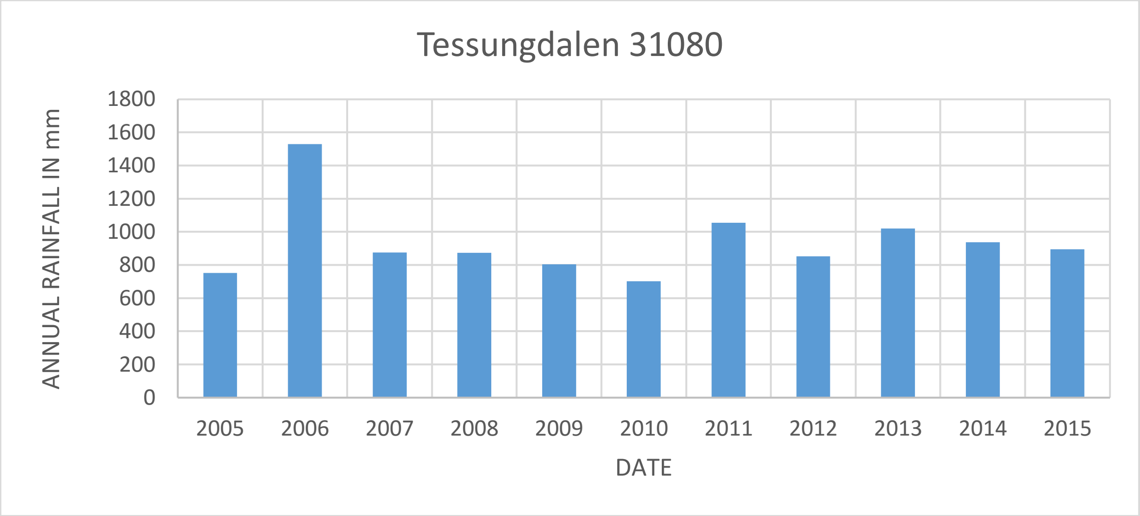


Figure 3-1: Graphs of Annual Rainfall data for catchment Austbygdåi

The graph shows annual precipitation from 2005 to 2006. In 2014 and 2015 annual rainfall is in the range of 900mm.

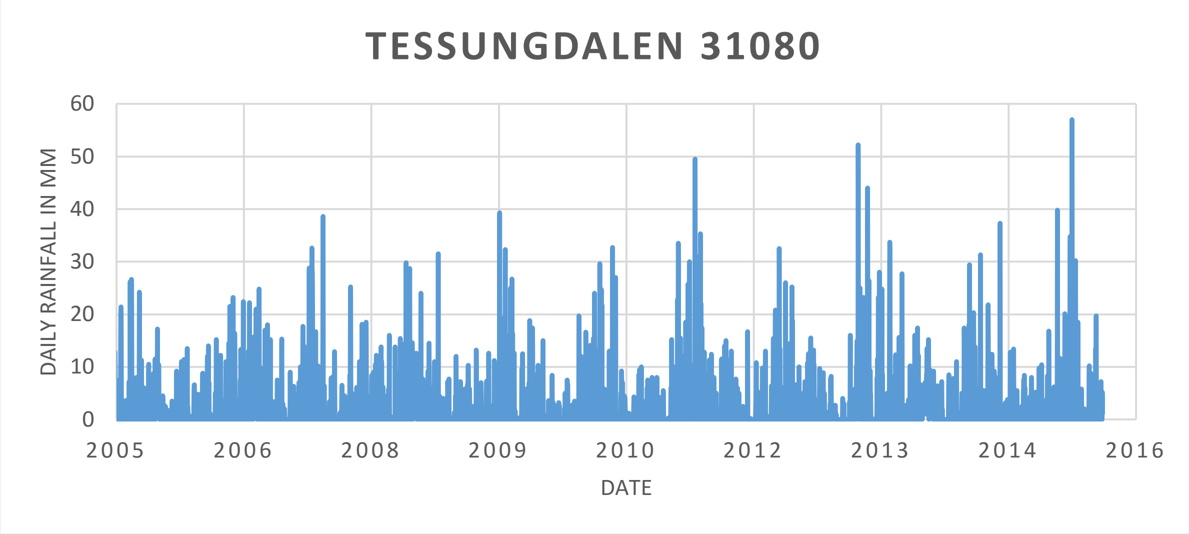


Figure 3-2: Graph of Precipitation data for catchment Austbygdåi

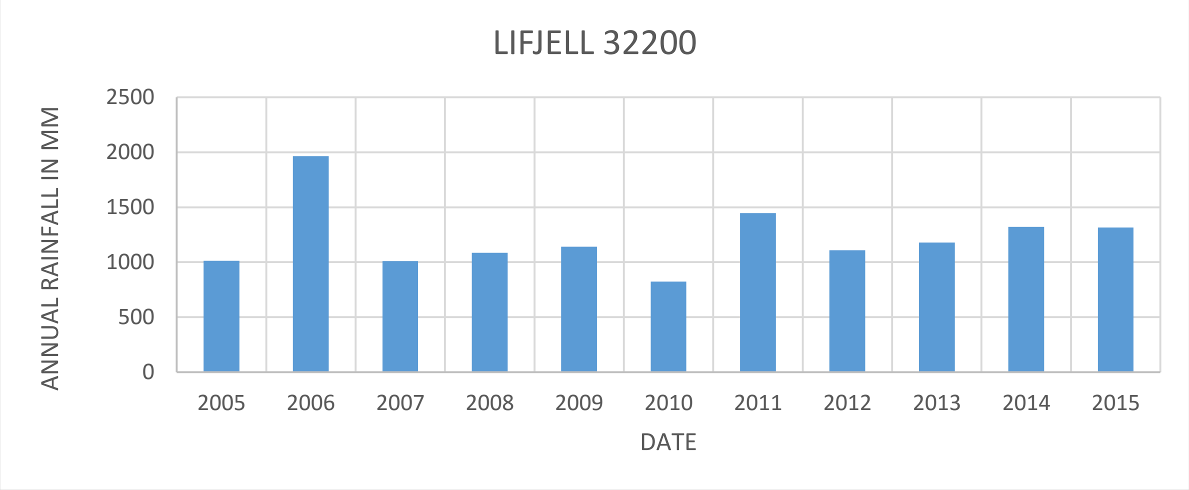


Figure 3-3: Graph for Annual Rainfall Data for Hørte

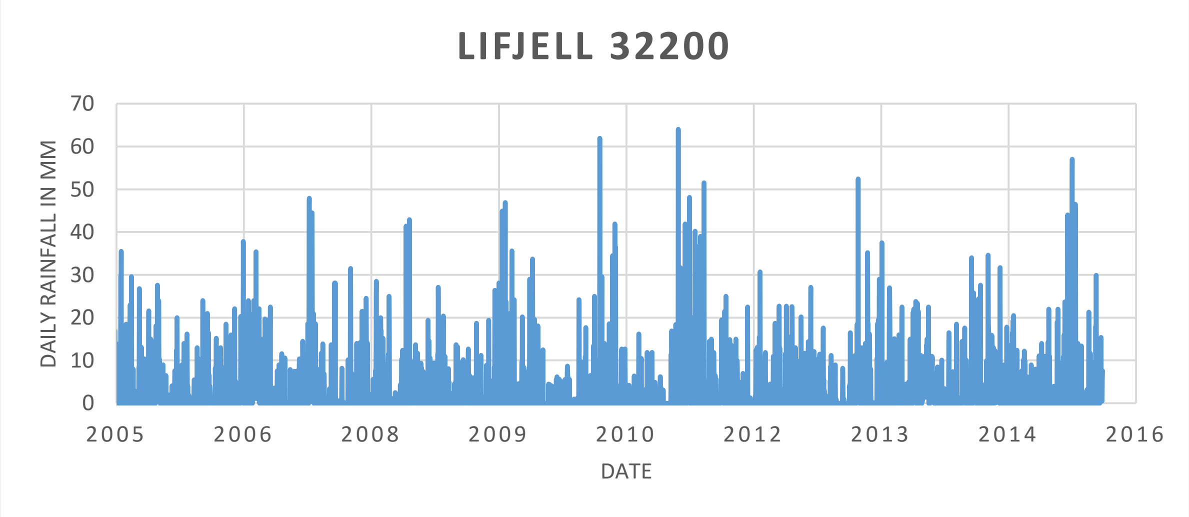


Figure 3-4: Graph for Precipitation Data for Hørte

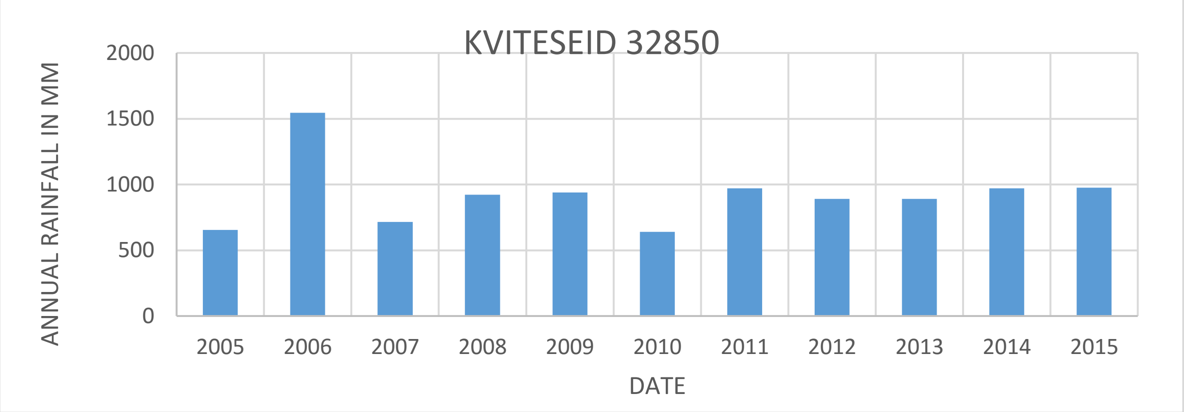


Figure 3-5: Graph for Annual Rainfall Data for Kileåi

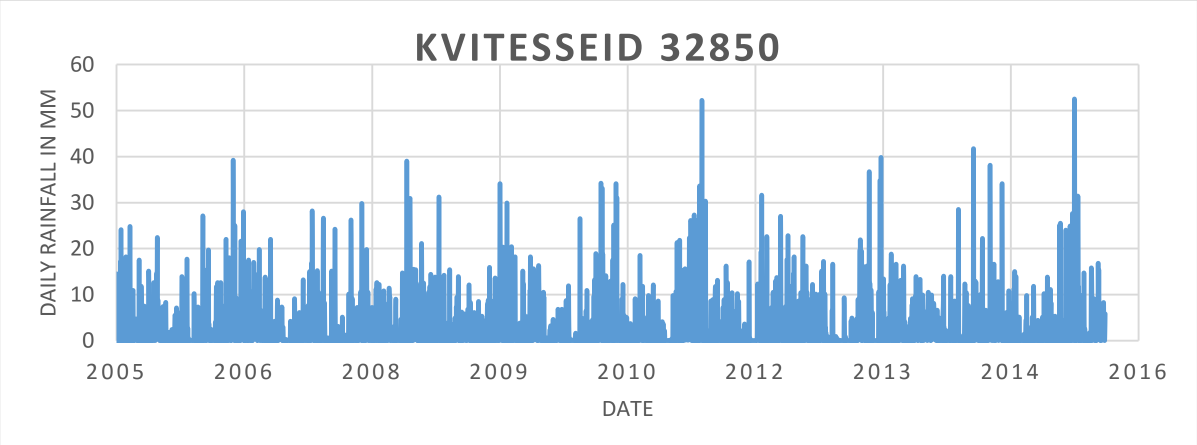


Figure 3-6: Graph for Precipitation Data for Kileåi

Figures above represent good quality data series with no data missing. The location of these stations on the catchments with normal annual precipitation from 1971-2000 is listed below:

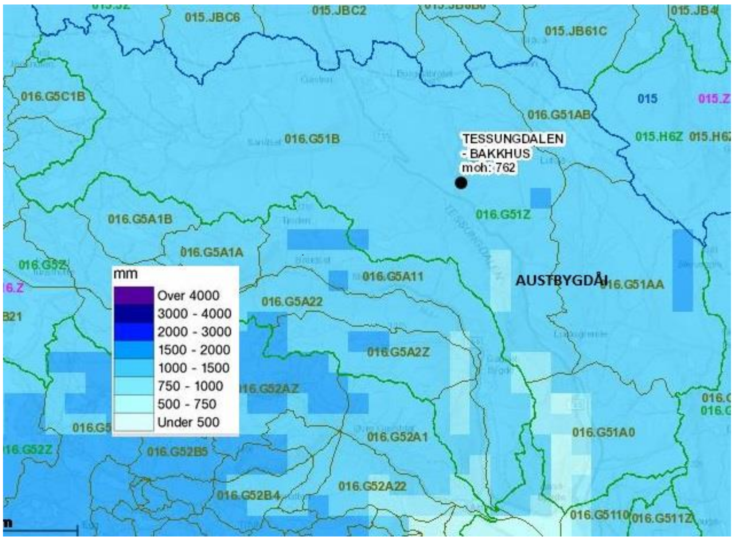


Figure 3-7: Austbygdåi with Selected Precipitation Station and Average Precipitation

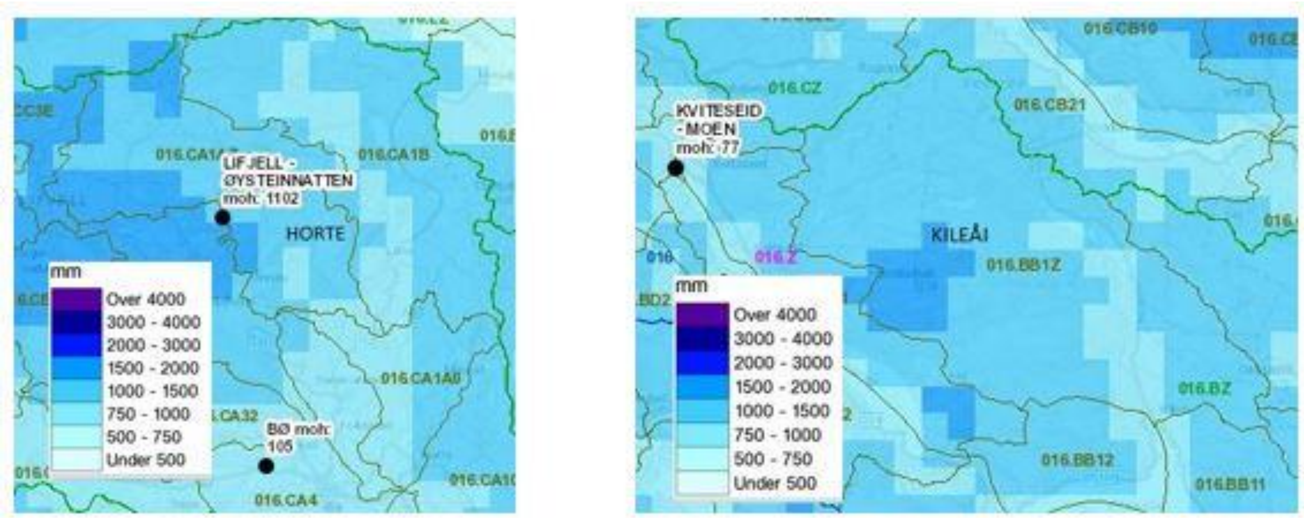


Figure 3-8: Hørte and Kileåi with selected Precipitation Station and Average Precipitation

The details about precipitation and temperature stations are shown in Table 3-1.

Table 3-1: Detail of Selected Precipitation and Temperature Stations

S. N.	Code	Precipitation Station	Latitude	Longitude	Elevation	Period	Catchment
1	P3108	Tessungdalen	60° 07' 46"	8° 42' 12"	762	1983-2016	Austbyddåi
2	P3220	Lifjell	59° 27' 18"	9° 02' 14"	354	1981-2016	Hørte
3	P3285	Kviteseid	59° 24' 23"	8° 28' 32"	77	1981-2016	Kileåi
4	T3162	Møstrand	59° 49' 29"	8° 20' 51"	977	1981-2016	All 3

3.1.2. Temperature Data Analysis

All three unregulated catchments use the same temperature station. The location of temperature station is far from all three catchments. The station is at higher elevation than Hørte and Kileåi. Møstrand has given the same result as by using other temperature stations near the catchment for all three catchments during calibration. Hence, this temperature station is selected without any major changes in calibrated parameters (Mahat 2006). Graphs of daily series and yearly average recorded at Møstrand temperature station are shown below.

.

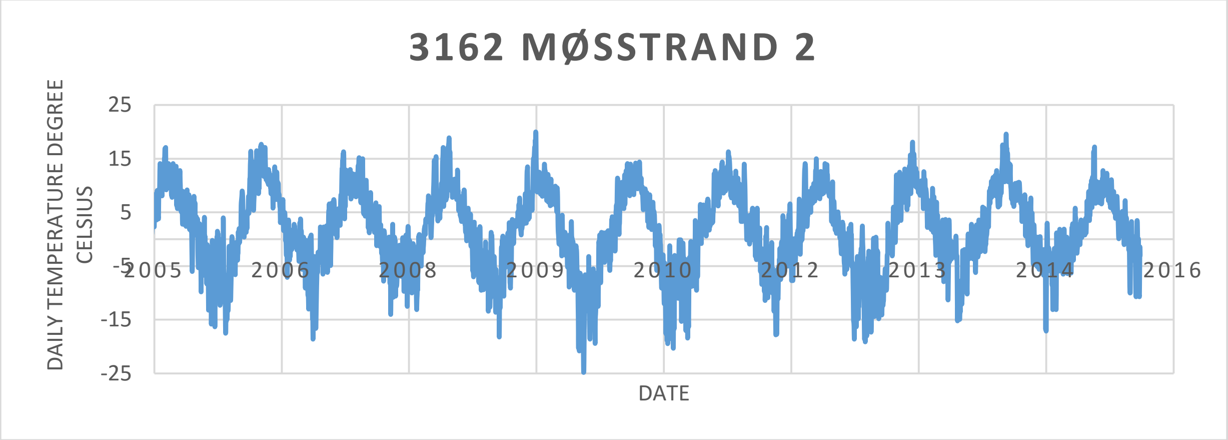


Figure 3-9: Graph for Daily Temperature Data for Austbygdåi, Hørte, and Kileåi

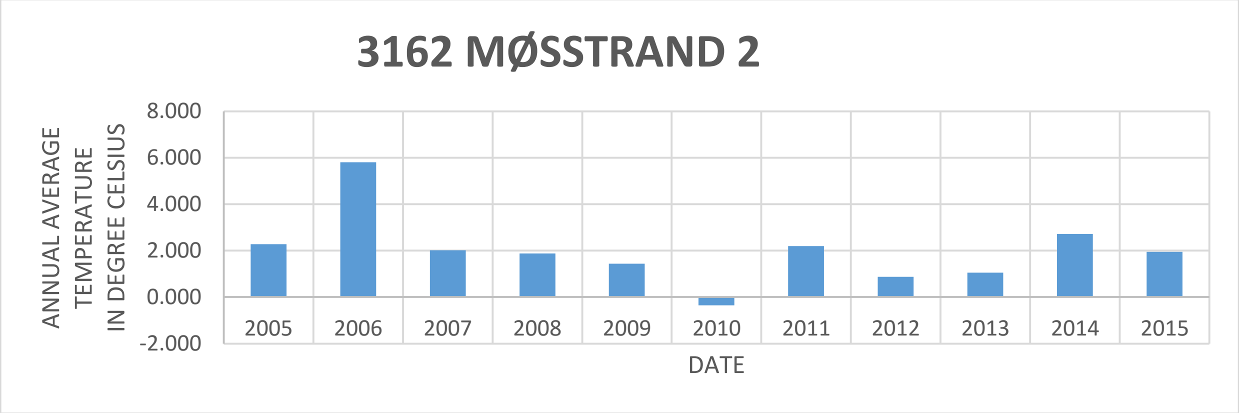


Figure 3-10: Graph of Annual Average Temperature for Austbygdåi, Hørte, and Kileåi

Figures above represent the good quality of data set and data series without any missing values. The location of temperature station and catchment selected are shown in Figure 3-11 with annual temperature from 1971-2000:

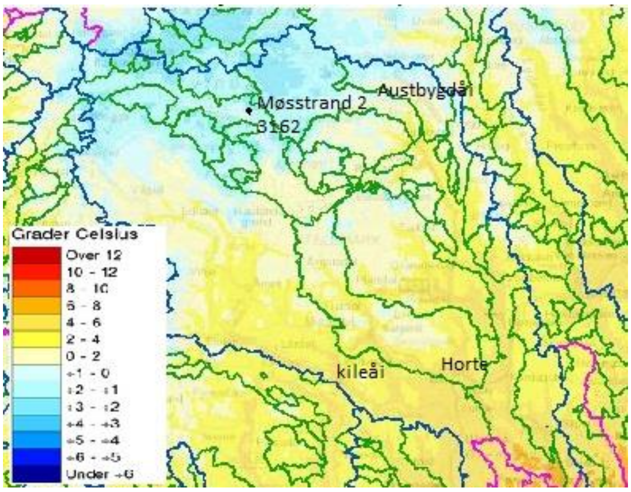


Figure 3-11: Austbygdåi, Hørte, and Kileåi with Selected Temperature Station and Average Temperature from 1971-2000

3.2. Acquisition of Hydrological Data

Hydrological data are collected from NVE xhydra, Statkraft Power Company, and Hydro Power Company.

3.2.1. Runoff Data Analysis

Daily runoff series for reservoirs Tinnsjø, Heddalsvatn, Norsjø, and Hjellevatn was received from NVE xhydra. Furthermore, runoff from unregulated catchments, Austbygdåi, Hørte and Kileåi was also received from xhydra. Also, runoff from regulated rivers and reservoirs are obtained from gauging stations, Omnesfoss, Hagadrag, Skotfoss and Farelva from NVE.

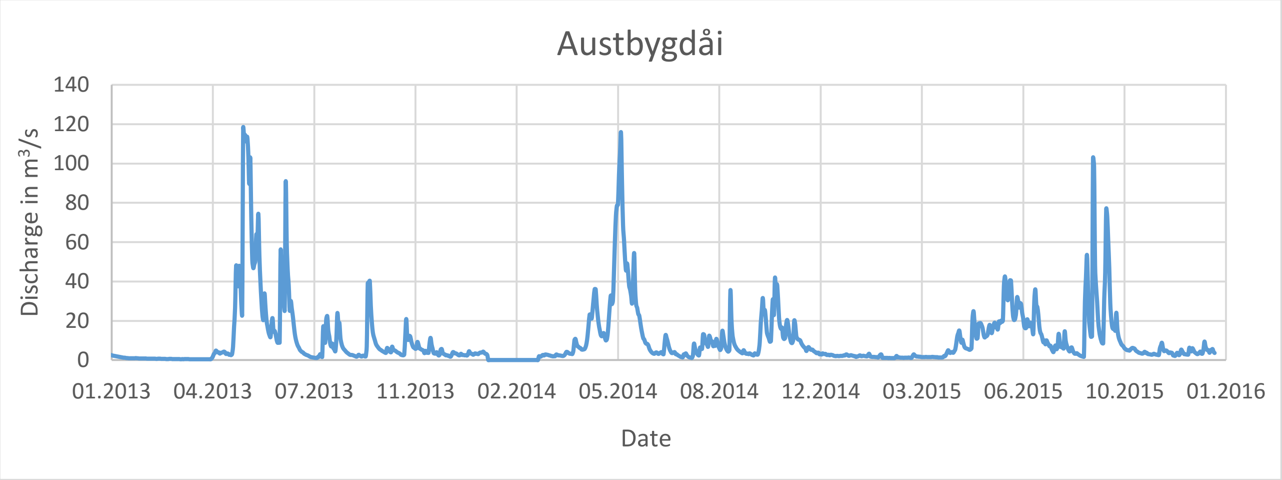


Figure 3-12: Daily flow series recorded in Austbygdåi

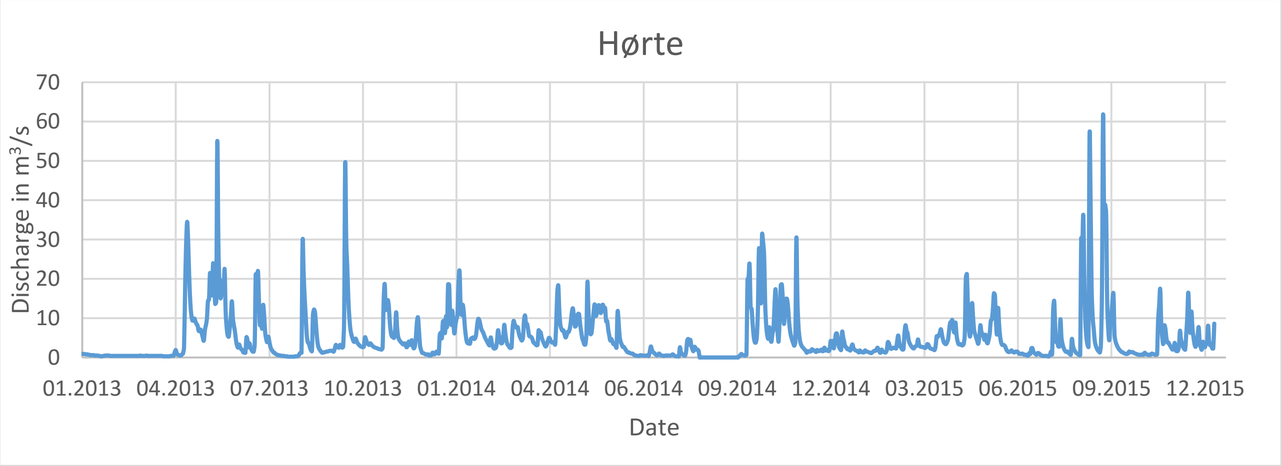


Figure 3-13: Daily flow series recorded in Hørte

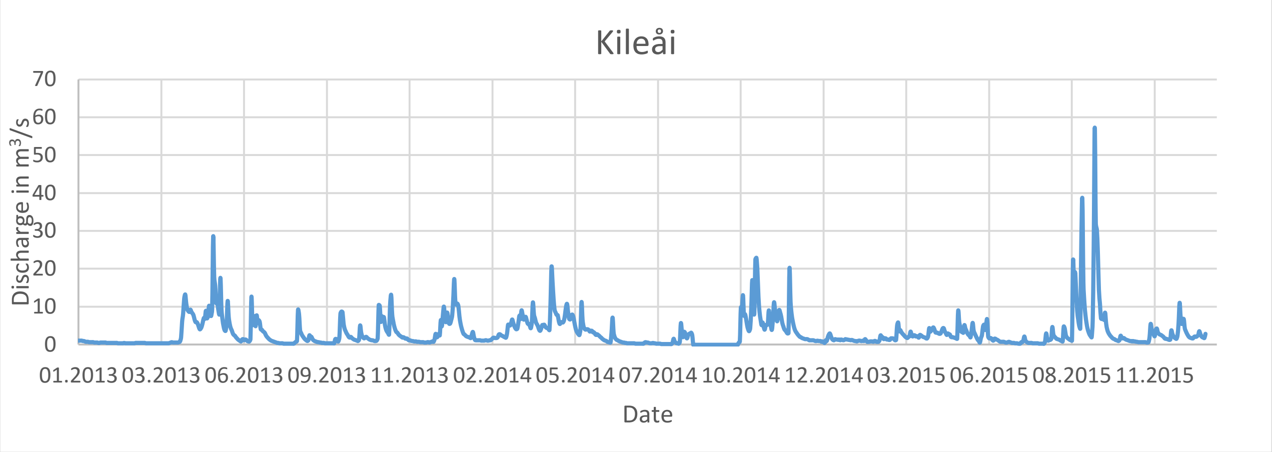


Figure 3-14: Daily flow series recorded in Kileåi

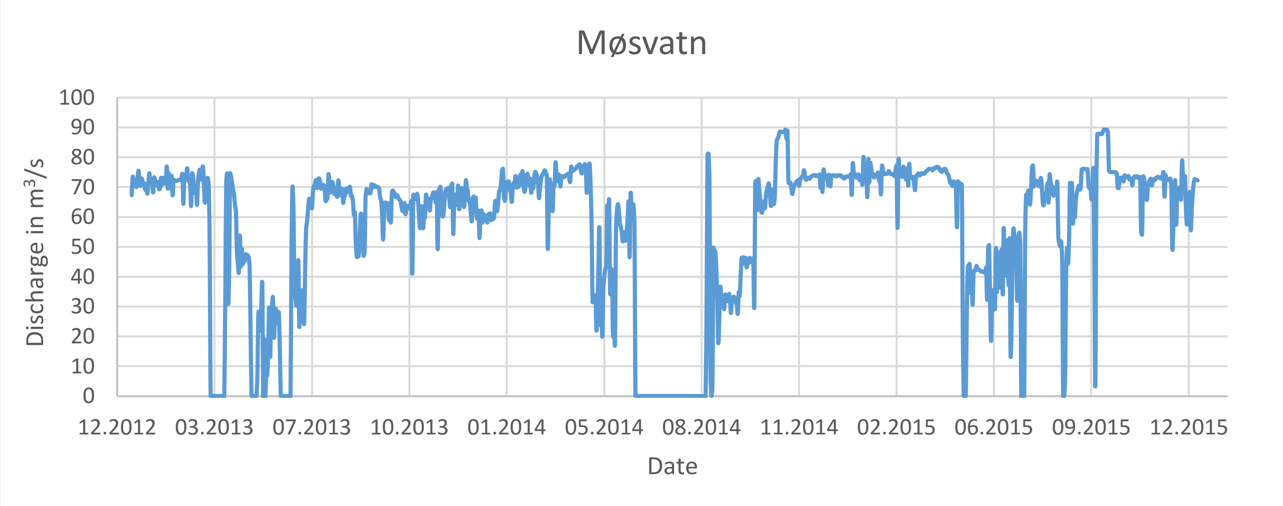


Figure 3-15: Daily flow series from Møsvatn as Production Flow to Frøystul Power Plant

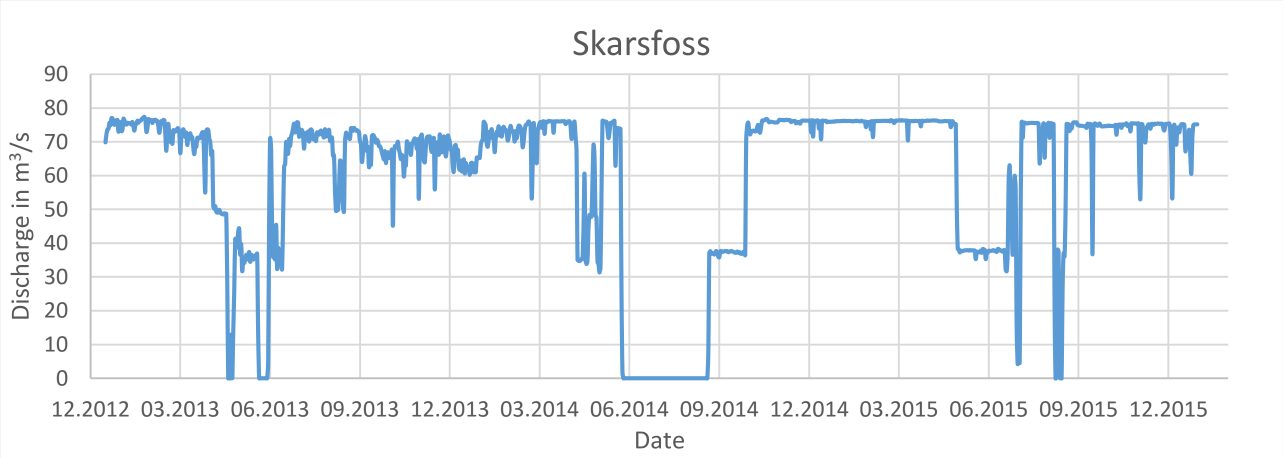


Figure 3-16: Daily flow series from Skarsfoss as Production Flow to Vemork Power Plant

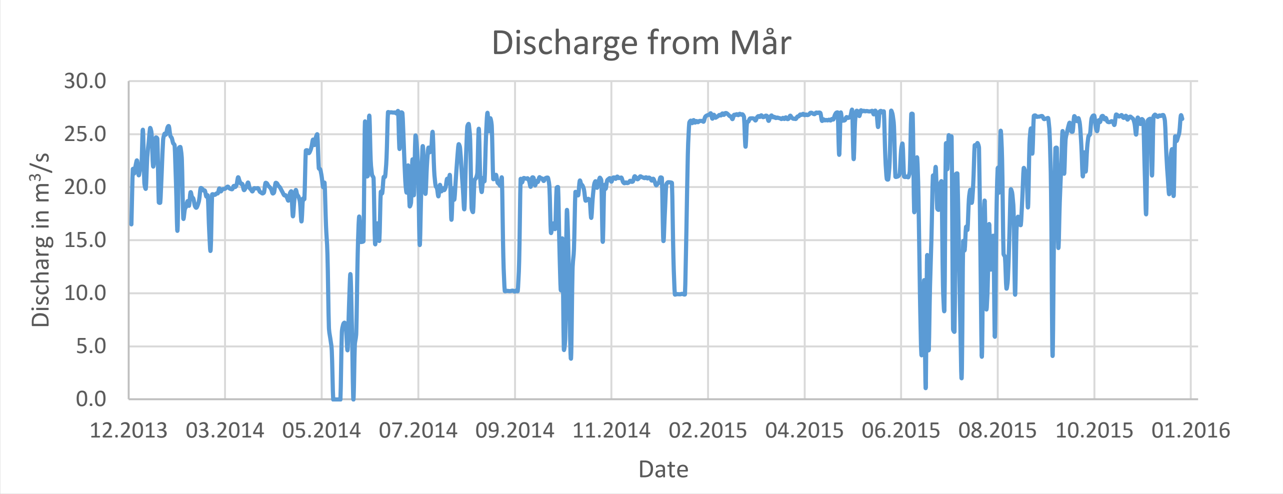


Figure 3-17: Daily flow series recorded from Mårvatn to Mår Power Plant

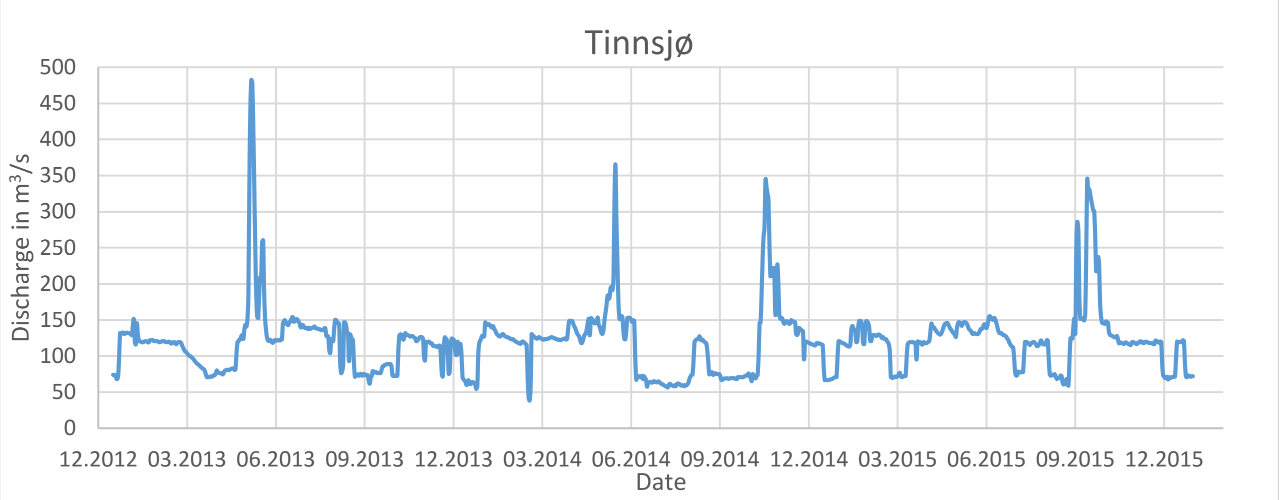


Figure 3-18: Daily flow series recorded at Kirkevoll Bru

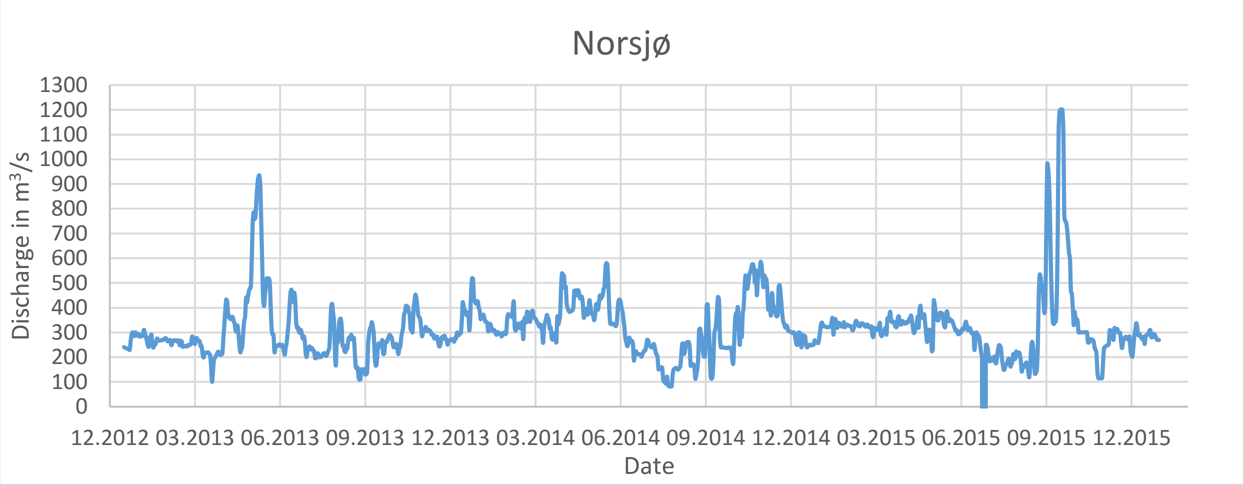


Figure 3-19: Daily flow Series recorded at Skotfoss

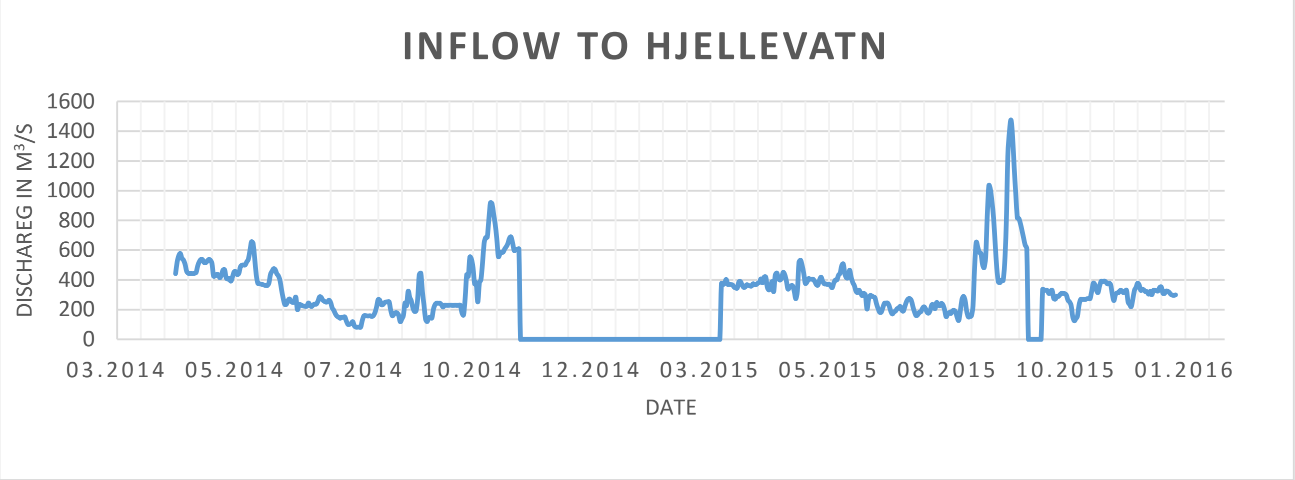


Figure 3-20: Daily flow Series recorded at Farelva

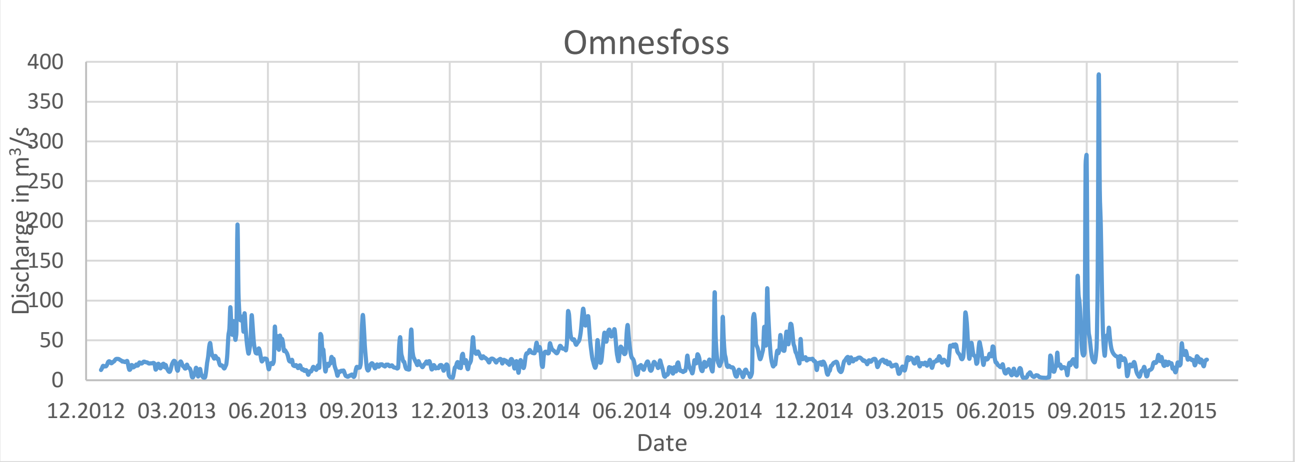


Figure 3-21: Daily flow series recorded at Omnesfoss

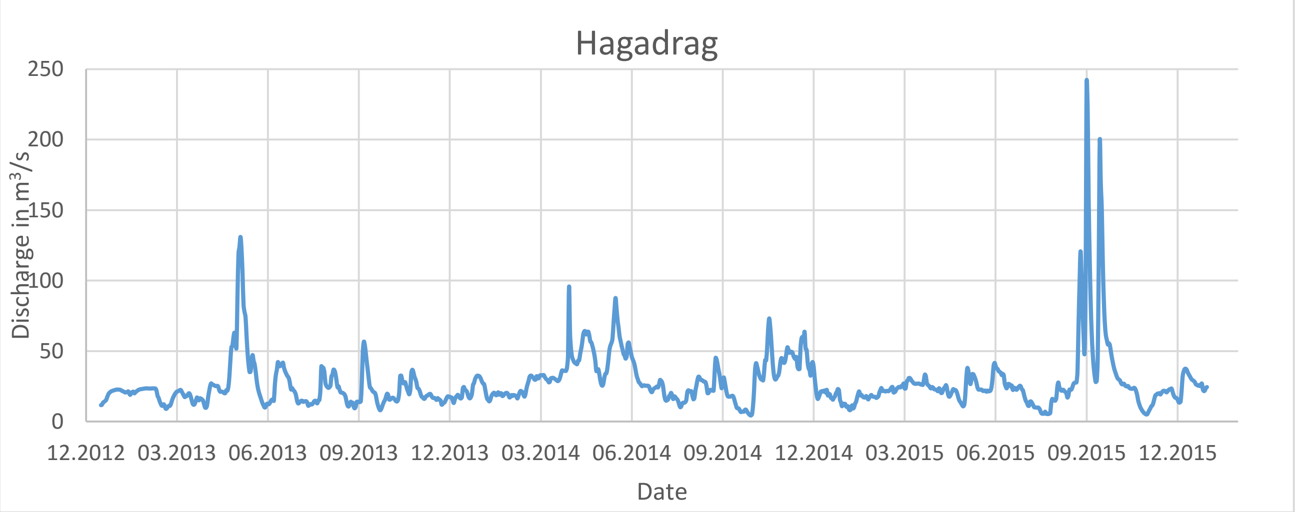


Figure 3-22: Daily flow series recorded at Hagadrag

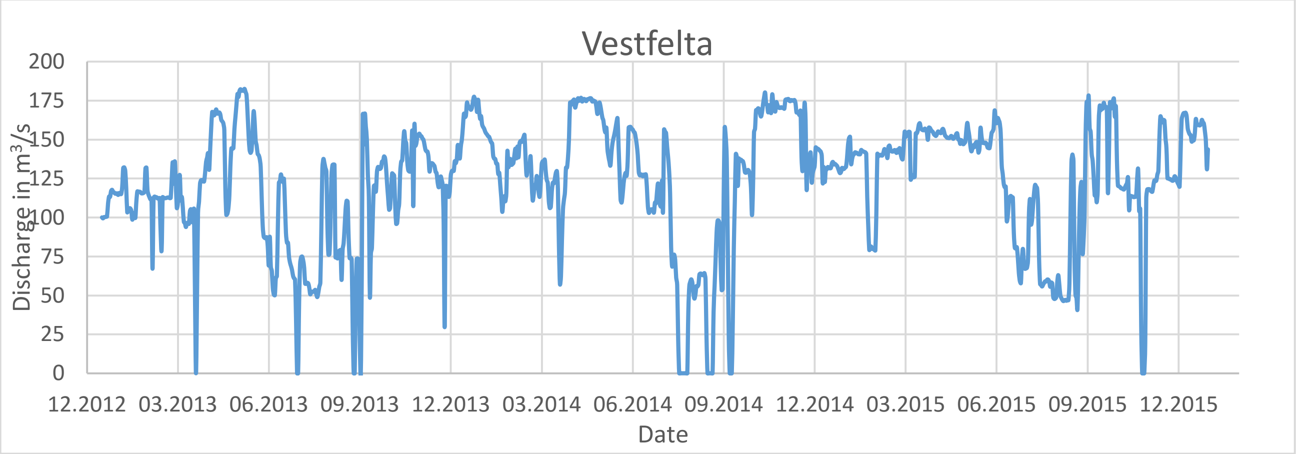


Figure 3-23: Daily Production Flow series recorded at Vrangfoss

From the Figure 3-18: Daily flow series recorded at Kirkevoll Bru, we see series of large flood events in Tinnsjø on May 2013, May 2014, November 2014, and two large flood events in September 2015. The water from Tinnsjø flows into Heddalsvatn. The other flow to Heddalsvatn is from the west which is recorded at Omnesfoss. The outlet from Heddalsvatn is through Sauarelva to Norsjø. There are no gauging stations in the river. The runoff for Sauarelva is missing in the graphs above as the outflow is calculated from Outlet curve being used by FMTV model which is presented in Appendix A (Table)- 1. In Appendix A (Table)- 1, the relation for volume curve is also presented along with relation to form discharge curve for Norsjø. The other flow to Norsjø is from Tokke-Vinje Power System. All the water through Tokke-Vinje area passes through Vrangfoss before Vestfelta River joins Norsjø. The other inflow to Norsjø from the west is recorded at Hagadrag. The outflow from Norsjø is recorded at Skotfoss, which flows through Farelva before ending up to Hjellevatn. The daily runoff series for all river reach in the study area is presented in graphs above. It is easy to see in graph during which period the runoff is large in the river which simply justifies during which period large flood occurred in the area. The list of the gauging stations from where necessary data were obtained is also represented in **T**Appendix A (Table)- 2. The outlet curve to find discharge in Sauarelva is shown in Appendix A- 1.

3.2.2. Flood Spill Data Analysis

Spill Data were obtained from Statkraft Power Company for Skarsfoss, for Mår from Hydro Power Company, and for Vrangfoss Power Plant from Norsjø Kraft AS. The data for spill from Møsvatn dam was obtained from NVE for station Møsvatn Langhol. The data for Møsvatn, Vemork, Mår, and Vrangfoss was obtained in m^3/s. The data received are listed with the description in chapter 4.

3.3. Filling of Missing Data

Data acquisition is always a tough task with always some missing data giving trouble in modeling. Missing of data can occur due to the problem in gauge, difficulty in reading daily data, personal mistakes in storage, poor storage system and much more (Marahatta 2015). It is the trouble faced by all doing hydrological projects. It is possible to obtain data by simple interpolation for random missing data but for long missing series, it is good idea to use nearby stations for getting precipitation and temperature, while for runoff it is possible to obtain data by manual calculation by using gauging stations upstream or downstream of location.

It was impossible to obtain data for Mår tapping before 2014. So, it was checked with the possibility of having a similar reading from Strengen (16.142.0) and for most periods of years, 2014 and 2015 the data were matching as seen in figures below.

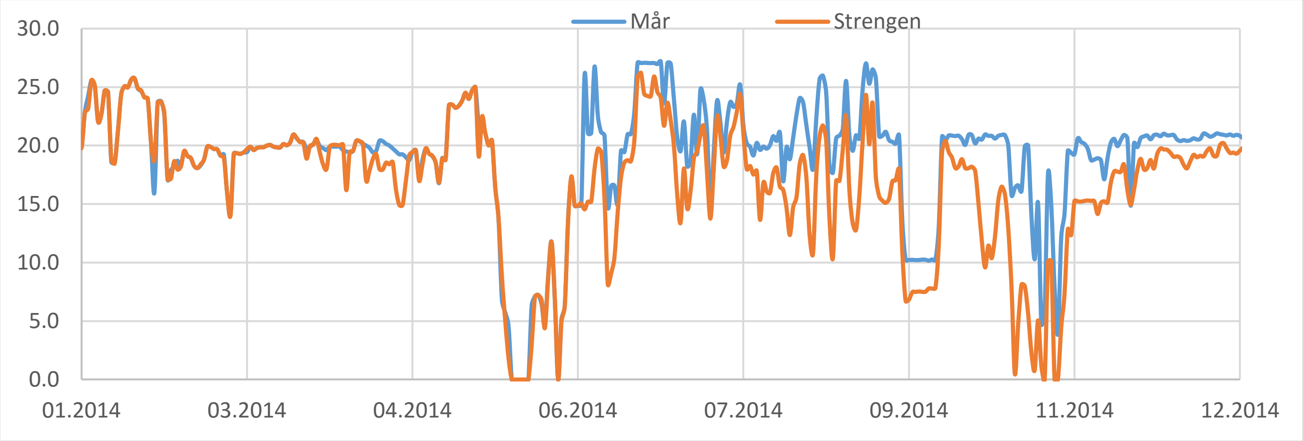


Figure 3-24: Comparison of data recorded for Mår and Strengen for 2015

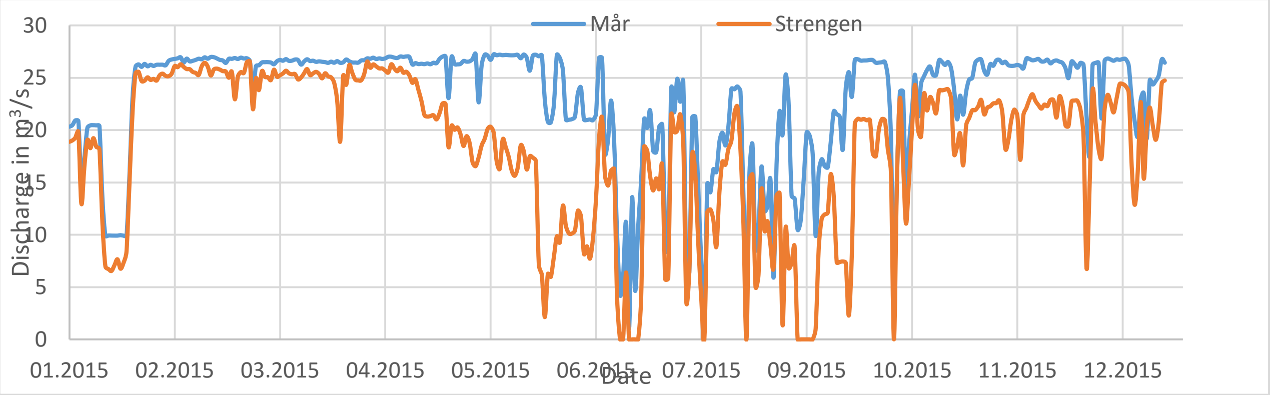


Figure 3-25: Comparison of data recorded for Mår and Strengen for 2015

From Figure 3-24: Comparison of data recorded for Mår and Strengen for 2015, it is seen that for 2014 the data for Strengen and Mår are quite similar whereas for 2015 the data for

Strengen seems to be somewhat lower than daily flow data for Mår. However, there was no other option than using strengen data for simulation of flood events for 2013.

Hjellevatn has no gauging station downstream so data from Farelva (16.497.0) is used as Hjellevatn tapping considering inflow equal to outflow as it is known that it can convey approximately 950 m^3/s before the water level starts rising above HRWL. We must therefore just assume outflow=inflow for flow less than 950 m^3/s. Thus, Farelva is used as data for Hjellevatn tapping. The Farelva seems to be a disturbed station with data available from 08.04.2014 and data were also missing for dates in 2014 and 2015, and no data was available for 2013. So the inflow to Hjellevatn for 2013 and other missing dates was considered as flow recorded at Skotfoss plus local inflow from Falkumelva, which is estimated from HBV-catchments by scaling from Kileåi (Mahat 2006). The detail calculation is shown for a month of January 2013 in Appendix B(Table)- 1.

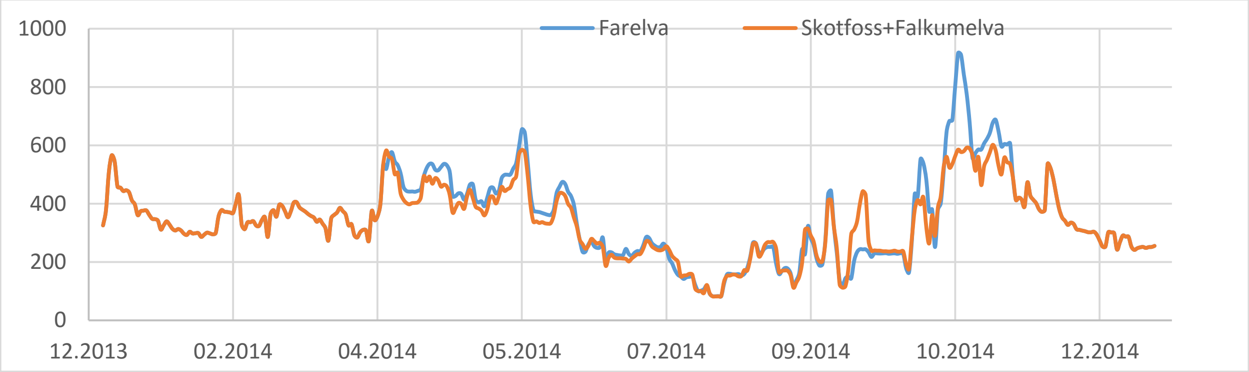


Figure 3-26: Comparison of Runoff recorded at Farelva and Skotfoss plus Falkumelva for 2014

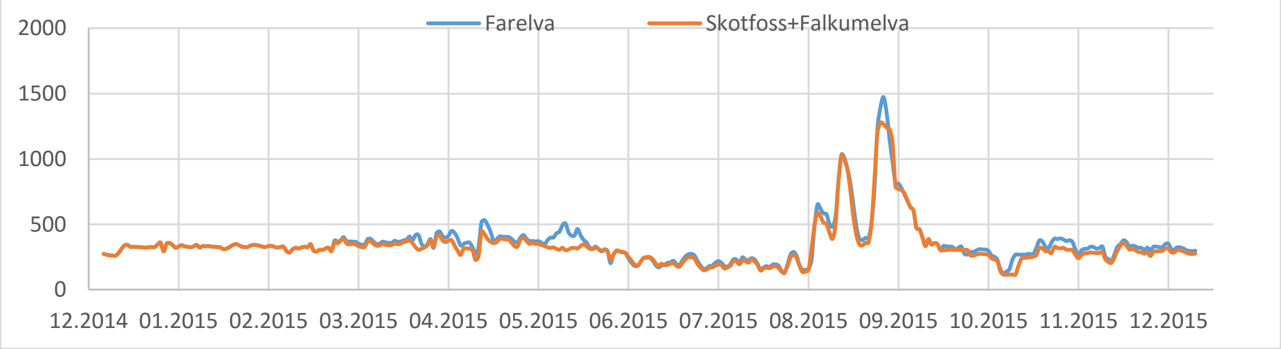


Figure 3-27: Comparison of Runoff recorded at Farelva and Skotfoss plus Falkumelva for 2015

By looking at Figure 3-26 and Figure 3-27, it looks right decision to take the runoff recorded at Farelva as the sum of Skotfoss and local flow from Falkumelva.

3.4. Data Quality Check

Consistency in data series is important for good results. It is also necessary to check data to maintain the quality of data. The various methods used in this thesis are

3.4.1. Visual Inspection

Visual inspection is essential to maintain good result in simulation. By visual inspection, the missing values were evaluated and respective periods were omitted during simulation of historical flood events.

3.4.2. Double Mass Curve

This method was used to see the consistency of data record for precipitation stations. Cumulative annual precipitation for each station is calculated and plotted in a graph against cumulative annual rainfall for all stations. Thus, the plot gives a double mass curve.

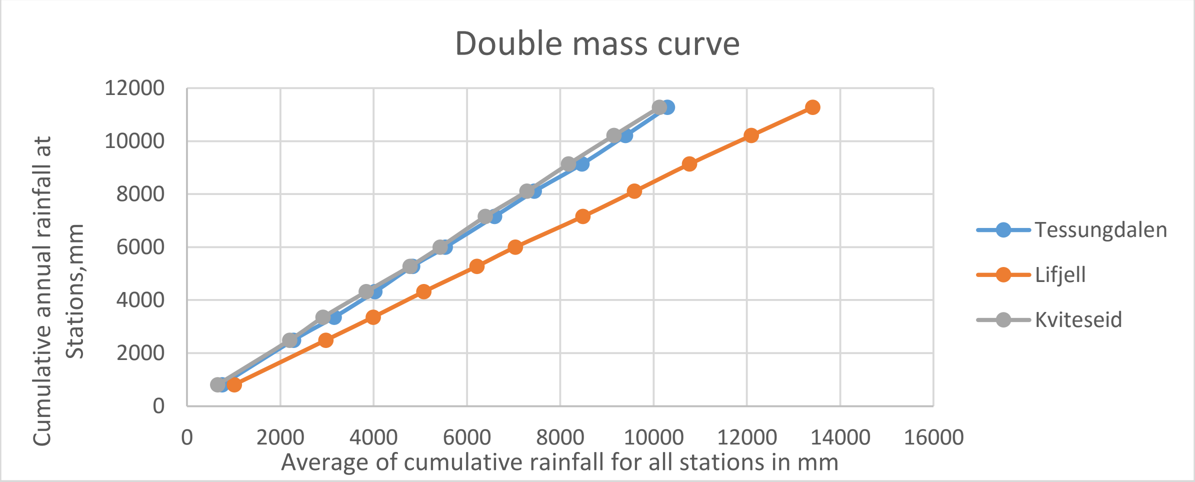


Figure 3-28: Double Mass Curve

From Figure 3-28, it is clear that all the double mass curve for all stations look good. Thus, it is clear that data records are consistent.

3.4. Field Visit of Study Area

The indoor study is not sufficient to have a better result in the completion of the project. A site visit has proved to be a valuable aspect of every project. The most important aspect of the site visit is the freedom it provides to do the reality check of the work carried out. The purpose of our site visit was to have better insight about the study area and to gather information on missing realities in our study. Professor Ånund Killingtveit organized the field trip and made possible to go to all the sites and gauging stations which we were studying to get the better findings. The most important factor we noticed were we got a closer look at flood-prone areas and the outlet system in every study area and also in the areas of the reservoirs. It was possible to decide after site visit that Skarsfoss was the inflow to be considered for Tinnsjø instead of Møsvatn as water from Møsvatn and Frøystul power plant was controlled by the Skarsfoss dam.

Furthermore, snowmelt and temperature play a vital role in a runoff to the reservoirs. In the field visit, variation in climate over upper part and lower part of Telemark Watercourse was viewed as there was spring in Hjellevatn, Norsjø, Heddalsvatn, and Tinnsjø with decreasing temperature with altitude but still prevailing winter with snow in Møsvatn. Some pictures are presented below from site.

Figure 3-29: Møsvatn on 17 May 2016

Figure 3-30: Hjellevatn on 19 April 2016

Figure 3-29 and Figure 3-30 describe the pattern of climate change over the Skien river system. This climatic scenario results in variation of rainfall and snowmelt along the catchment.

4. FLOOD SPILL DATA PREPARATION

Flood spill is periodic inflow to the reservoirs, but these can be very high resulting in flooding during the large flood period. FMTV model seems to be excluding flood spills during calculation. It might be the reason for the deficit in the inflow to the reservoir. The task is to check if the inclusion of these spills can improve flood forecasting simulation results. The spill is from dam and brook intakes which are considered for the study.

4.1. Flood Spill from Dam

Spill from Mår, Møsvatn, Skarsfoss and Vrangfoss dam were considered for further study. The data for spill from different dams are received from power companies. Flood spill calculation from the dam at Tinnsjø, Hjartsjåvatnet, and Seljordsvatnet was not necessary as these dams are provided with a gauging station at downstream, so all the spills are recorded. These recorded values are being used in FMTV model at present. Some pictures from different dam site showing the spillways for spill of excess water are shown below.

Figure 4-1: Skarsfoss Dam

Figure 4-2: Gated Spillway in Vrangfoss Dam

4.1.1. Data collection for Spill from Dam

Hydro provided data for spill from Skarsfoss dam. Data of flood spill from Mår, Møsvatn, and Vrangfoss was obtained from Statkraft Power Company and Norsjø Kraft AS. Data was obtained with the message that gates in Mår and Møsvatn were never used and hourly data obtained for spill from Mår was zero from 2014 to 2015. It was hard to get data from Vrangfoss, and it seemed impossible to get spill data for Vrangfoss. At the later stage, it was obtained with a daily average with production flow and spill in m^3/s. The Spill data obtained for Møsvatn, Skarsfoss and Vrangfoss is presented in figures below.

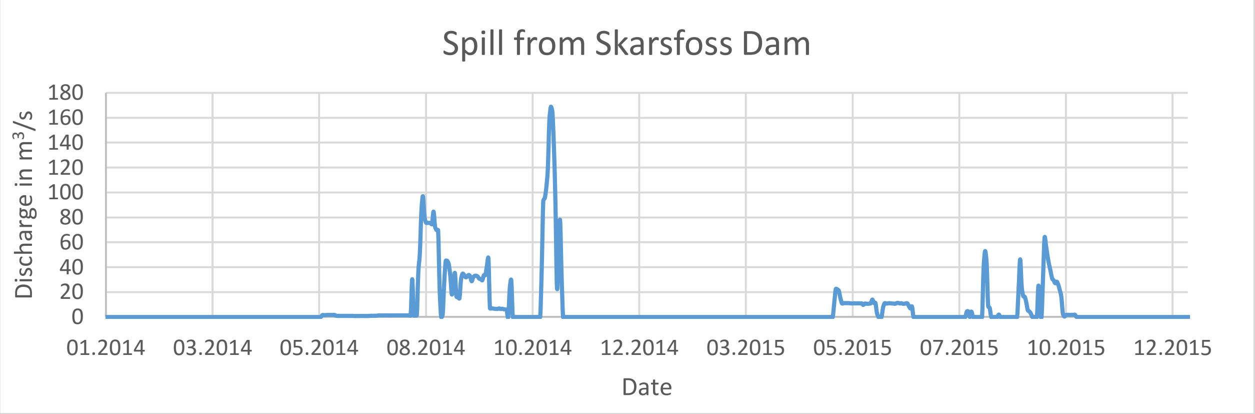


Figure 4-3: Daily Spill from Skarsfoss dam

Error! Reference source not found. shows very high spill during large flood period in the year 2014 and 2015.

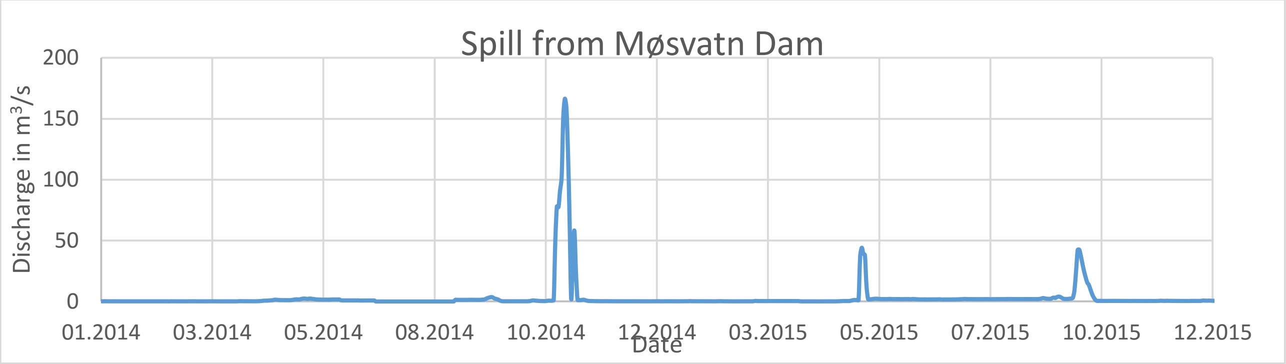


Figure 4-4: Daily Spill series recorded at Møsvatn Langhol

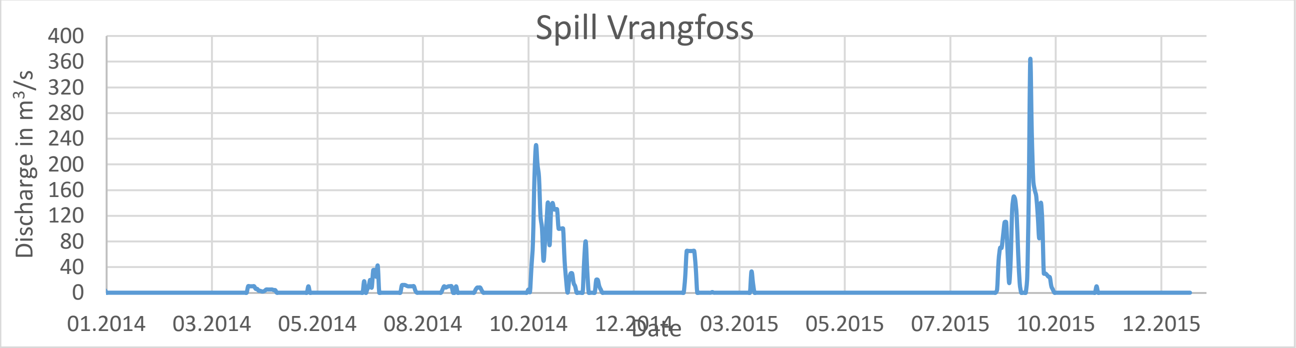


Figure 4-5: Daily Spill Series recorded at Vrangfoss

There is no spill at Mår and also in Skarsfoss and Vrangfoss for most period of the year. It is visible in Figure 4-3, Figure 4-4, and Figure 4-5 that spill seems to be high during large flood event even exceeding above 150m^3/s. This spill was compared with the flow at the respective period from Møsvatn, Skarsfoss and Vrangfoss, which is shown in the figures below.

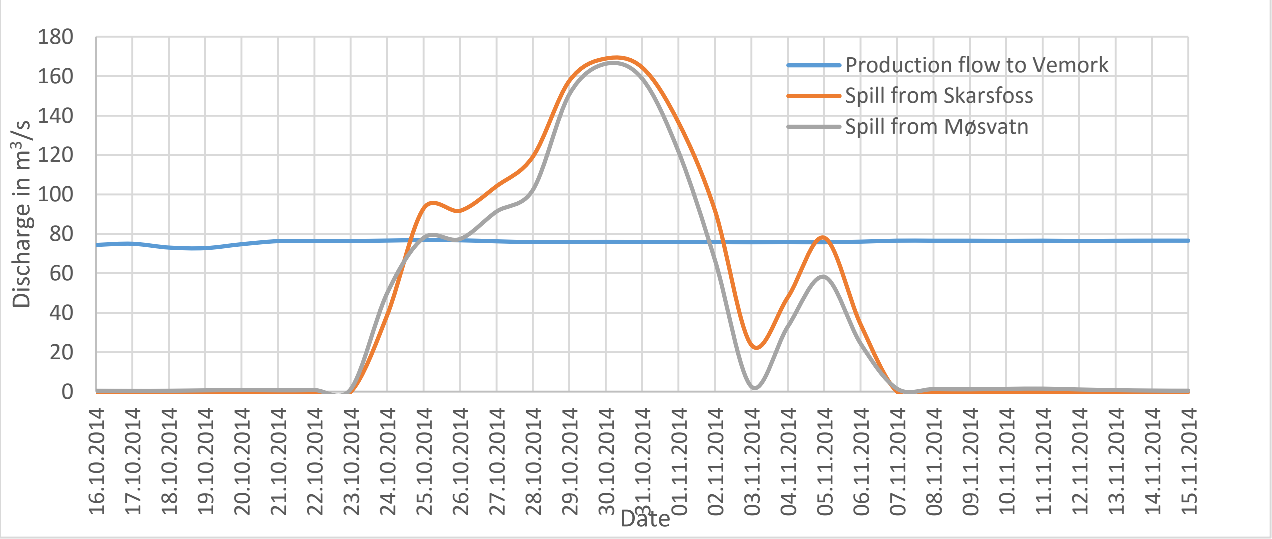


Figure 4-6: Production flow and Spill from Skarsfoss and Møsvatn during large flood event in 2014

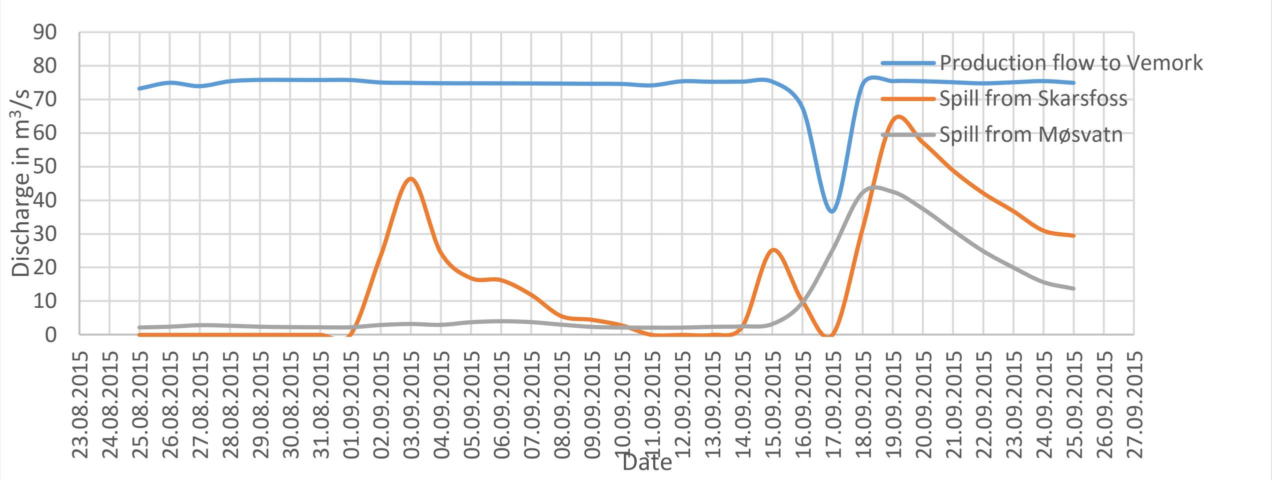


Figure 4-7: Production flow and Spill from Skarsfoss and Møsvatn during large flood event in 2015

In Figure 4-7, the spill from Skarsfoss dam is for a longer period and is larger than from Møsvatn dam. Figure 4-6 shows that spill is same for Skarsfoss and Møsvatn dam.

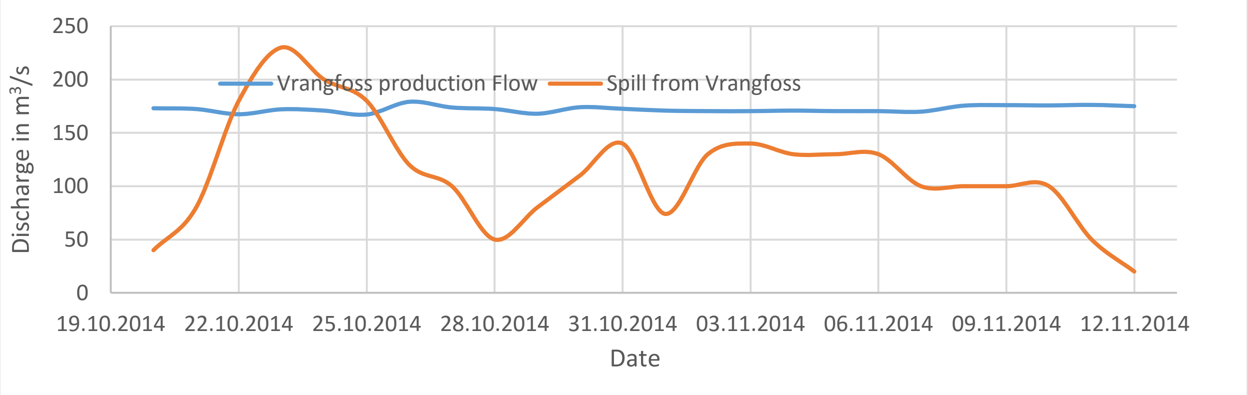


Figure 4-8: Production Flow and Spill from Vrangfoss during large flood event in 2014

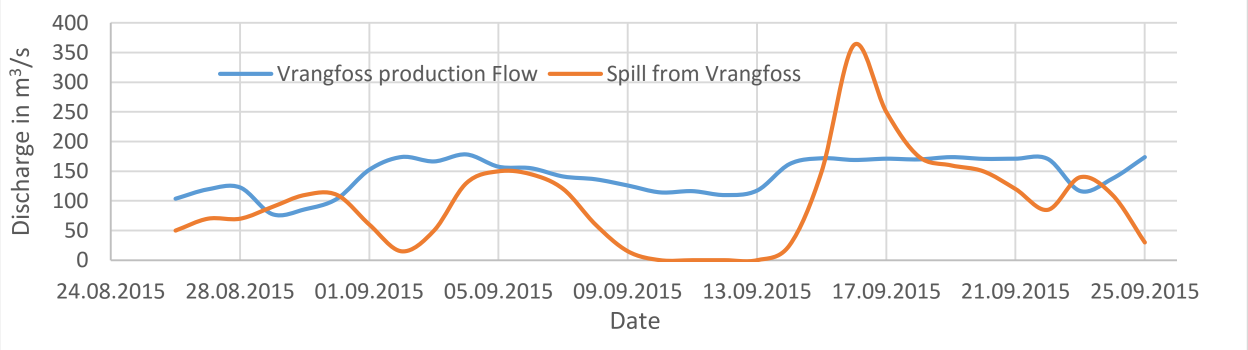


Figure 4-9: Production Flow and Spill from Vrangfoss during Large Flood Event in 2015

The spill from Vrangfoss seems to be large with highest being recorded in September 2015 exceeding discharge of 350m^3/s. The graph for spill from Mår is not shown as for the year 2014 and 2015 all spill values are zero.

The spill from Vrangfoss, Møsvatn, and Skarsfoss are large during large flood event more than production flow which gives insight that addition of these spills to FMTV will provide good results during reservoir routing by the model. **(Killingtveit and N.R.Sælthun 1995)**

4.1.2. Cross Check for the data received

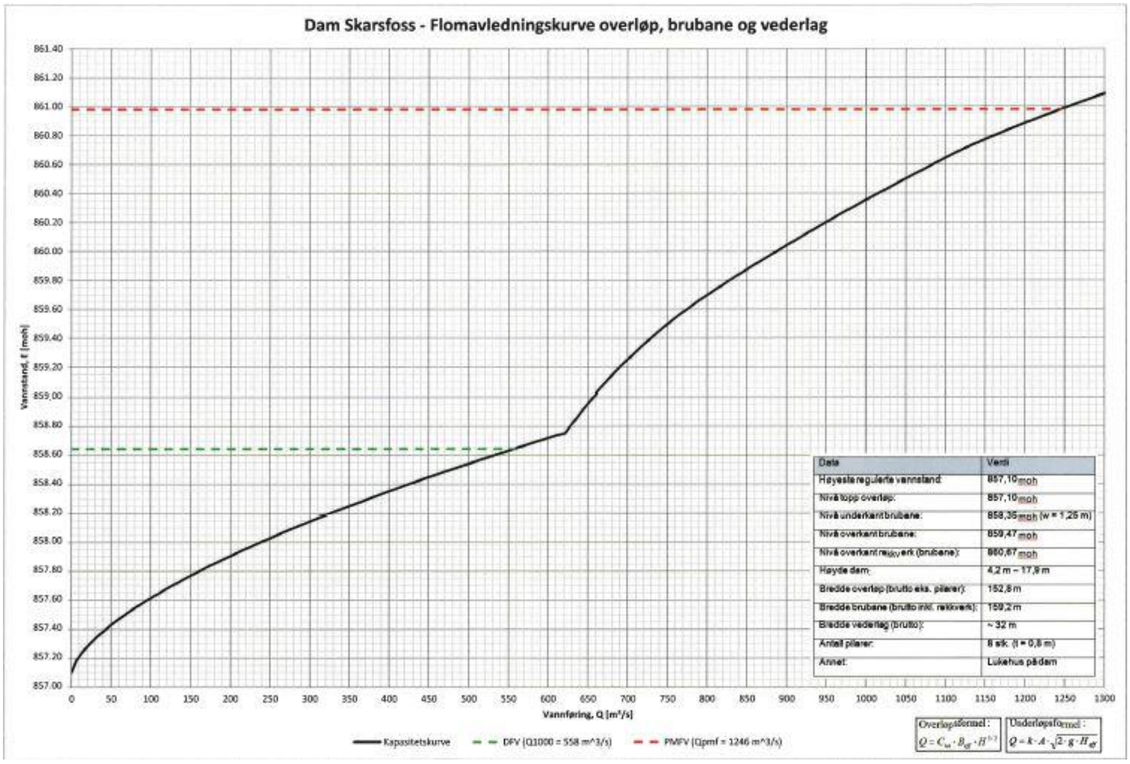


Figure 4-10: Spillway Curve for Skarsfoss Dam

Hydro provided data for in m^3/s per day but after cross checking data from spillway curve, it was found that spill was not matching with the water level. Thus, further investigation was made, and hourly data was received from Hydro Power Company, and hourly data as shown in Table 4-1 was matching with water level as shown in the spillway curve for Skarsfoss, Figure 4-10.

Table 4-1: Hourly Spill from Skarsfoss in 2014.10.30

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00
Spill (m3/s)	170	170	169	169	169	169	169	169	169	169	169	169
Time	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Spill (m3/s)	169	169	169	169	169	169	169	169	168	168	168	167
Average: 168.96 m3/s												

4.1.3. Inclusion of Flood Spill from Dam in the FMTV Model

FMTV model does have provision to include these flood spills. Thus, it was an important task to find the way to include these spills into the model for simulation. After discussion with Professor Trond, it was finally decided to add these spill by adding to the production flow which is being considered as an outlet from Mår, Møsvatn, and Vrangfoss at present.

4.2. Flood Spill from Brook Intake

There are many brook intakes along the tunnel in Møsvatn and Mår to hydropower plants. There are ten additional intakes along the way from Møsvatn to Tinnsjø and five additional intakes along the way from Mår to Tinnsjø. All the flows from Møsvatn and Mår join at Måne River before flowing to Tinnsjø. The Møsvatn supplies water for the operation of five power plants, first serving to Frøystul Power Plant and then to Vemork, Såheim, Moflåt, and Mæl power plant by collecting water from ten brook intakes in the tunnel on the way. Mårvatn supplies water to Mår power plant by collecting water from five intakes in the tunnel. The outflow from Mår power plant joins with water from Møsvatn and flow into Tinnsjø after passing through Mæl power plant.

Table 4-2: Intakes along Headrace Tunnel from Mår

Intake	**Region**	**Area Code**	**Catchment Area**	**Specific Runoff**
			Km^2	**l/s.km^2**
A	Sandremåi	0.1652A2C3A	9.8	25.1
	Strortevatn	016.G52A2C3A		
	Vrengle	016.G52B6B		
	Tjørnan	016.G52A2C3B		
B	Bergbuåi	016.52A2D	12.47	24.95
C	Våervatnet	016.H31Z	42.7	23.36
	Olabubekken	016.G52A2B3		
D	Sandvatn until Middøla	016.G52A2BZ	4.2	22.4
		016.G52A2BC4		
		016.G52A2BC5		
E	Middøla	016.H1B	27.55	27.55
		016.H1C		

The catchment area of intakes along tunnel from Mår seen in Table 4-2 was decided as per the document obtained from Hydro power company (Ødegård 1996), while specific runoff was obtained from NVE (NVE 2015). The position of intakes along with their catchment area is shown in figure presented in Appendix C 1.

The detail about Intake along tunnel from Møsvatn to Moflåt Power Plant is shown in Table 4-3.

Table 4-3: Intakes along Tunnel from Møsvatn to Moflåt Power Plant

Intake	**Area Code**	**Catchment Area**	**Specific Runoff**
		Km^2	**l/s.km^2**
1	016.H42B	0.47	25.11
2	016.H419B	2.44	25.26
3	016.H418Z	0.98	24.24
4	016.H4181Z	0.67	21.88
5	016.H41Z	3.92	25.32
6	016.H415Z	1.46	26.58
7	016.H414Z	2.77	27.91
8	016.H413Z	1.34	24.22
9	016.H2Z,016.H2C	14.88	27.68
10	016.H313	2.98	20.59
	016.H4130		

The catchment area was obtained from NVE atlas and also from Tunnelutvidelse Såheim Kraftverk map provided by Professor Trond, and specific runoff was obtained from NVE (NVE 2015). The position of intakes along with their catchment area is shown in Appendix C 2.

4.2.1. Calculation of Flood Spill from Brook Intakes

The broad crest weir is mostly used spillway for brook intakes. The equation used for finding discharge from intake is

$Q = 1.7\ L\ H_o^{(3/2)}$

The weir coefficient is C=1.7 for weirs of width between 1.5 and 3.0 times the total head H_o. (Lysne, Glover et al. 2003)

The sufficient information about the brook intakes was not available to calculate the capacity of these brook intakes by using formula. The intake capacity was calculated by scaling from HBV catchment based on catchment area and specific runoff of the intake. (Mahat 2006)

The capacity of intakes along the tunnel from Møsvatn and Mår to Tinnsjø was calculating by scaling from HBV catchment, Austbygdåi. The catchment areas of the intakes lie within the local catchments of Tinnsjø. Thus, annual specific runoff was compared for Austbygdåi and local Catchments to Tinnsjø before using Austbygdåi to calculate intake capacity.

Table 4-4: Annual Specific Runoff in l/s.km^2

Year	2014	2015
Local Catchment (Tinnsjø)	31.07	27.50
Austbygdåi	31.41	28.87

The annual specific runoff for Austbygdåi and local catchment to Tinnsjø seem to be same for 2014 and 2015.

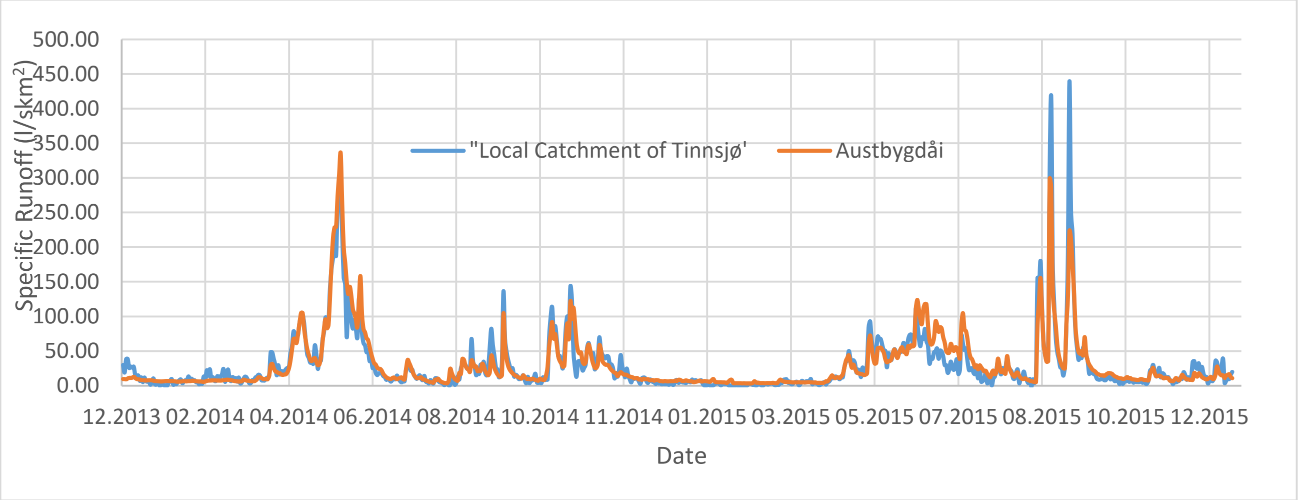


Figure 4-11: Daily Specific Runoff of Local Catchments, Tinnsjø, and Austbygdåi (2014 and 2015)

The daily specific runoff also seems to have a correlation between local catchments and Austbydåi. After Verification of annual Specific runoff and daily specific runoff HBV catchment, Austbygdåi was used to find intake capacities of brook intakes in headrace tunnels from Mårvatn and Møsvatn by scaling from Austbygdåi. The detail calculation of the intake capacity from 2015.08.25 to 2015.09.25 is shown for both tunnel from Mår and Møsvatn in Appendix C(Table)- 1: Intake capacity of Brook Intake along headrace tunnel in Mår and Appendix C(Table)- 2**.** The daily discharge contributing additional water in the tunnel is shown in Figure 4-12 and Figure 4-13. Also, it is believed that during large flood tunnel is full and these additional water from intake act as spill which are not regulated and can add as local inflow to Tinnsjø.

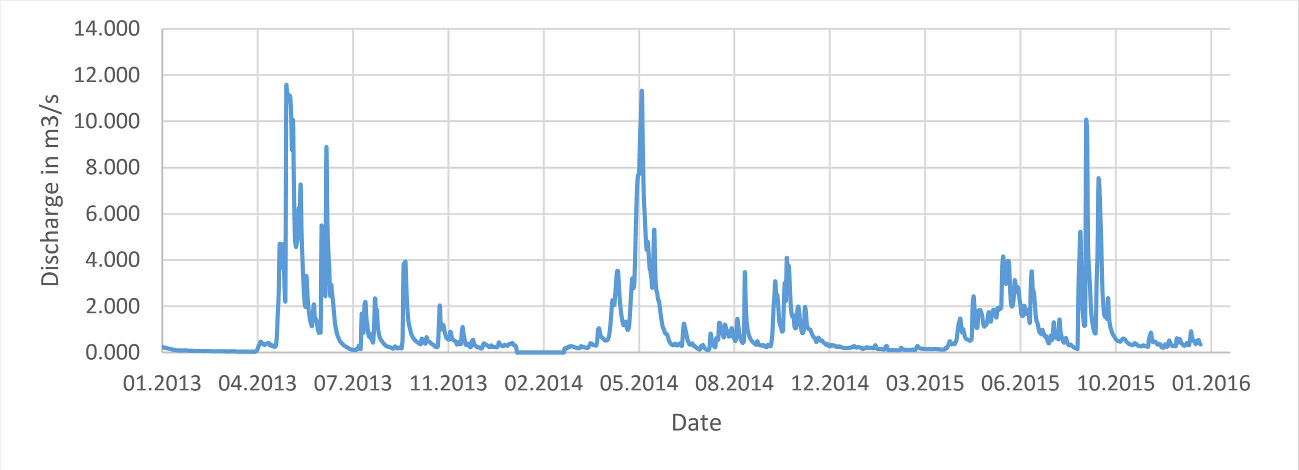


Figure 4-12: Intake Capacity of Brook Intakes along Tunnel from Møsvatn from 2013-2015

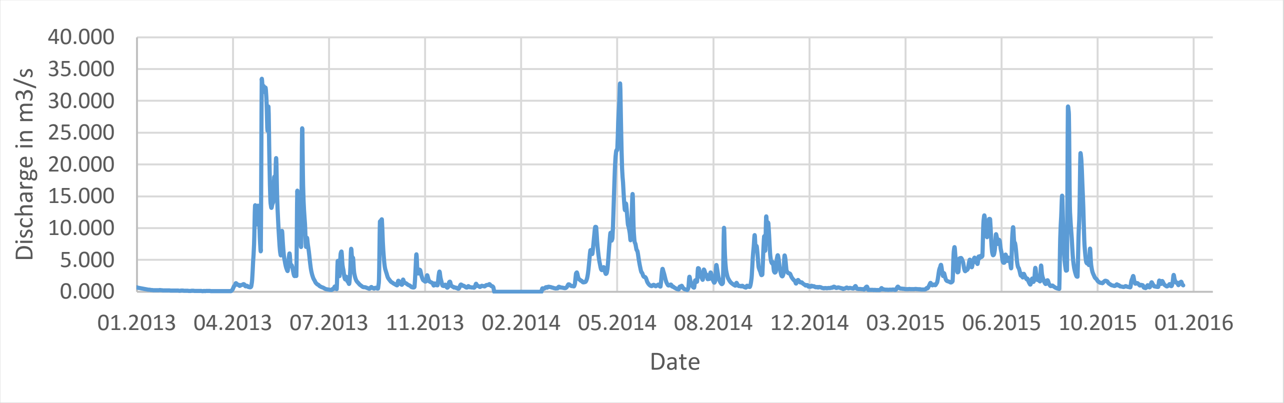


Figure 4-13: Daily Intake Capacity of Brook Intakes along Tunnel from Mårvatn from 2013-2015

It is clear from the Figure 4-12 and Figure 4-13, flow from brook intakes is low for most of the period. Intake capacities for brook intakes in Møsvatn is low for most of period in three years. The total capacity of brook intakes in Mår hydropower systems is higher for large flood events in 2013, 2014 and 2015. So, comparison was made between spill from brook intakes in the tunnel from Mår and Møsvatn with outflow for the respective period presented in Figure 4-14 and Figure 4-15.

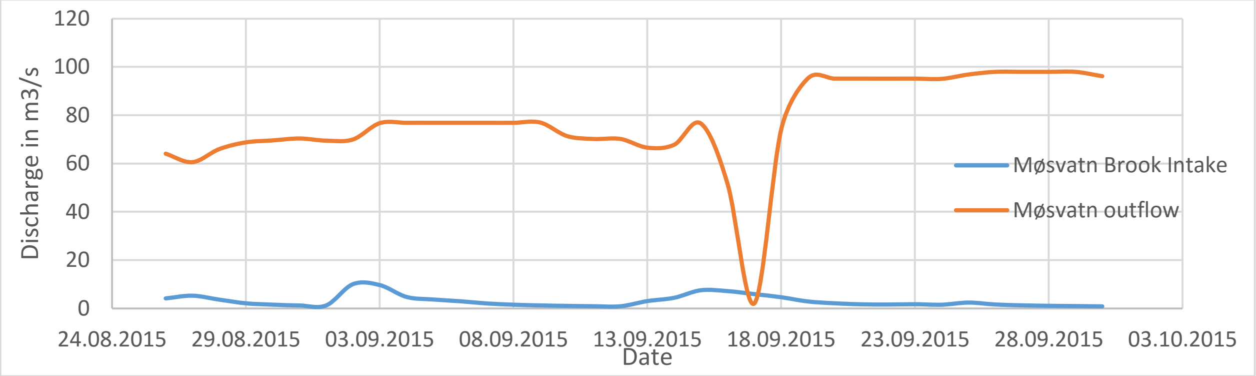


Figure 4-14: Production Flow and Spill from Brook Intakes in Tunnel from Møsvatn during Large Flood event in 2015

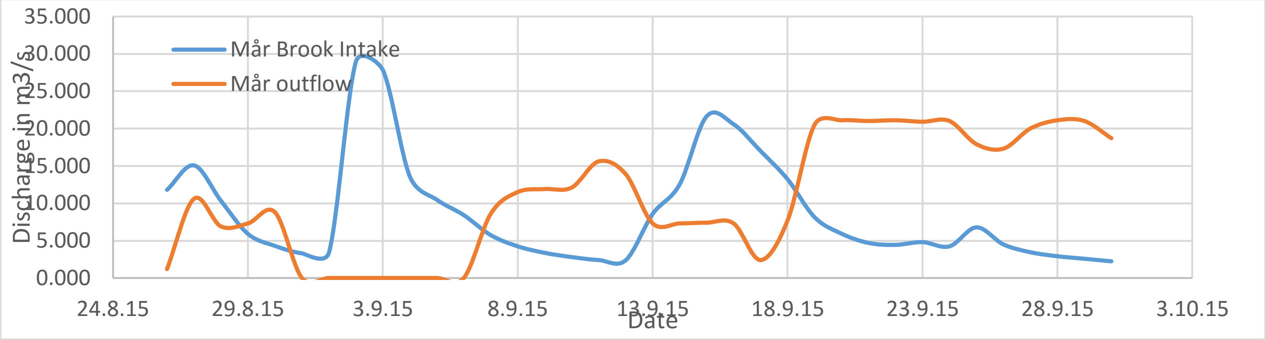


Figure 4-15: Production Flow and Spill from Brook Intakes in Tunnel from Mår during Large Flood event in 2015

From Figure 4-14, the total intake capacity from ten brook intakes are not large enough, and it is seen that the maximum inflow is above 12 m^3/s for three days period. So, these intakes were considered for simulation during large flood event in 2015 only.

Furthermore, it is seen from the Figure 4-15 that the intake capacities of brook intakes in headrace tunnel from Mårvatn is large for a significant period. During large floods, the combined intake capacities of five intake are more than maximum daily outflow from Mårvatn to Mår Power Plant. After seeing this large capacity, these inflows were considered to be included in FMTV model for simulation.

4.2.2. Inclusion of Capacity of Brook Intakes in the FMTV Model

FMTV model has not any provision to include these spills in the model during simulation. The capacities do not seem to be large for brook intakes in Mår and Møsvatn Hydropower System with almost no flow during small and medium floods. After discussion with Professor Trond it was finally decided to add these spill from Brook intakes to their respective system Mår and Møsvatn tapping along with flood spill from dam and production flow to power plant to include them in the model for the further calculation.

4.3. Spill and Diversion from other regulated flows

In the upstream of Omnesfoss, there are many power plants with several intakes in the tunnel and diversion providing additional water to reservoirs. The water from upstream is recorded at Omnesfoss gauging station, so the extra intakes and diversion upstream are not taken into consideration.

In the upstream of Seljordsvatnet, there are many power plants and diversions but as in Omnesfoss, it is considered all the flows from upstream are recorded at Hagadrag station. Thus, these intakes and diversions are not taken into account for further calculation.

Tokke-Vinje Power Station occupies the area to the west with many diversion, reservoirs, lakes, and power plants. The water from western parts ends up at Vranfoss power station. Thus, the collective flow from the west is the outflow from Vrangfoss to Norsjø. So the water from the big portion in the east to Norsjø is simply taken as flow from Vrangfoss represented by Vestfelta in the model.

5. LOCAL INFLOWS

There are a number of unregulated catchments in Skien water system. Fitting gauging stations in all the unregulated catchments is impossible. The local inflows can be calculated for the respective unregulated catchments by scaling method and water balance equation method.

5.1. Scaling Method.

The runoff for unregulated catchment is determined by scaling of simulated runoff data obtained from HBV model for three calibrated catchments. The formula used for determining runoff for ungauged catchment from gauged catchments is:

$Q_{ungauged} = K{*}Q_{gauged}$

$K= \text{Scaling Factor} = \frac{Aung*Sung}{Agau*Sgau}$

A_{ung} = catchment area of ungauged station

S_{ung}= mean specific runoff of ungauged catchment

A_{gau} = catchment area of gauged station

S_{gau} = mean specific runoff of gauged catchment

Discharge for ungauged catchment was determined by multiplying simulated runoff for gauged catchments (Austbygdåi, Hørte, and Kileåi) obtained from HBV model with a scaling factor. The scaling factor adapted by FMTV is presented in Table 5-1.

Table 5-1: Scaling factor used by Local Catchments used in FMTV

S.N.	**Local Flow**	**Area(km^2)**	**Spec. Runoff from Nve**	**Scaling from Austbygdåi**	**Scaling from Hørte**	**Scaling from Kileåi**
1	Hjellevatn local	320.77	22.15			2.082
2	Norsjø local	311.2	9			1.592
3	Bøelva local	329.75	13.94		0.754	
4	Heddøla local	193.71	10.29		0.414	
5	Heddalsvatn local	256.93	11.11			2.982
6	Tinnsjø local	1454	23.12	3.71		

5.2. Water Balance Equation.

The local inflows to the reservoir are calculated by using water balance equation by considering storage change in the reservoir. The inflow computation can be done by using following equation

$Q_{loc} = Q_{out} - Q_{in} + \frac{\Delta S}{\Delta T}$ (Killingtveit and N.R.Sælthun 1995)

Where,

Q_{in} is upstream inflow to the reach/reservoir in question

Q_{out} is outflow

Q_{loc} is the local inflow

ΔS is storage changes

ΔT is the observation interval

Normally, the local inflow should be non-negative, but high evapotranspiration or high river bed infiltration to groundwater can result in negative inflows. During routing, negative values can be obtained while routing for short periods if storage term is neglected. Furthermore, negative values can also be obtained due to wrong data or due to components missing in outflow calculation.

6. TELEMARK FLOOD FORECASTING MODEL (FMTV)

This section is derived from Alfredsen, Killingtveit et al. (2008)

6.1. Model Introduction

Telemark Flood Forecasting Model also known as FMTV, designed by Professor Trond Rinde issues forecasts and prepares plans for actions for reservoir operation.

The model has been designed by integrating number of data sources and computer models into one system. The model will investigate four conditions that influence flood levels:

1. Inflow to four reservoirs (Tinnsjø, Heddalsvatn, Norsjø, and Hjellevatn) and river reaches from the catchments.

2. Operation plans for upstream reservoirs.

3. Hydraulics of lakes, river and reservoirs.

4. The operational characteristics of gates and hydropower plants.

The model will build the system topography which is shown in Figure 6-1.

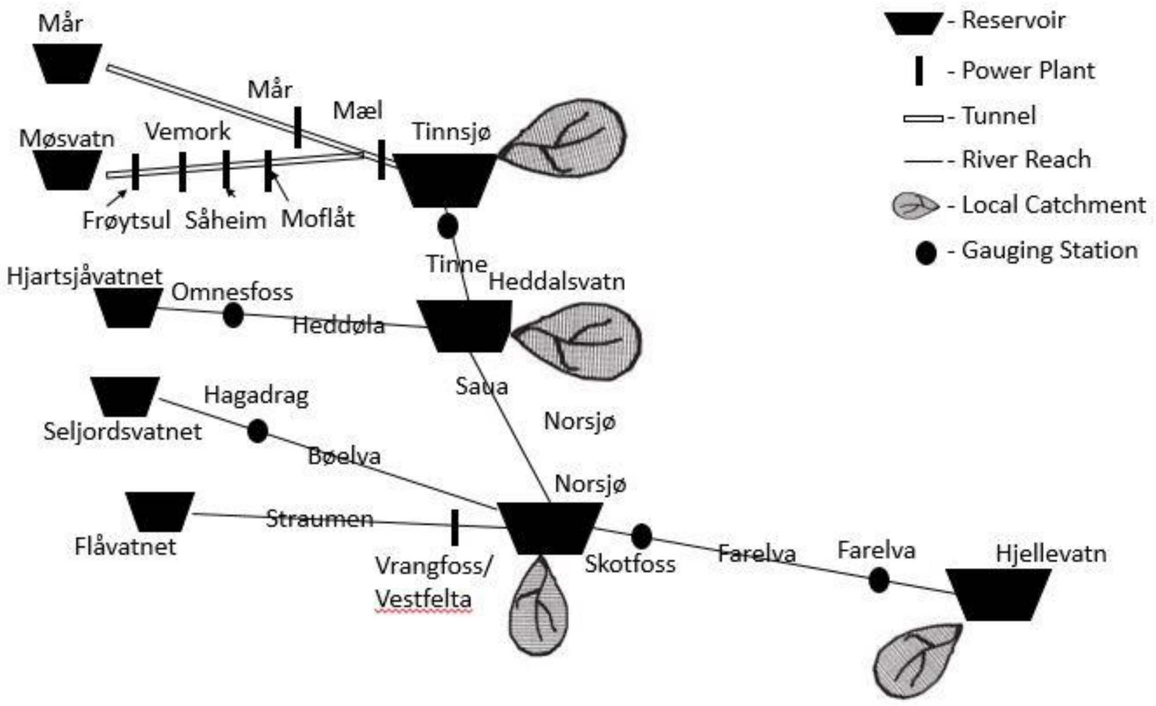


Figure 6-1: The model representation of the Skien watercourse (catchment symbol represents undeveloped parts of the river system that are not treated in detail in the model)

6.2. System Structure

The structural components are the core and describe the elements of the real world system with their state, structure, and behavior. These components are interrelated in a network and work as the topology of the hydrological system in the real world.

FMTV consists of several modules that communicate through file transfer. The layout of the system is shown in the figure below.

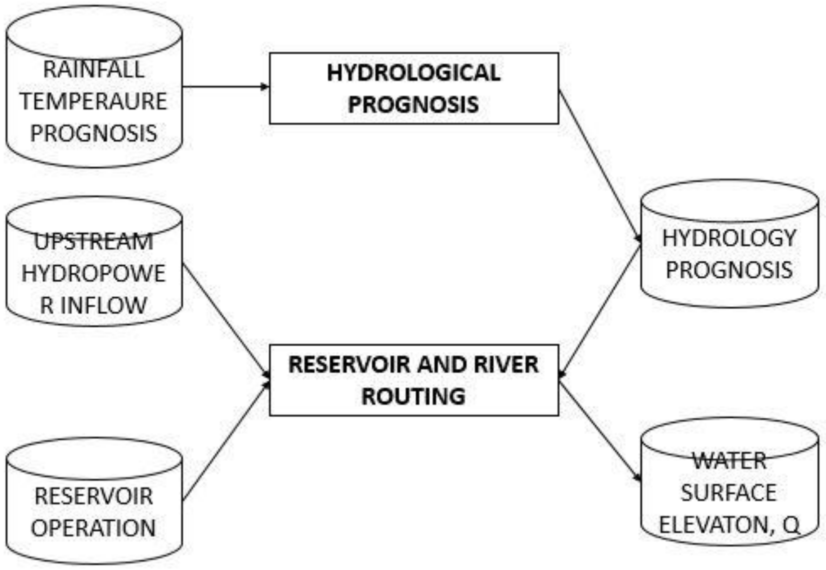


Figure 6-2: Structure of FMTV (Alfredsen, Killingtveit et al. 2008)

The structural components help to define a hydrological system of Skien Water Course. The hydrological prognosis is generated by HBV model (Killingtveit and N.R.Sælthun 1995). The calibration of the model is done with the observed data and is updated till the date just prior to the forecasting period. The forecasting data, usually for 10-days period is provided by the meteorological institute. It is also possible to simulate other predictions for analysis of variability in predicted temperature and precipitation.

The routing model is based on an object-oriented toolkit (Alfredsen and Sæther, 2000) which allows a modular development of the structure of the river system. The model consists of the common base which allows insertion of components into the network structure and derivation of new structural components. The model also allows an inclusion of computational methods for routing and analysis. Mass-balance routing is used by the setup in the reservoirs and river reaches depending on complete release from each reservoir permitted by the user and inflow from local and external catchments.

6.3. Model Setup and Operation

6.3.1. System Model

The Skien watercourse is located in the southern part of Norway and has a total catchment of 10772 km^2 and an annual runoff of 274 m^3/s. The flood-forecasting system covers the area from Tinnsjø to the outlet, a total catchment of about 5440 km^2 (Alfredsen, Killingtveit et al. 2008). The reservoirs to be considered are Tinnsjø, Heddalsvatn, Norsjø, and Hjellevatn. The remaining catchment is divided into the Western part (Tokke-Vinje hydropower System), the Møsvatn hydropower system and the Mår hydropower system.

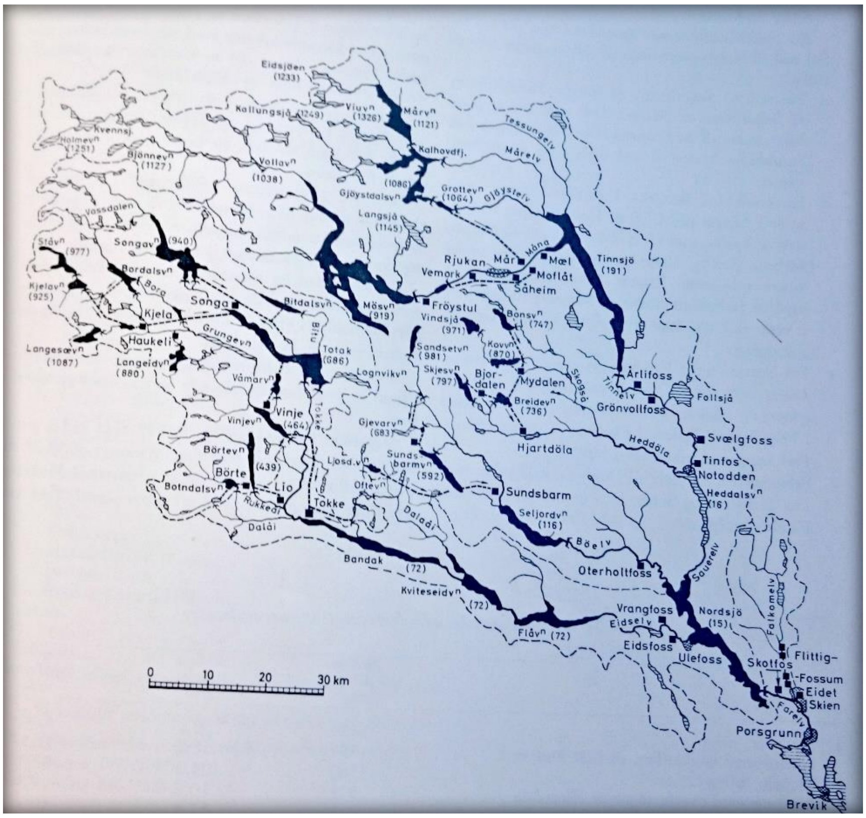


Figure 6-3: The Catchment of Skien Watercourse

The area from Tinnsjø to the outlet is divided into series of components, and each of them is represented as objects in the main model which is shown in Figure 6-4.

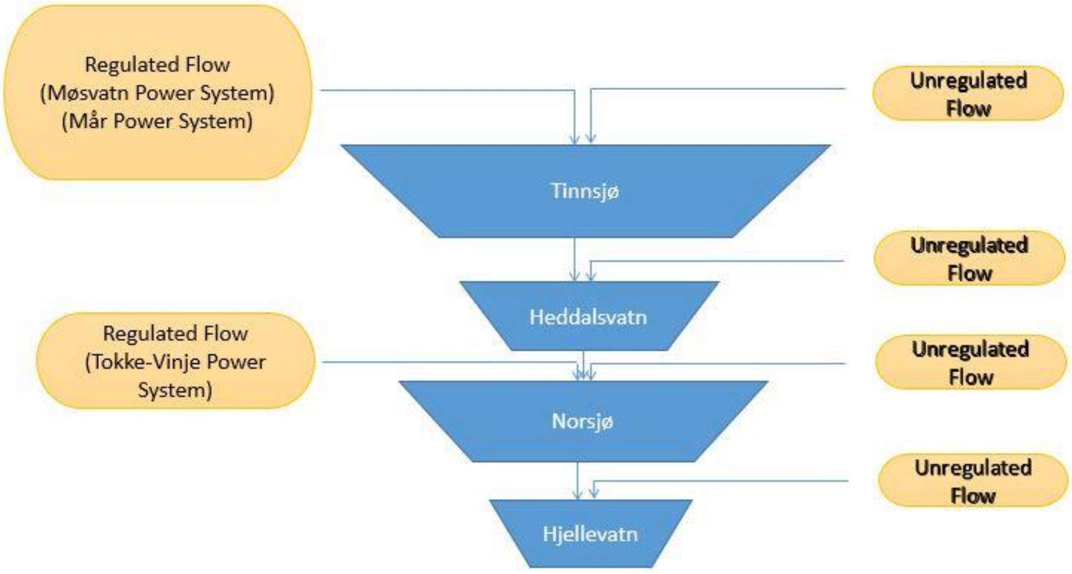


Figure 6-4: Components in FMTV

6.3.2. Inflow Computations

6.3.2.1. Data for Unregulated Catchment

Austbygdåi, Hørte, and Kileåi are three gauged catchments within the model area selected for calibration in HBV on historical data. The precipitation and temperature data are downloaded from Tessungdalen, Lifjell, Kviteseid, Møstrand station and prognosis input is prepared for the HBV model. In addition, the model is also updated with observed discharge for each catchment in the previous day. After modification of model by Professor Trond Rinde, it is possible to re-simulate historical flood events without updating the model to the recent date. In order to re-simulate the historical events, it is not necessary to input forecasted precipitation and temperature. The dummy values can be used as it is more about seeing how the model is performing during flood events other than forecasting flood.

After providing all the dataset for the prognosis, the model is run for each catchment until the start of the prognosis period, and if necessary it is also possible to update the model to ensure the lead-up period to prognosis fit with the observed data. After this, the prognosis for inflow is stored and transferred to a routing part of the model.

The inflow from the unregulated catchments to the reservoirs are computed by HBV from the three calibrated catchments using scaling factor depending on area and specific runoff of the catchment which is obtained from specific runoff maps.

6.3.2.2. Data for upstream hydropower systems

Different companies are running hydropower plant in this area. Thus, data for Mår and Tokke-Vinje hydropower system is obtained from Statkraft and for Møsvatn is obtained from Hydro Power Company. These are received by email from operational centers and updated into the flood routing system. Møsvatn and Tokke-Vinje system provide a weekly updated prognosis and Mår send data on a daily basis. Sometimes the inflow computed from the meteorological prognosis does not match with the prognosis from the external sources. To manage this, they are extended with constant values. Normally a five day period with observed data is imported with the prognosis to work as a control period for the simulation.

6.3.2.3. Reservoir Operation and Routing

When the model has computed future inflow and has been updated with external input prognosis, the final step is to generate water levels for each reservoir (Tinnsjø, Heddalsvatn, Norsjø, and Hjellevatn) through routing. The user specifies a release plan for each reservoir and lake depending on the observed data for that period obtained from different sources, NVE xhydra, Statkraft, and Hydro. The reservoir levels are imported from observed data in the database operated by the Øst Telemark Regulatory Association (ØTB).

The procedure used for the routing computations is to define the starting point for the simulation some days before, usually ten days before the start of the prognosis period to get a control of the computation. If there is seen a deviation in the observed water level from simulated water level, it is necessary to update the model to ensure proper starting point for the prognosis period. The model possesses a number of uncertainty in the data for lower reaches like for Norsjø and Hjellevatn. The most uncertain component is the scaled inflow from unregulated catchments to the reservoir as it is adjusted by the model to get the simulation of the water level correctly.

The area from Heddalsvatn to Norsjø is relatively flat. Thus, the water level at Norsjø will influence the outlet capacity of Heddalsvatn. As downstream is influencing upstream a special consideration is to be taken in the routing model. The model will update the release capacity curve in which release capacity of Heddalsvatn is computed based on the water level of Norsjø.

The detail description of the procedure to run the simulation in FMTV is presented in **Appendix D1** along with procedure to use FMTV dataset for input in the model presented in Appendix D2.

7. FMTV MODELLING TOOLS

7.1. HBV model

This section is derived from Killingtveit and N.R. Sælthun (1995).

7.1.1. Model Introduction:

HBV is conceptual precipitation run-off model developed by Dr. Sten Bergström to simulate runoff process in a catchment depending on precipitation, temperature and evapotranspiration data (Bergström and Forsman 1973). Snow accumulation, snow melt, actual evapotranspiration, storage in soil moisture and groundwater and runoff from catchment is computed by model. It is necessary to adjust a number of parameters for the catchment before calibrating a model for a catchment so that it can be used for practical purpose.

7.1.2. Model Structure

The model is based on water balance system of its main components, i.e. snow, soil moisture, upper zone and lower zone as represented in Figure 7-1.

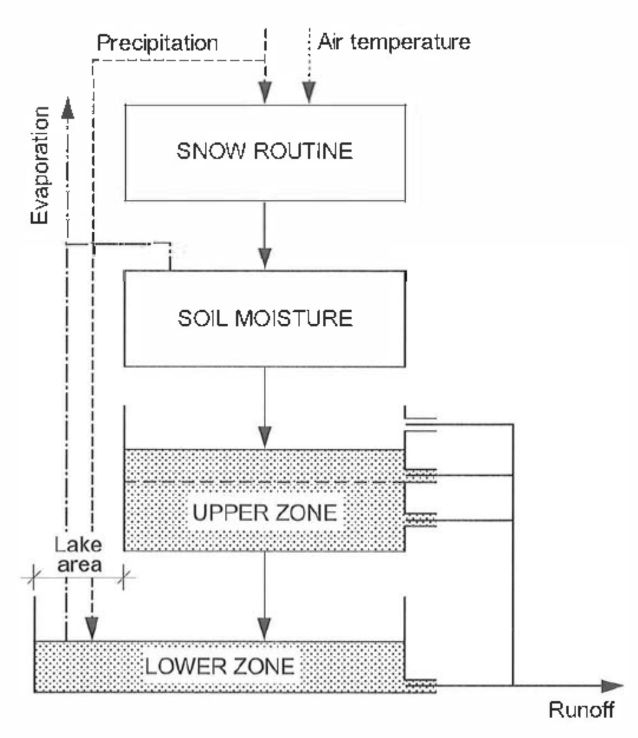


Figure 7-1: Structure of HBV model (Bergström and Forsman 1973)

7.1.3. Model Setup

The input provided for the model are temperature, precipitation, and runoff. The temperature, precipitation, and runoff data for three catchments, Austbygdåi, Hørte, and Kileåi are obtained from respective stations.

The next step is to calibrate each of these catchments on historical data. The quality of runoff data is of great importance for calibration quality. Calibration of the model is basically done to determine a set of free parameters that gives the best possible correspondence between observed and simulated runoff for a catchment. It is necessary to set parameters before calibration. Confined parameters are fixed from maps, field surveys, and other information about catchment and is not changed. Free parameters are set before calibration and changed until a good fit is obtained between observed and computed runoff. In the study, it was already calibrated with parameters, but the results were checked as shown in Figure 7-2, Figure 7-3 and Figure 7-4, and the good correlation between Simulated and Observed runoff was obtained, so it was decided it is not necessary to further calibrate the model. It was also seen that where runoff was varying in large values between observed and simulated runoff correction in precipitation was made as shown in Table 7-1.

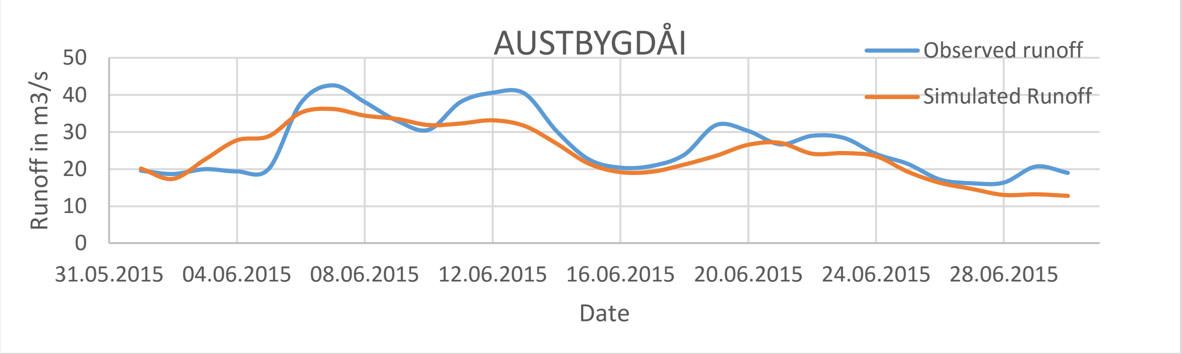


Figure 7-2: Simulated and Observed Runoff for Austbygdåi obtained from HBV model

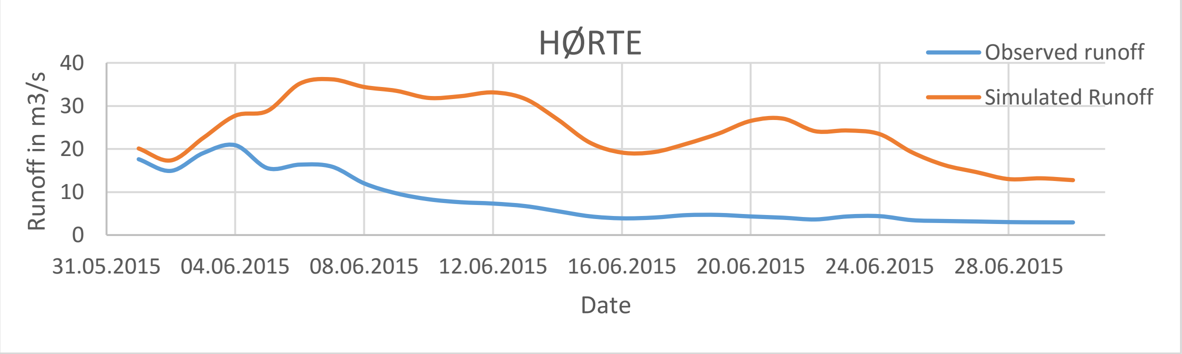


Figure 7-3: Simulated and Observed runoff for Hørte obtained from HBV model

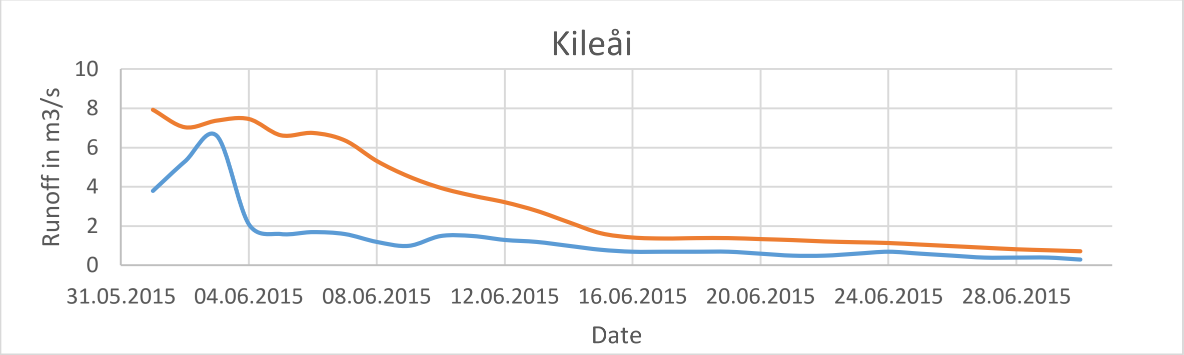


Figure 7-4: Simulated and Observed Runoff for Kileåi obtained from HBV model

Table 7-1: Correction applied to Correlate Observed and Simulated Runoff for Austbygdåi

Date	Prec. (mm)	Temp. (°C)	Obs Q(m^3/s)	SimQ(m^3/s)	dPrec
12.08.2014	20.3	8.1	5.7	15.74	5
13.08.2014	9.6	7.5	13.1	32.85	30
14.08.2014	3.5	8.7	12.9	45.87	20
15.08.2014	0.7	9.1	9.9	48.48	15
16.08.2014	3.2	8.9	8.5	42.22	-12
17.08.2014	0	7.2	7.7	32.14	-3

The model was already calibrated, and parameters are already set, and there seems to be a good correlation between observed and simulated runoff, so it was decided not to change any parameter as they were already set for the best possible values. The overview of the parameters used can be seen in Appendix D(Table) 1.

7.3. Runoff Forecasting

This Section is derived from Killingtveit and N.R. Sælthun (1995)

The large unexpected inflow from unregulated rivers will result in overfilling of the reservoir. This also disturbs release from regulated reservoirs and also in the production of energy from hydropower plants. The correct forecast of inflow from unregulated rivers can reduce flood damage. Local inflow forecasting is useful when the local inflow between release point and control point is a significant part of total flow at the control point. In this case, runoff forecasting will reduce unnecessary releases.

Flood forecast will help to reduce flood damage by triggering operational measures such as prerelease from reservoirs or provisional heightening of levees. If flooding cannot be reduced, flood warning can reduce damage by giving time for evacuation and removing goods and mobile equipment from flood-prone areas.

In Skien water course, Tinnsjø is an upper reservoir and misjudging flood in upstream means either holding water in the upstream flooding surrounding area around Tinnsjø for some period but eventually it should be drained out at some stage. The flooding of Tinnsjø means more water release and spill from Tinnsjø to downstream. This will eventually result in flooding downstream resulting in more damage. The control of flood in upstream will help in reducing flood damage in most inhabited areas, Skien, and Notodden in downstream.

Runoff forecast will always possess some uncertainty. The underestimation is more critical than overestimation but depending on the accuracy of data available, it is possible to have close flood forecast. The short-term runoff forecasting normally depends on meteorological data, i.e. precipitation and temperature. Hence, the performance of forecast depends on the accuracy of meteorological data available and model quality.

7.3.1. Long Term Forecast

Long term forecasting is based on runoff volume rather than the actual distribution in time. It usually depends on snow-melt runoff. Thus, snow storage is to be decided before the start of melt period. In addition, it is necessary to determine the state of soil moisture, groundwater storage and precipitation volume at the time of snow melting for snowmelt volume prediction. The long-term forecasts are made by dynamic rainfall-runoff models, or by regression models.

7.3.2. Short-term Forecast

The short term forecast forecasts runoff for one week or ten days period. The accuracy of short-term forecasting depends on meteorological data. This study is mainly concern about the short-term forecast.

Procedure for Short Term Forecast:

- Updating Model: It is necessary to update the model from the period elapsed since the last forecast. Data must be collected for this elapsed period to make model up to date to establish new starting conditions. The data required are precipitation and temperature data. For re-simulating the historical event, it is not required to see the real forecast for the upcoming event.
- Model Correction: It is evident that Model might have some error or simulated runoff might not correlate to the observed values. In these cases, it is necessary to adjust the model. It can be done by inverting the model from the observed output or by applying

error correction sub model like Kalman filtering techniques (Fjeld and Aam 1980), running in parallel with the hydrological model. In our study, the model has been automatically corrected by providing some factors to make the simulated runoff match with observed runoff.

- A collection of meteorological forecasts for selected catchment: It is essential to collect meteorological forecasts to forecast runoff. The forecasts are provided by Norwegian Meteorological Institute. We are simulating historical events in the study, so dummy values are used in place of precipitation and temperature forecast.
- Running HBV model for forecast simulation: After updating, the model is run with meteorological forecast data as input. The program automatically does additional forecasts for high and low input data, i.e. temperature -2^{o}C than input temperature and 200% precipitation, 100% increase than input precipitation.
- Exporting result: After runoff forecasting, forecasted runoff is transferred into the reservoir operation simulation model or flood model. In our case, we are transferring this forecasted runoff to Kortfom model.

7.2. KORTFLOM

This section is derived from Alfredsen and Sæther (2000).

Kortflom is an Object-oriented toolkit developed by Knut Alfredsen for obtaining desired modularity and reuse in software development. The main objective of the model is to route water through a system of rivers, lakes and reservoirs. It also analyses the flood response of the river system depending on how the regulation installations in the river system are operated during flood conditions. The model should be capable of using both hydraulic and hydrologic routing methods (Maidment 1988.) depending on the characteristics of the reach. In addition to the routing calculations, the model should be able to handle the water transfer and reservoir operations of a hydropower system as control and operation of regulation is necessary for flood propagation.

The good result in hydrology and hydraulics depends on data availability. Thus, the model should handle these data effectively. The routing procedure requires both spatial data in the form of geometry information and temporal data structures during operation.

7.2.1. Model Components

The model components include both relevant parts of the underlying framework and the derivations made when the flood model was created. The underlying structure is divided into five main parts.

7.2.1.1. Structural Components

The structural components can be described as the foundation for representing the real world hydrological system. These can be defined in a hierarchy with a common base. The base class (Hydcomp) is the common node for insertion of components into the network, and it also helps to derive new structural components. This class is restricted for users to use directly. This base class has a number of constraints, which acts as a common base for another constraint which is clearly represented by the figure of hierarchy of structural components shown in Figure 7-5. Furthermore, the base class stores link to its upstream and downstream neighbours and helps to retrieve these data.

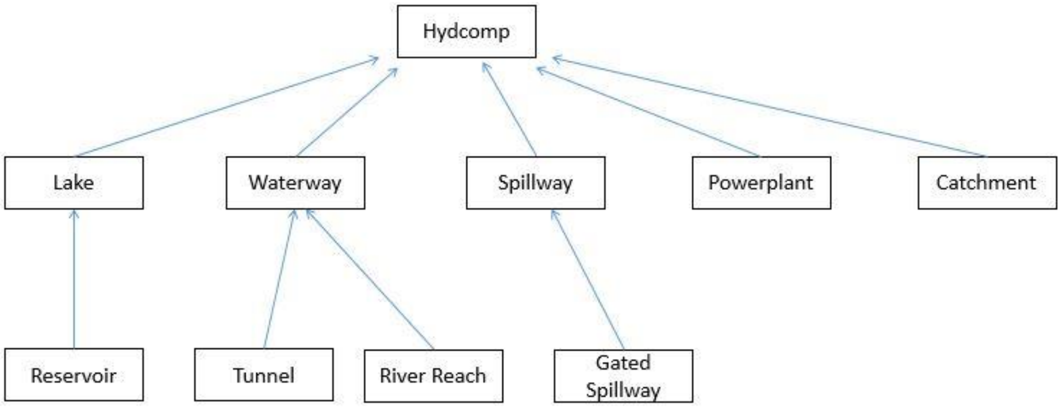


Figure 7-5: Hierarchy of Structural Components (Booch 1996)

Data regarding physical category (e.g. Cross-section for river reach) or state parameter (e.g. discharge and water level) can be added as per necessity to the structural components.

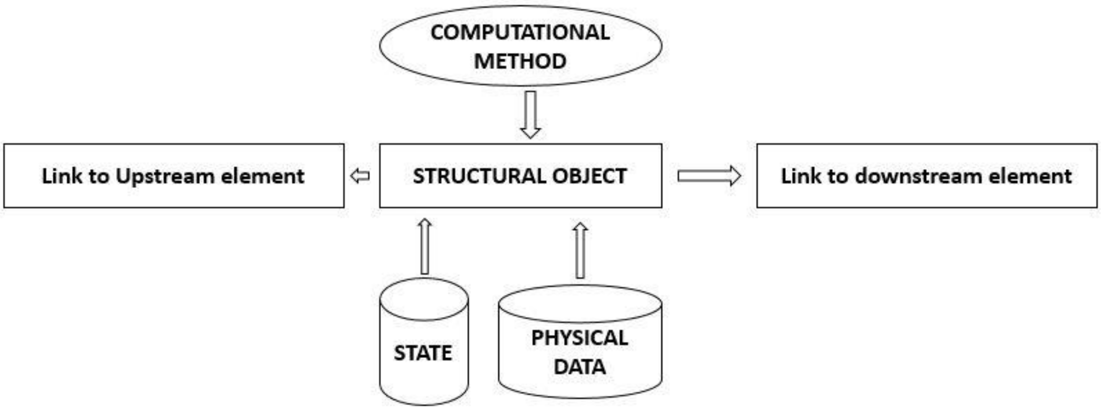


Figure 7-6: Computational Element (Alfredsen and Sæther 2000)

All computational methods are separated from structural components and can be added at need by the user. After adding data and computational methods to structural components, we have a complete computational element than can be inserted into the network. Figure 7-6 shows the structure of a computational element.

The base class has a default function to define transport matters which can be redefined if necessary. A control system controls transfer items from an upstream reservoir to downstream reservoir correctly. The mapping is defined by the user and it is possible to transport structure as long as it has equality and other operators are properly defined. It is also possible to add control functions to verify the transport.

The structural components are designed to create a system for representing a real river system with data and interactions without linking to any specific computational application. Furthermore, structural elements and topological information can be used to visualize real river system.

After defining computational elements, they are inserted into network defining the natural topology in the form of graph structure where each node represents an element in the hydrological system. An iterator is made to traverse the structure during calculation. The procedure establishes a list of nodes which are not dependent on upstream elements first. The resulting lists are traversed, and methods of calculation for each element are invoked. It is necessary to provide special attention for the cases where a downstream element influences upstream element (e.g. in cases of backwater effects) or where default flow direction changes in flat areas during simulation. It is necessary to provide special attention for flow between Heddalsvatn and Norsjø as these two reservoirs do not have much difference in level.

7.2.1.2. Computational Method

In the model, computational methods are separated from structural components. It provides freedom to users to add new methods without changing structural components. The set of virtual functions like calculation, verification and data retrieved represented in the base class for computational objects (Compobject) are needed to be implemented, while developing the new method. When data provided is insufficient, the user gets information to either add the data or select a method with reduced data set.

Parameters which are specific to the mathematical method are transferred in a specific data block. This approach has proved to be a very effective way in creating applications with flexible number and types of available computational methods. It is possible to add methods depending on the characteristics to be computed and the needed degree of output.

7.2.1.3. Data

The most important data types in the model are time series. It uses time series both as input and output. The example of it can be the discharge series produced by the model for selected points along a river system or the input series of precipitation and temperature to a catchment model. The main types of time series are Regular time series and Irregular time series. These series keep data and their attributes having regular time intervals, and irregularly spaced or event data, respectively.

The time series data classes allow them to be part of a model-view-controller structure (Sæther 1996). This facility helps for dynamic presentation of results during a simulation, as well as the dynamic presentation of environmental data which are automatically recorded by data acquisition system. Specialized classes for time series transformations have been developed:

- Functional transformations: This function uses an (x,y) curve to produce a new time series from the original.
- A time series calculator supports simple arithmetic transformations of regular time series.
- Sorting and the creation of duration curves.
- Time series statistics.

The time series generated by the model is stored and managed by a time series collector.

In hydrological models, two-dimensional and three-dimensional curves are frequently used. A set of classes for these type of data has been developed, giving a consistent interface to the curve data.

7.2.1.4. Input/Output

The data for simulation are handled by several file systems and relational databases. Each individual components of the model can read and save itself to a variety of file formats and database systems depending on the choice of the user. Every file format or database needs a unique source code for the structural objects, computational object and container objects so to save and restore them. Every data class in the application will have one member function for reading, and one for writing.

A global object, ApplicationSetup stores information of input/output system which is used at the moment. Another utility class *IoFactory* (Gamma 1995), is responsible for a storage system in use. Every data class type must have a standalone input/output class hierarchy with abstract base class.

7.2.1.5. Simulation Control

The simulation control unit controls the program operation and handles all communication with the main program structure. The main functions of simulation control are:

7.2.1.5.1 Build System Structure

This function builds the system structure.

7.2.1.5.2 Verification of Structure

This function helps to verify the soundness of the model. It checks the topology for cycles and incomplete structures and also checks the length of the simulation.

7.2.1.5.3 Simulate

This function will activate the topology iterator. It will also create a simulation sequence and execute a simulation for the defined time period. The timing in the model is handled by a global time control class. Functions in the simulation control units provide an interface to the timer with the possibility of defining the start and end times of the simulation and the time steps.

The model runs with a simple controller that reads a control file as input and runs through simulation. It is necessary to modify the simulation control unit when the third party hydraulic models are incorporated into the system. Some of these will not be possible to configure to run on a time step basis in order to fit in the model. So, it is necessary to construct a stepwise simulation system which runs the internal methods upstream of the external model reach, then runs the entire simulation for the external reach before it continues with time step simulations again. A modification is a need in the simulation control system to accommodate this.

8. MODEL SIMULATION UNDER DIFFERENT HISTORICAL FLOOD EVENTS

8.1. Background and Input Data

The flow is different throughout the year varying from very large to very small over the year depending on the season, precipitation and snow melt. The function of FMTV is not only to predict the large flood and to protect damage, but it also bears the responsibility to optimize water level for maximum energy production during dry periods. Thus, FMTV model should be able to forecast large flood and also small flood precisely so that reservoir can store water from large flood to be used during dry periods and can pre-release water to control large floods.

The flow over the years was differentiated into three categories; small, medium and large flood depending on the runoff over the catchment. When runoff in Austbygdåi is below ten m^3/s the flow is considered as small flood. When the flow is in between $10m^3/s$ and $50m^3/s$ it is considered as medium. When the flow in Austbygdåi is above $50m^3/s$ it is considered as large flood. One event was selected from every year from 2013 to 2015 to see the performance of the model during three different events. The floods were differentiated by looking at the graphs shown in Chapter 3. The data being used by FMTV at present was used to see in which type of flood events the error is occurring.

It was considered that during the large flood the tunnel will be full for Møsvatn and Mår hydropower system resulting the capacity of intake resulting in spill. Thus, spill data was prepared to see what effects these spills will make in simulation results during the large flood.

Table 8-1 shows that intake capacity of brook intakes in Mår is larger for large flood events. Thus, addition of spill can be a better idea for the further study. Whereas the intake capacity of brook intakes in Møsvatn hydropower system is small except in 2015, when we can see the highest runoff of 10 m^3/s. Thus, spill from Mår was considered for computation in all flood events, but spill from Møsvatn brook intake was considered during a large flood in 2015 for computation. The table shows intake capacity during large flood for book intakes in Mår and Møsvatn brook intakes in 2013, 2014, and 2015.

Table 8-1: Intake Capacity of Brook Intakes in Mår and Møsvatn Hydropower System during large floods

Date	Mår	Møsvatn	Date	Mår	Møsvatn	Date	Mår	Møsvatn
15.06.2013	4.1	1.4	15.10.2014	4.0	1.4	25.08.2015	8.4	2.9
16.06.2013	4.2	1.5	16.10.2014	3.5	1.2	26.08.2015	11.8	4.1
17.06.2013	3.8	1.3	17.10.2014	3.1	1.1	27.08.2015	15.1	5.2
18.06.2013	2.9	1.0	18.10.2014	2.6	0.9	28.08.2015	10.4	3.6
19.06.2013	2.5	0.9	19.10.2014	2.7	0.9	29.08.2015	5.9	2.0
20.06.2013	2.6	0.9	20.10.2014	6.5	2.2	30.08.2015	4.3	1.5
21.06.2013	2.5	0.9	21.10.2014	8.7	3.0	31.08.2015	3.3	1.2
22.06.2013	15.7	5.4	22.10.2014	6.5	2.3	01.09.2015	3.4	1.2
23.06.2013	9.5	3.3	23.10.2014	11.8	4.1	02.09.2015	29.0	10.0
24.06.2013	10.5	3.6	24.10.2014	9.4	3.3	03.09.2015	27.8	9.6
25.06.2013	8.6	3.0	25.10.2014	10.9	3.8	04.09.2015	13.6	4.7
26.06.2013	7.2	2.5	26.10.2014	8.9	3.1	05.09.2015	10.5	3.6
27.06.2013	25.5	8.8	27.10.2014	6.1	2.1	06.09.2015	8.4	2.9
28.06.2013	16.8	5.8	28.10.2014	4.9	1.7	07.09.2015	5.8	2.0
29.06.2013	12.8	4.4	29.10.2014	4.5	1.6	08.09.2015	4.3	1.5
30.06.2013	10.6	3.7	30.10.2014	4.7	1.6	09.09.2015	3.4	1.2
01.07.2013	7.1	2.5	31.10.2014	3.3	1.1	10.09.2015	2.8	1.0
02.07.2013	8.5	2.9	01.11.2014	3.0	1.0	11.09.2015	2.4	0.8
03.07.2013	7.4	2.6	02.11.2014	3.2	1.1	12.09.2015	2.4	0.8
04.07.2013	6.3	2.2	03.11.2014	5.0	1.7	13.09.2015	8.6	3.0
05.07.2013	5.0	1.7	04.11.2014	5.8	2.0	14.09.2015	12.6	4.3
06.07.2013	3.8	1.3	05.11.2014	5.0	1.7	15.09.2015	21.7	7.5
07.07.2013	3.0	1.0	06.11.2014	3.8	1.3	16.09.2015	20.6	7.1
08.07.2013	2.4	0.8	07.11.2014	3.0	1.1	17.09.2015	17.0	5.9
09.07.2013	2.0	0.7	08.11.2014	2.5	0.9	18.09.2015	13.2	4.6
10.07.2013	1.8	0.6	09.11.2014	2.5	0.8	19.09.2015	8.2	2.8
11.07.2013	1.5	0.5	10.11.2014	2.9	1.0	20.09.2015	6.0	2.1
12.07.2013	1.3	0.4	11.11.2014	5.6	2.0	21.09.2015	4.7	1.6
13.07.2013	1.2	0.4	12.11.2014	5.1	1.8	22.09.2015	4.5	1.5
14.07.2013	1.1	0.4	13.11.2014	3.5	1.2	23.09.2015	4.8	1.7
15.07.2013	0.9	0.3	14.11.2014	3.1	1.1	24.09.2015	4.3	1.5
			15.11.2014	2.9	1.0	25.09.2015	6.8	2.4

8.2. Simulation result provided by present used dataset.

The simulation was performed for large, medium and small flood events and the results obtained are presented below. The time period for each event was selected, and hydrological prognosis was performed by HBV model. The dummy values were used as forecast values as we were performing simulation for historical events in this study. After prognosis, Reservoir routing was performed for each flood events. The period of a month was selected for study of each flood events.

8.2.1. Small Flood Events

Most of the period in the year the reservoirs have small inflow, so it is necessary to adjust the water level to the maximum capacity by storing water from large flood in order to maximize energy storage. FMTV helps to achieve maximum energy by optimizing operation with help of its routing system. The simulation results provided by FMTV for small floods are described below in detail.

8.2.1.1. Tinnsjø

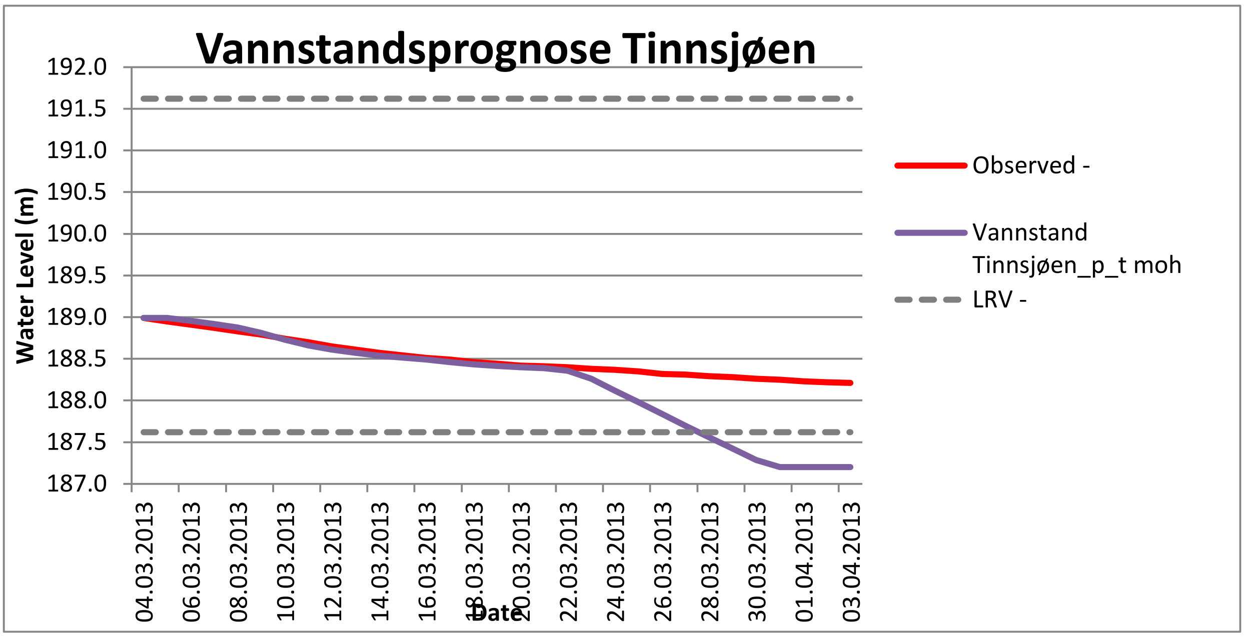


Figure 8-1: FMTV simulation result for a small flood period for Tinnsjø in 2013

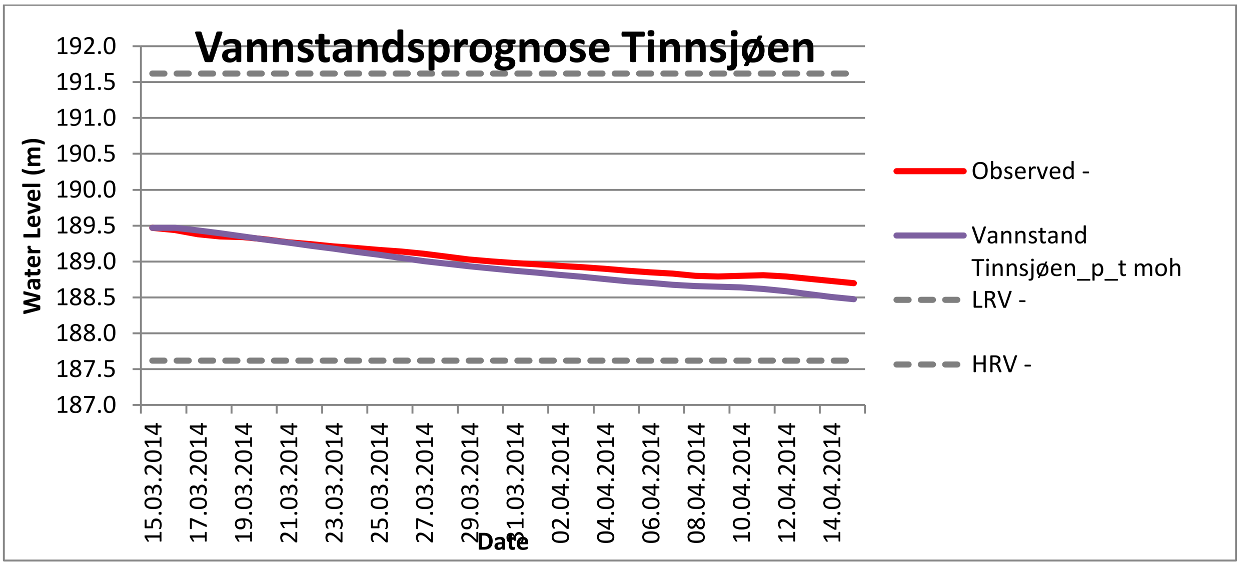


Figure 8-2: FMTV simulation result for a small flood period for Tinnsjø in 2014

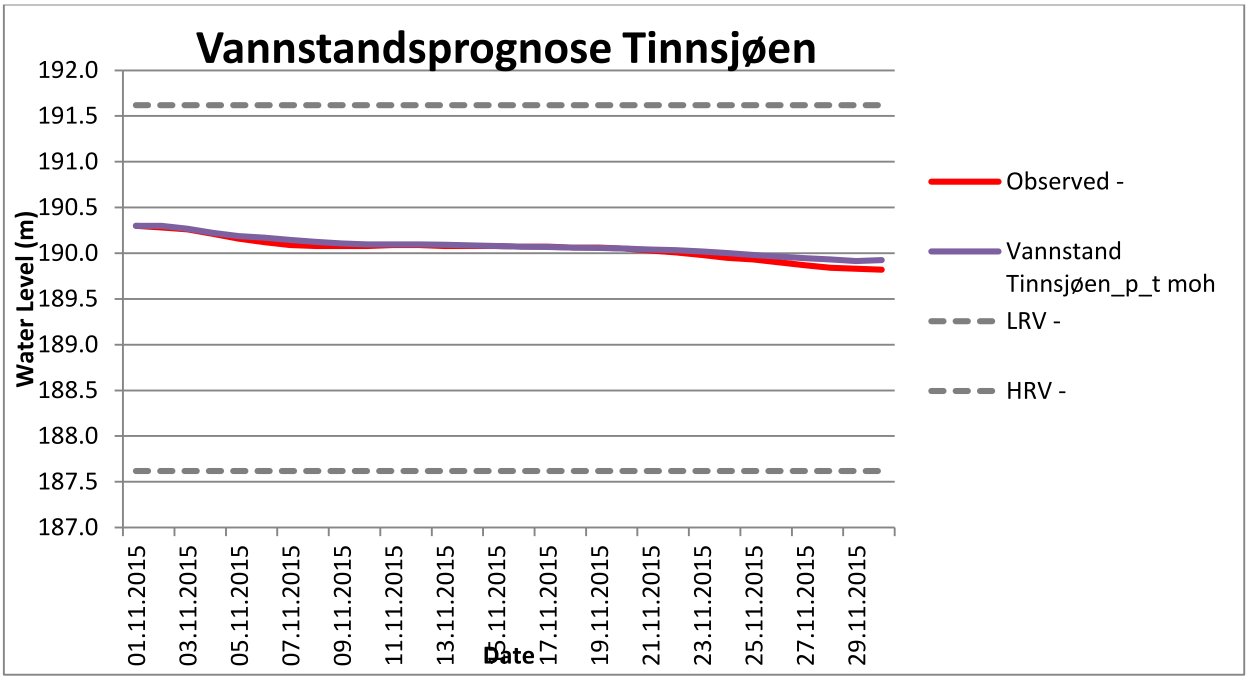


Figure 8-3: FMTV simulation result for a small flood period for Tinnsjø in 2015

Figure 8-1, Figure 8-2, and Figure 8-3 show period of occurrence of small floods. FMTV model is performing well for small flood events at Tinnsjø as the simulated water level is almost coinciding with observed water level with a difference of just 0.05% except for 2013 where forecasted water level is deviating from observed water level. The task would be to see if changing of Møsvatn tapping to Skarsfoss tapping and inclusion of spill from brook intakes will provide a more promising result.

8.2.1.2 Heddalsvatn

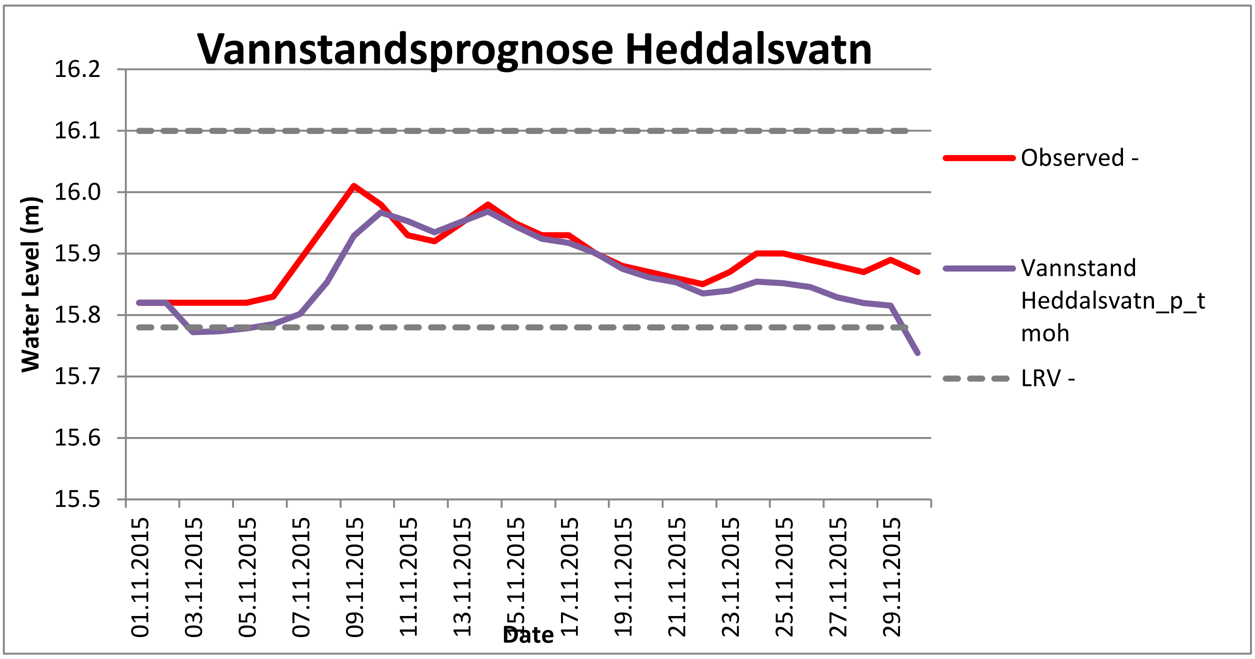


Figure 8-4: FMTV simulation result for a small flood period for Heddalsvatn in 2015

It can be seen from Figure 8-4 that FMTV model is performing well for forecasting the runoff at Heddalsvatn as the simulated water level is slightly less than water level with a difference of only 0.47%. Similar simulation results were obtained for a small flood event in 2013 and 2014 which is shown in Appendix E 1 and Appendix E 2.

8.2.1.3 Norsjø

The result provided by FMTV model for small flood event for Norsjø doesn’t look good as compared to Tinnsjø and Heddalsvatn. Figure 8-5 show FMTV model is not giving a good result for Norsjø as maximum difference of 0.12 m is visible in 2015 between simulated and observed water level and the simulated water level is always below observed water level also for simulation results in 2013 and 2014 shown in Appendix E 3 and Appendix E 4. In addition, the pattern of simulated runoff is entirely different from observed runoff.

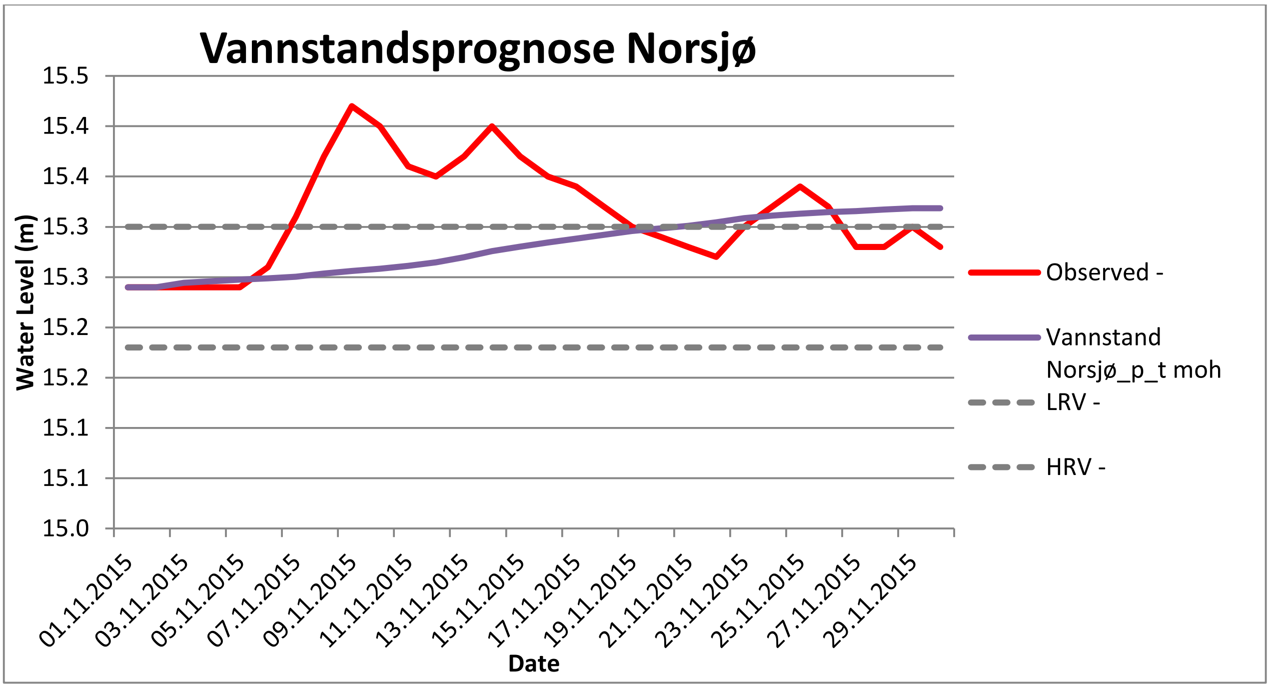


Figure 8-5: FMTV simulation result for a small flood period for Norsjø in 2015

8.2.1.4 Hjellevatn

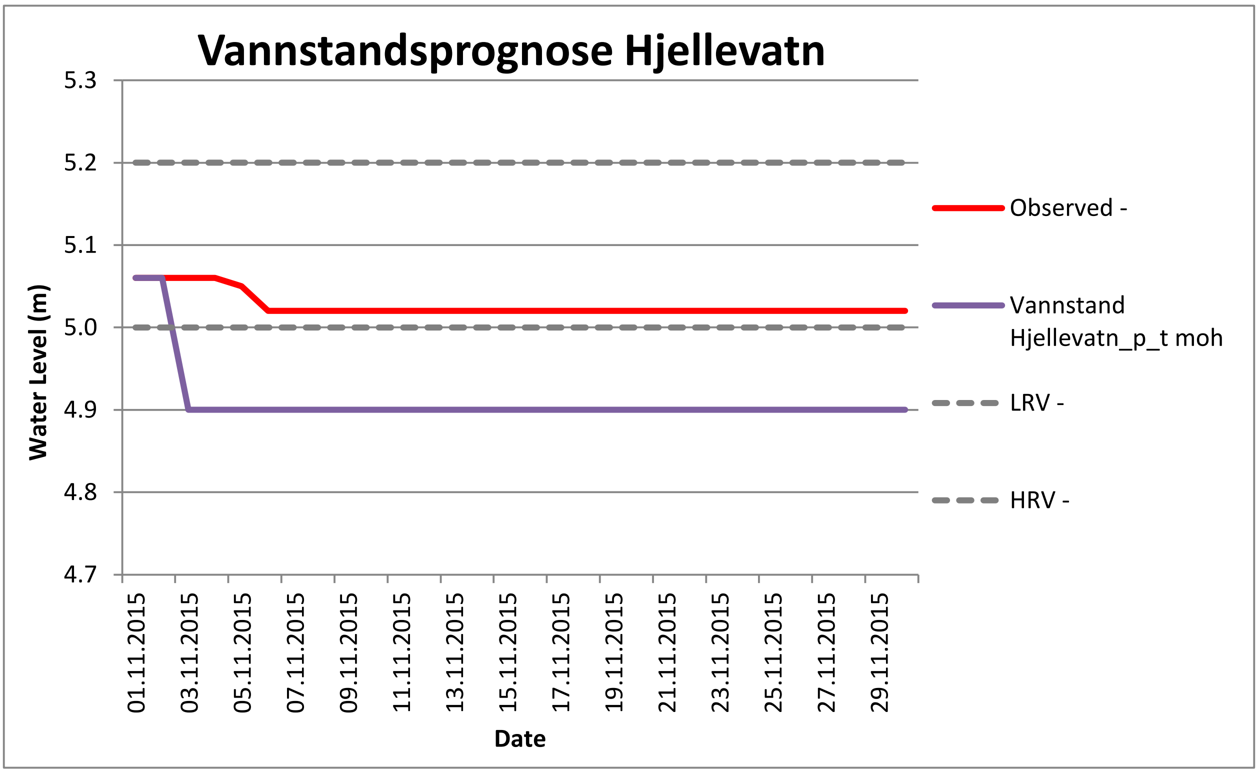


Figure 8-6: FMTV simulation result for a small flood period for Hjellevatn in 2015

It can be seen from the Appendix E 5, FMTV model provides good result for Hjellevatn from 2013.03.15 to 2013.04.15. In 2014 and 2015 it seems that simulated water level is running constantly at 4.9 m as lowest possible water level is 4.9 m permitted by the model and for observed water level it appears that the reservoir is maintaining constant water level by balancing between inflow and outflow. This is clearly visible in Figure 8-6: FMTV simulation result for a small flood period for Hjellevatn in 2015 and Appendix E 6: FMTV simulation result for a small flood period for Hjellevatn in 2014

8.2.2. Medium Flood Event

After seeing the performance of FMTV model for small flood period, the another task is to check it's performance for optimizing level during the increase of runoff in the study area due to snowmelt or rainfall or both. The detailed study of simulation result by the model for all four reservoirs was made.

8.2.2.1 Tinnsjø

It can be presented from Figure 8-7, Figure 8-8, and Figure 8-9 that FMTV is working well as the simulated water level is matching with observed water level with a maximum difference of 0.17% in 2014.

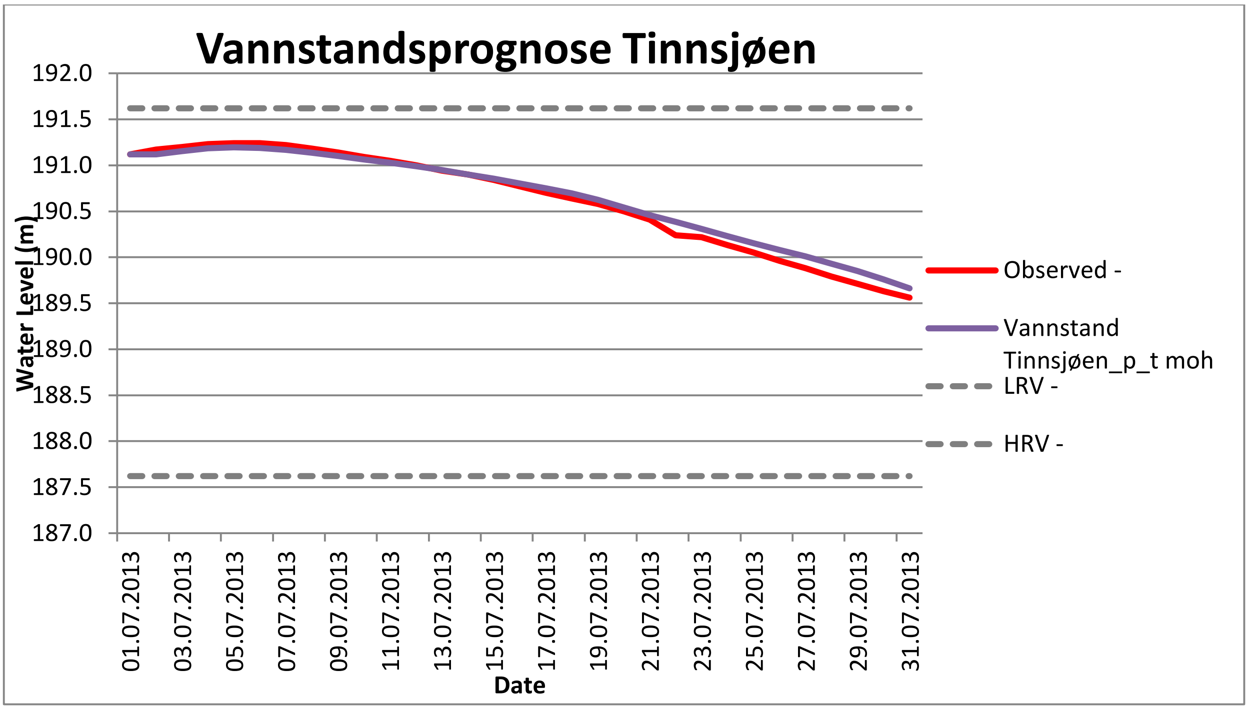


Figure 8-7: FMTV simulation result for a medium flood period for Tinnsjø in 2013

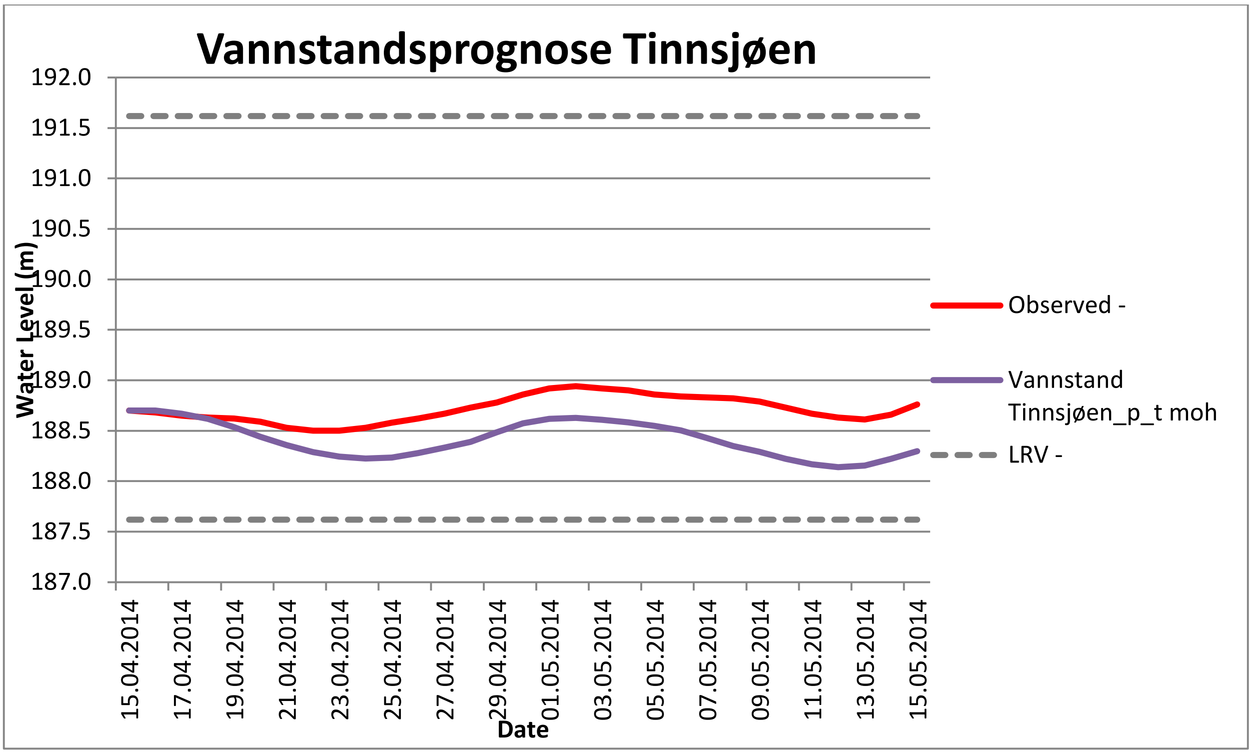


Figure 8-8: FMTV simulation result for a medium flood period for Tinnsjø in 2014

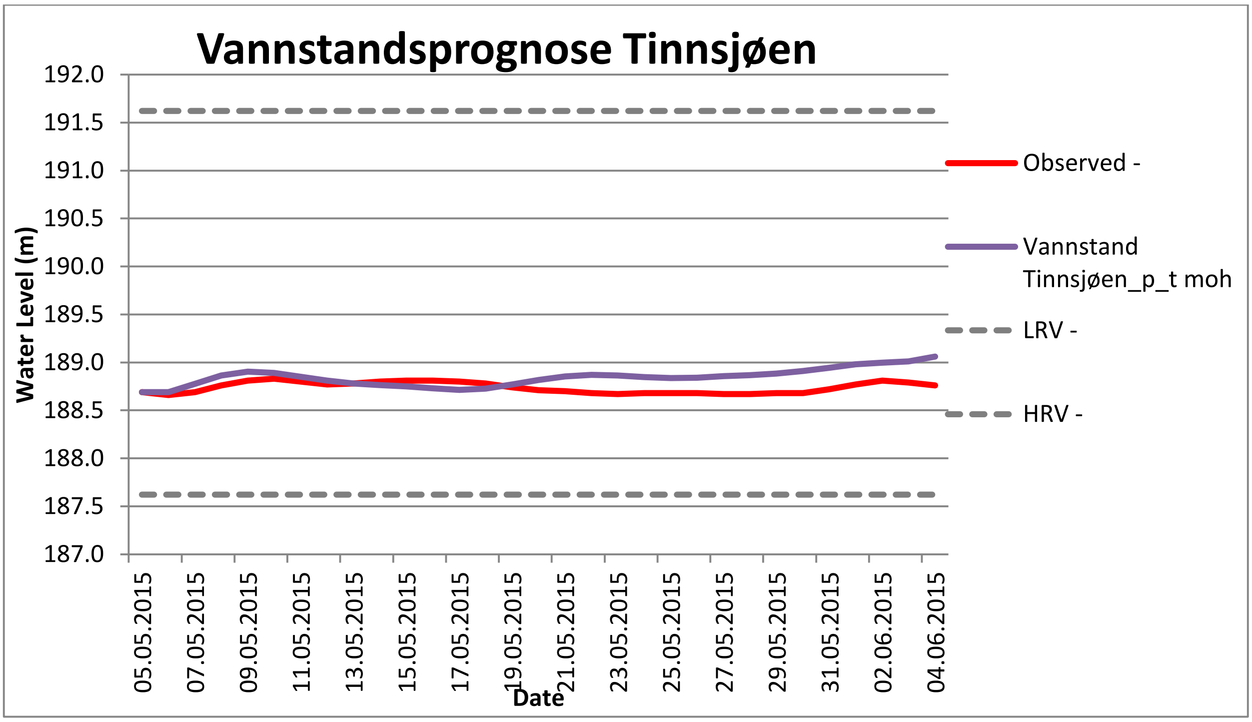


Figure 8-9: FMTV simulation result for a medium flood period for Tinnsjø in 2015

8.2.2.2. Heddalsvatn

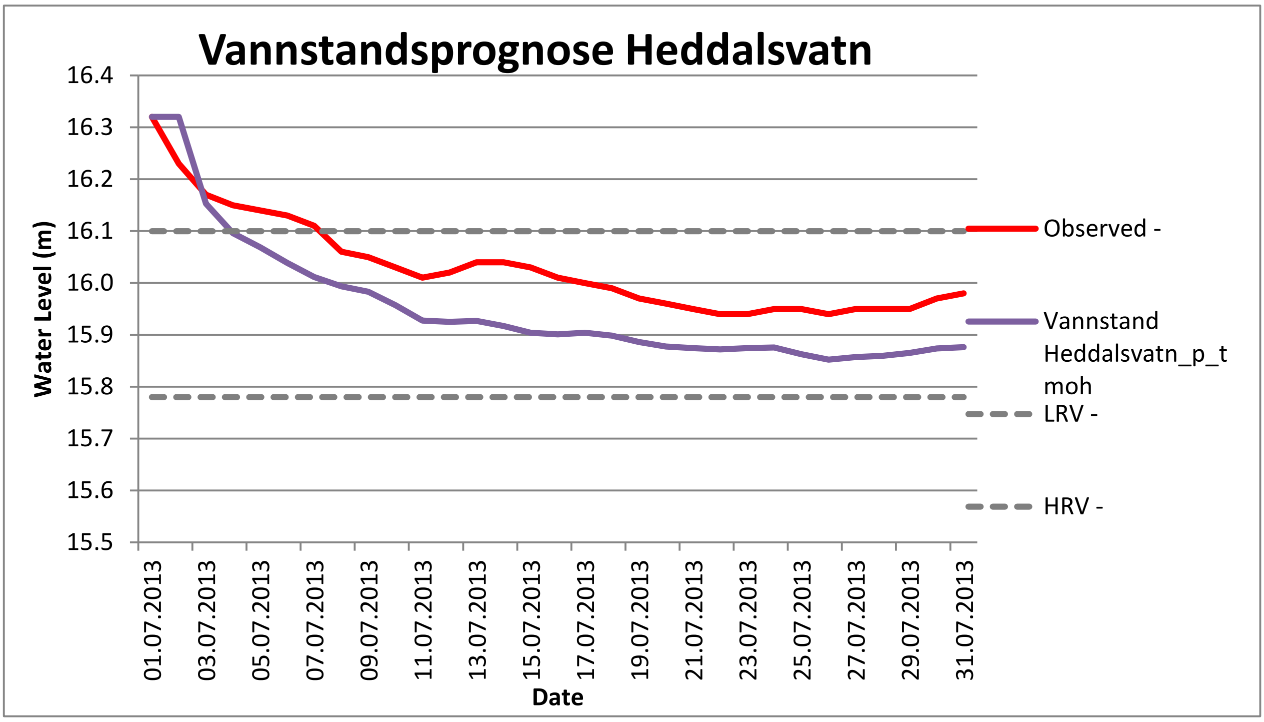


Figure 8-10: FMTV simulation result for a medium flood period for Heddalsvatn in 2013

It can be seen from the Figure 8-10 that FMTV model is performing well for forecasting the runoff as the simulated water level is slightly less than water level for a medium flood event in 2013 with difference of 0.53%. It seems to be little higher than observed in 2014 and 2015 as shown in Appendix E 8 and Appendix E 7. It can be also read as with the increase in the runoff the simulated water level seems to be increasing, but it is also evident that difference in simulated and observed runoff is not significant.

8.2.2.3 Norsjø

The result for Norsjø is same as for small flood events i.e. the model is providing much-varied results as in small flood event. In 2013 and 2014, the model has completely failed for predicting the operational level whereas for 2015 it seems to be performing well than in 2013 and 2014. The simulation result for 2013 and 2014 is presented in Appendix E 9Appendix E 10.

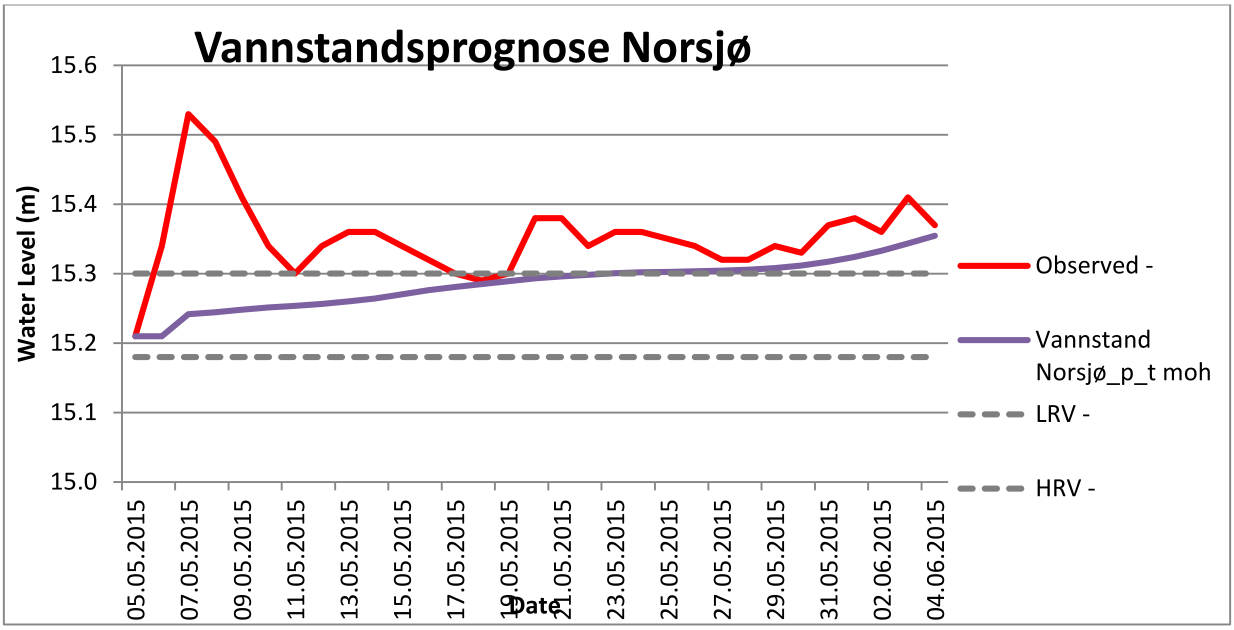


Figure 8-11: FMTV simulation result for a medium flood period for Norsjø in 2015

8.2.2.4. Hjellevatn

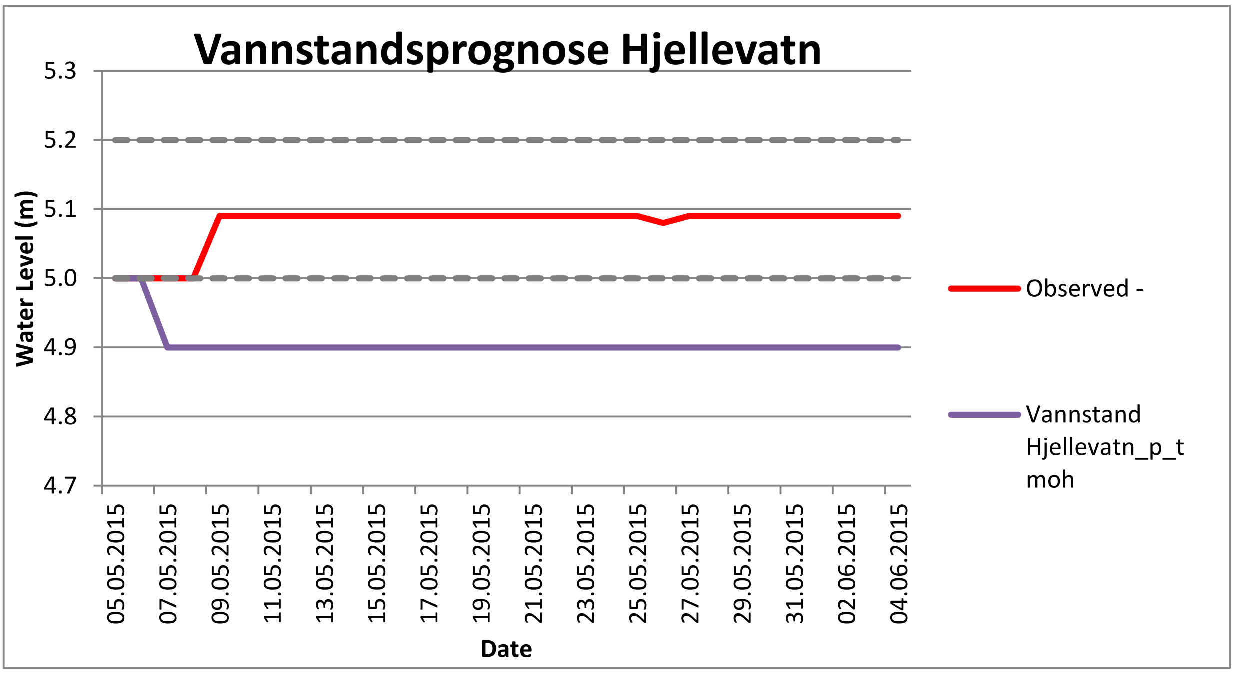


Figure 8-12: FMTV simulation result for a medium flood period for Hjellevatn in 2015

The model has completely failed to provide the result for Hjellevatn as for small flood periods. The simulated water level is constantly running at 4.9 m as the lowest possible water level is 4.9 m permitted by the model and for observed water level it seems that the reservoir is maintaining constant water level by balancing between inflow and outflow. The figures for 2013 and 2014 is shown in Appendix E 11 and Appendix E 12.

8.2.3. Large Flood Event

The large flood is most important flood events FMTV model needs to forecast. The failure to forecast flood during large flood can result in high economic loss and trouble for people living around the reservoirs. Thus, the simulation result obtained by FMTV were analyzed with importance.

8.2.3.1. Tinnsjø

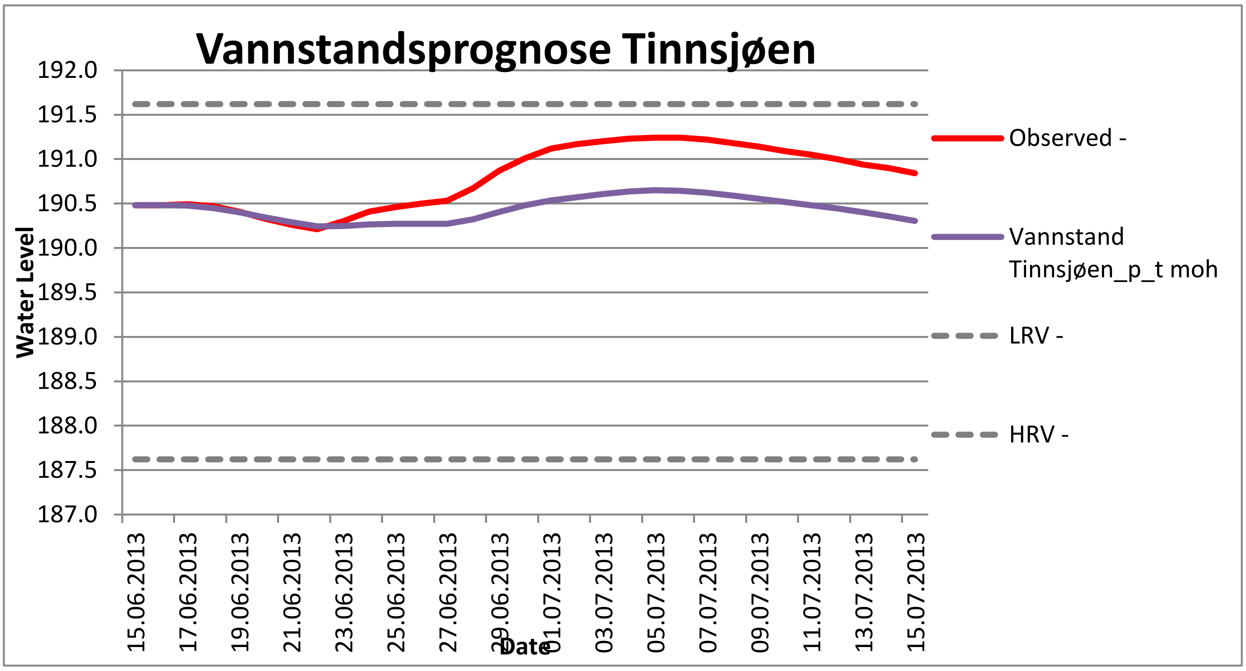


Figure 8-13: FMTV simulation result for a Large flood period for Tinnsjø in 2013

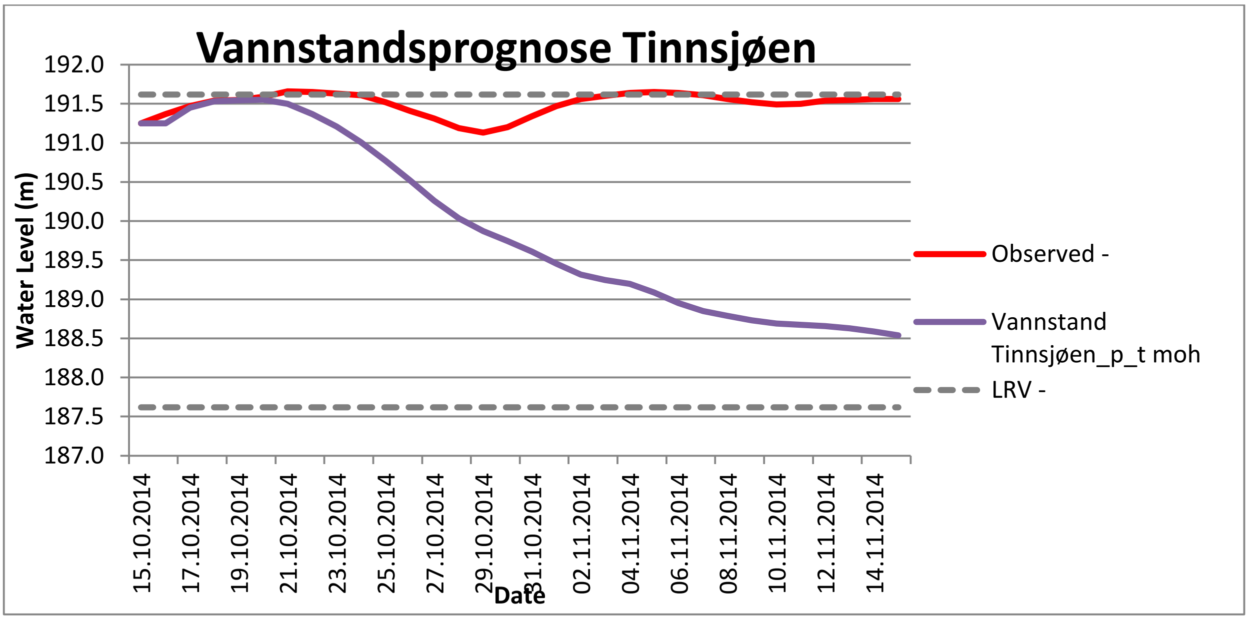


Figure 8-14: FMTV simulation result for a Large flood period for Tinnsjø in 2014

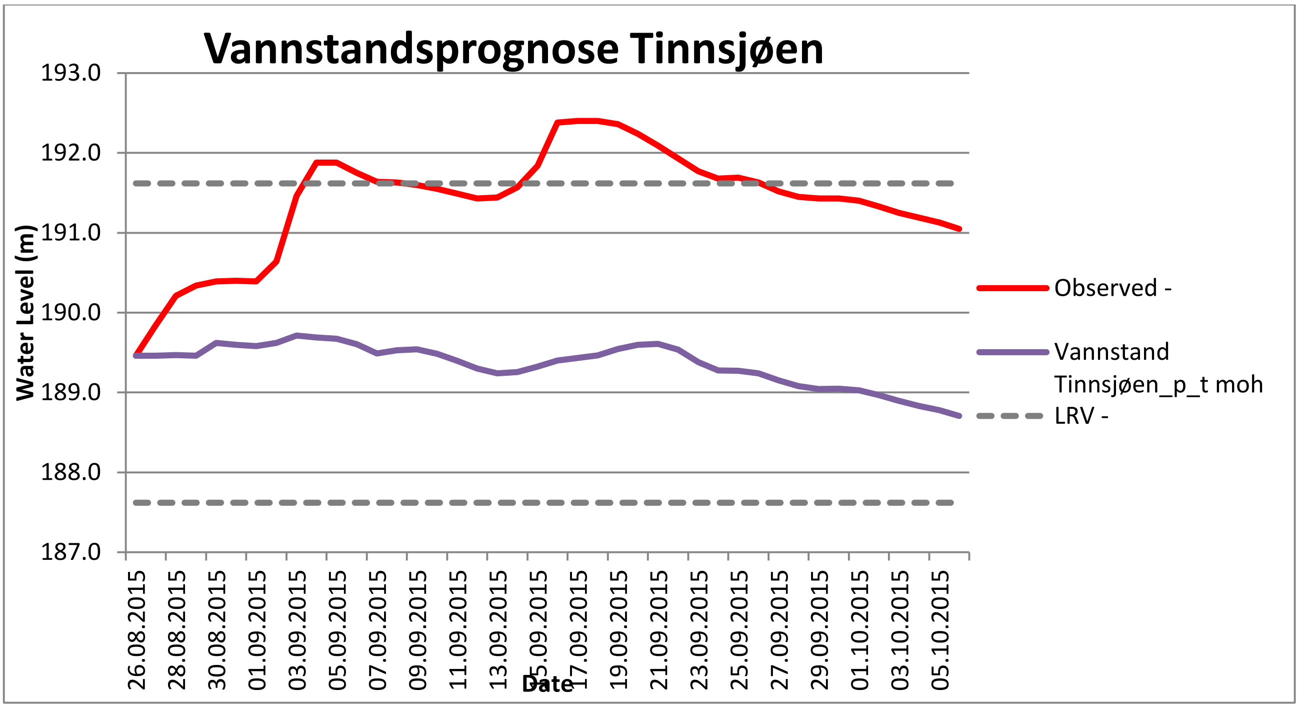


Figure 8-15: FMTV simulation result for a Large flood period for Tinnsjø in 2015

Figure 8-13, Figure 8-14, and Figure 8-15 provided by FMTV model for large flood periods for Tinnsjø show the model is not able to forecast large flood events as simulated water level is below observed water level with difference of 3.02m in 2014.11.15 and 3.36m in 2015.10.06. It can also be seen that the observed water level is going above highest reservoir level. As FMTV model is not able to predict the flood properly at upstream, the flood occurs at downstream river reach and reservoirs during flooding periods.

8.2.3.2. Heddalsvatn

Figure 8-16 for 2015 from the model for large flood periods, it can be seen that for Hjellevatn the model is providing excellent results even it is not performing well for Tinnsjø. The difference seems to be fairly less between observed and simulated water level with a maximum difference of 0.72m in 24.06.2013 shown in Appendix E 13: FMTV simulation result for a large flood period for Heddalsvatn for 2013. The water level has risen much above the highest reservoir level signaling danger of flooding in critical area Nottoden. The simulation result for large flood event in 2013 and 2014 is shown in Appendix E 13 and Appendix E 14.

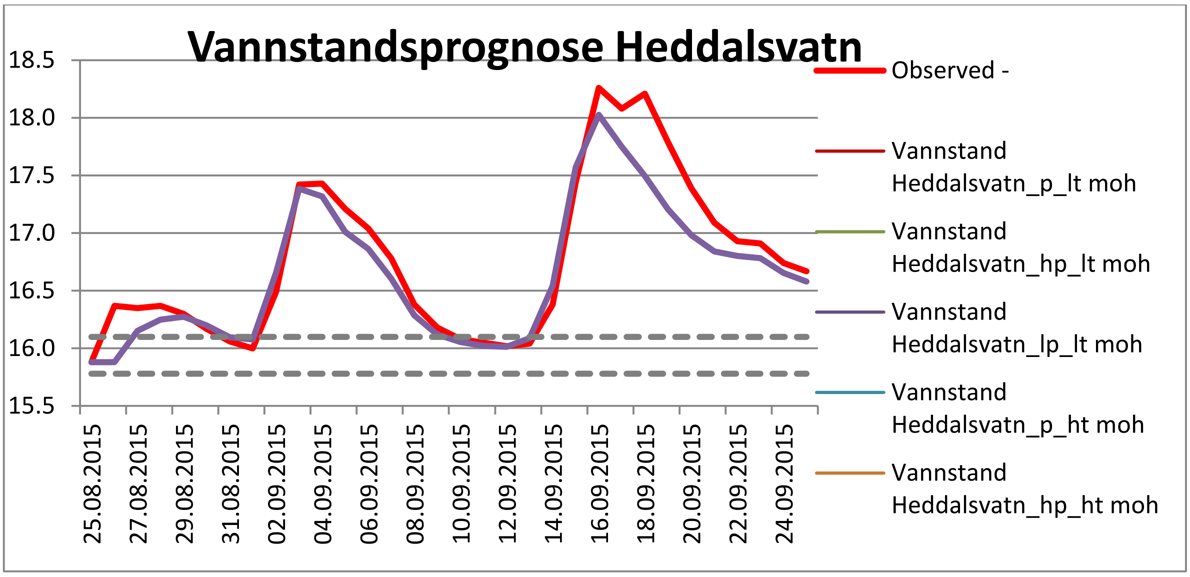


Figure 8-16: FMTV simulation result for a Large flood period for Heddalsvatn for 2015

8.2.3.3. Norsjø

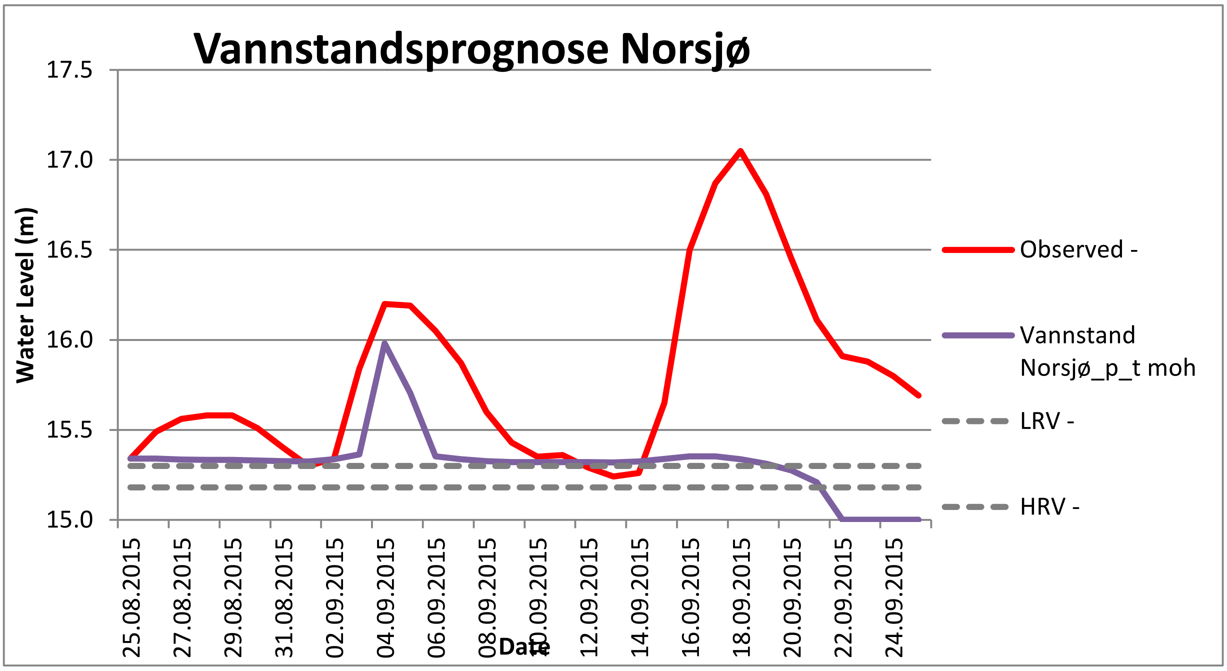


Figure 8-17: FMTV simulation result for a Large flood period for Norsjø for 2015

During Large flood event, the model is underestimating the inflow to Norsjø. It can also be that the software is not performing well for Norsjø. However, the fact from Figure 8-17 is observed water level is much higher than HRWL hinting water rose high enough giving the problem to people living around. The high water level means significant outflow to Hjellevatn, which will affect the areas around Hjellevatn. The simulation result for large flood event in 2013 and 2014 is provided in Appendix E 15 and Appendix E 16.

8.2.3.4. Hjellevatn

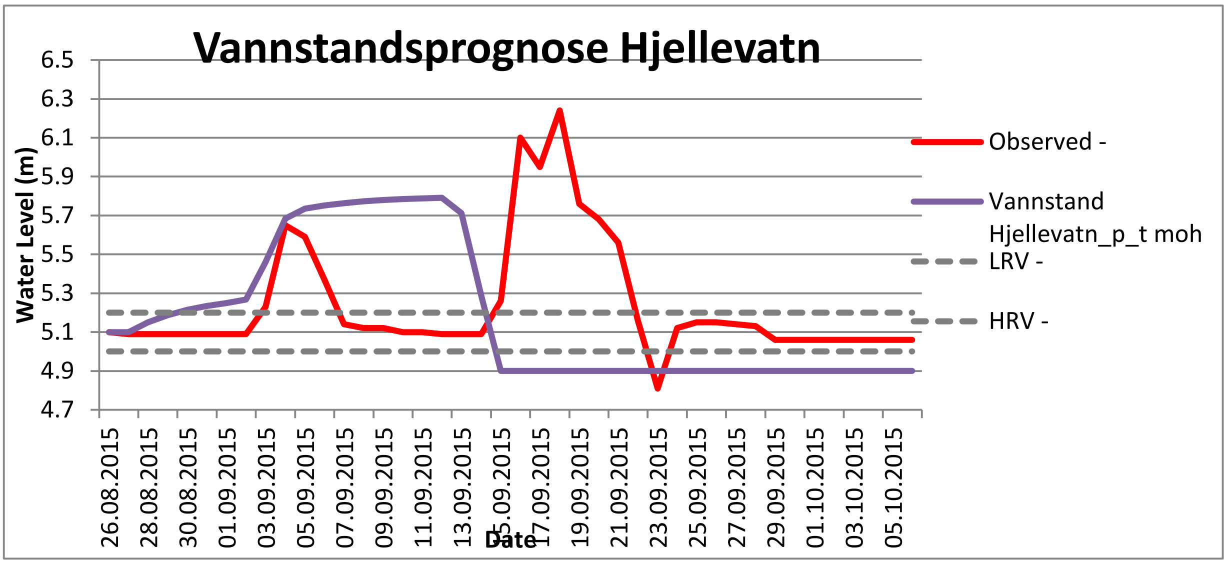


Figure 8-18: FMTV simulation result for a Large flood period for Hjellevatn for 2015

With the increase of outflow from Norsjø, the water level at Hjellevatn has increased. Out of two Large floods occurred in September 2015, the first flood is simulated by the model as seen in Figure 8-18 but has completely failed to forecast the second flood. The consistency of failure to forecast flood for all flood event hints the necessity of software to be revised. The result for Large flood events in 2014 and 2015 are also similar as for 2015 shown in Appendix E 11 and Appendix E 12.

8.3. Simulation results by replacing Møsvatn with Skarsfoss

Skarsfoss dam is located downstream of Møsvatn dam. Møsvatn supplies water to Frøystul power plant which ends up at Skarsfoss dam. At present FMTV model is using production flow to Frøystul Power Plant. The further research is carried out pointing selection of Møsvatn outlet as inflow to Tinnsjø is wrong. Thus, the study is conducted to check whether replacing Møsvatn with Skarsfoss i.e. adapting production flow to Vemork instead of Frøystul will help to improve simulation result for Tinnsjø.

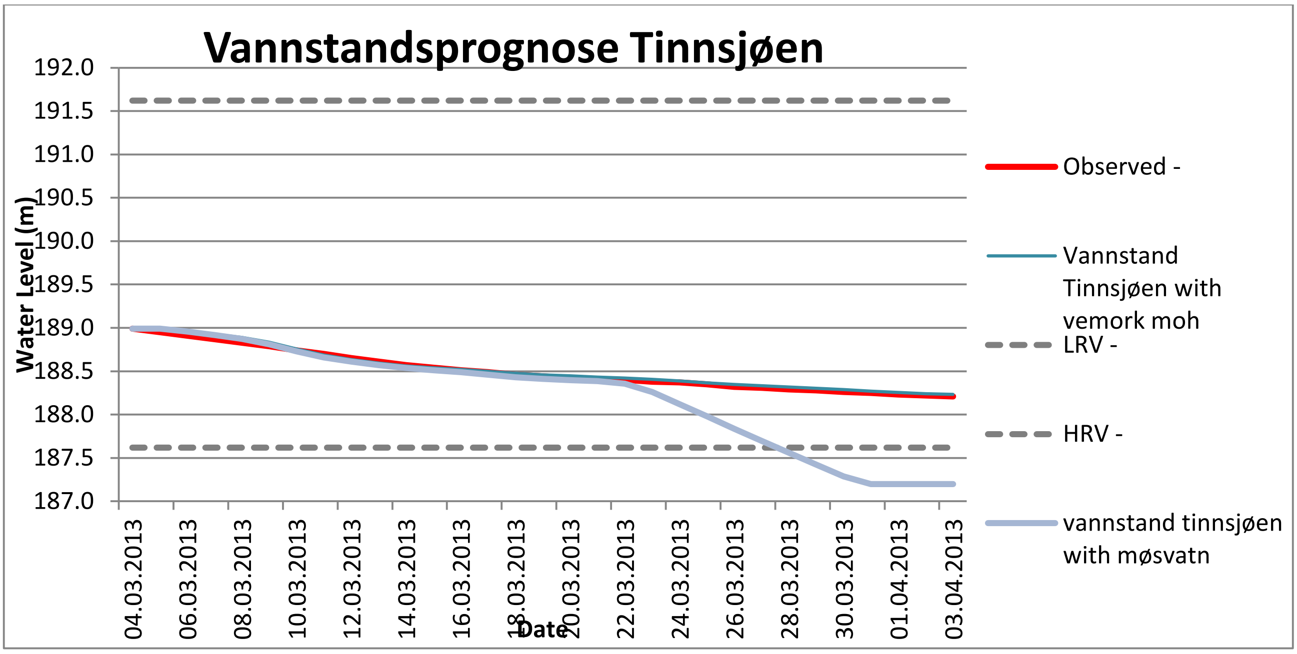


Figure 8-19: FMTV simulation using Skarsfoss outlet for a small flood period in 2013

The result for small flood event in 2013 presented in Figure 8-19 clarifies the fact that selection of Skarsfoss outlet is the right decision, as there are no spill and no rainfall or snowmelt during this period this was the only factor that could provide an improvement in result during the small flood.

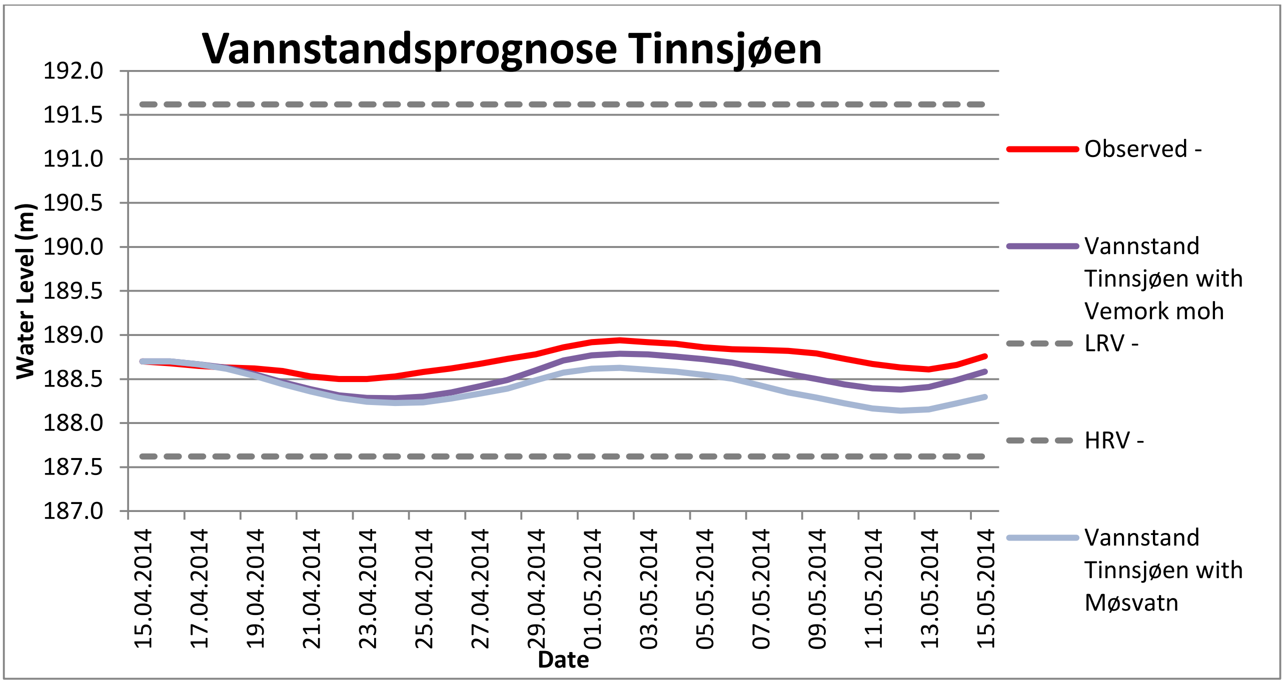


Figure 8-20: FMTV simulation using Skarsfoss outlet for a medium flood period in 2014

With the increase in flow, the model is not able to give exact figures as for small flood but still selection of Skarsfoss provides an improvement in simulated water level during the medium flood as seen in Figure 8-20.

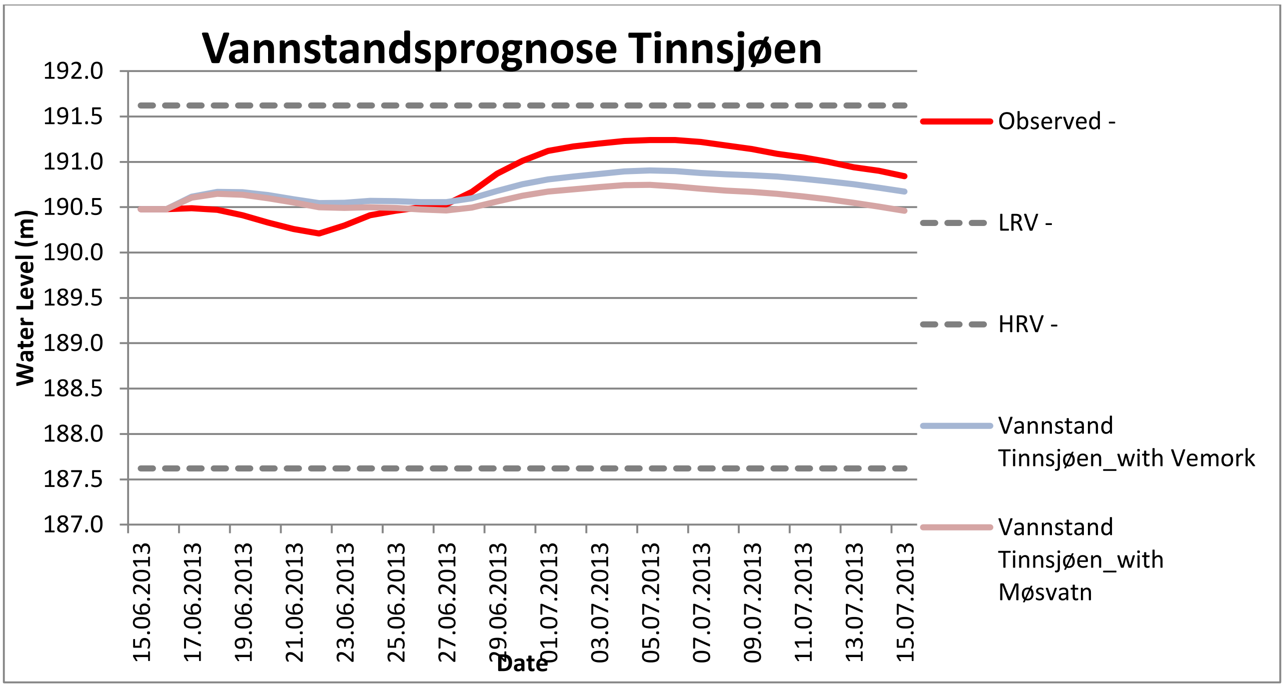


Figure 8-21: FMTV simulation using Skarsfoss outlet for a Large flood period in 2013

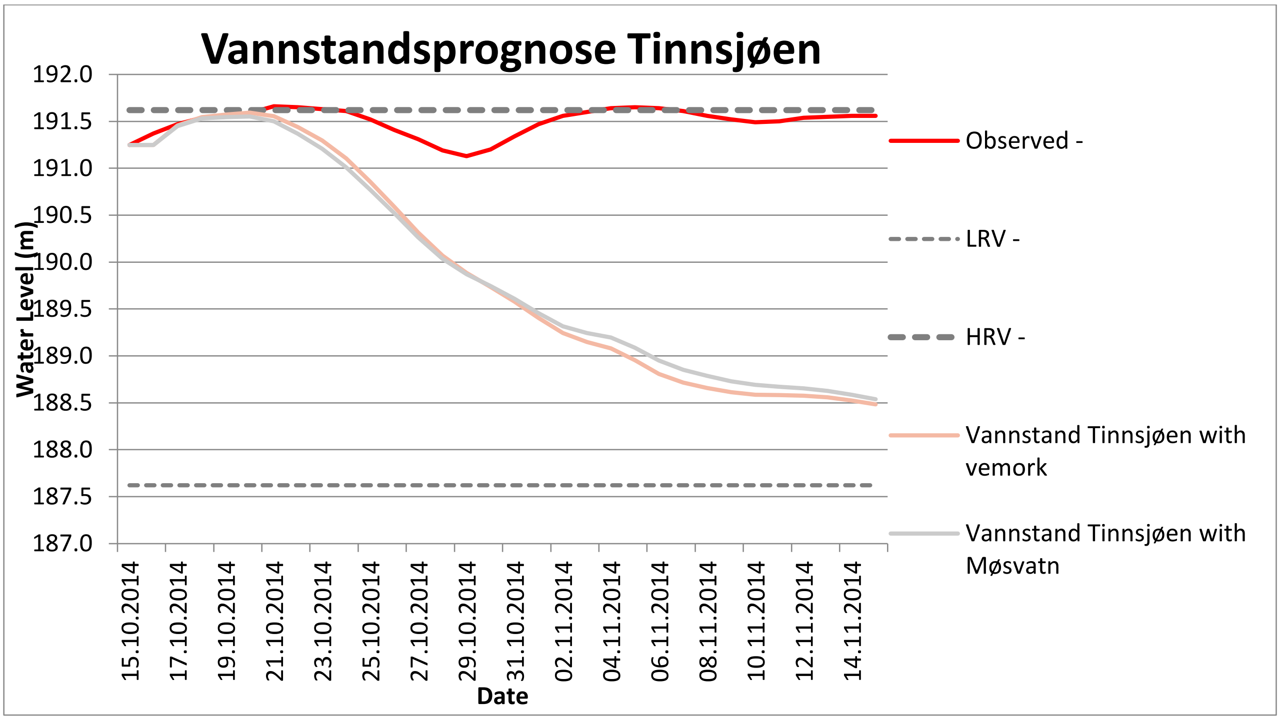


Figure 8-22: FMTV simulation using Skarsfoss outlet for a Large flood period in 2014

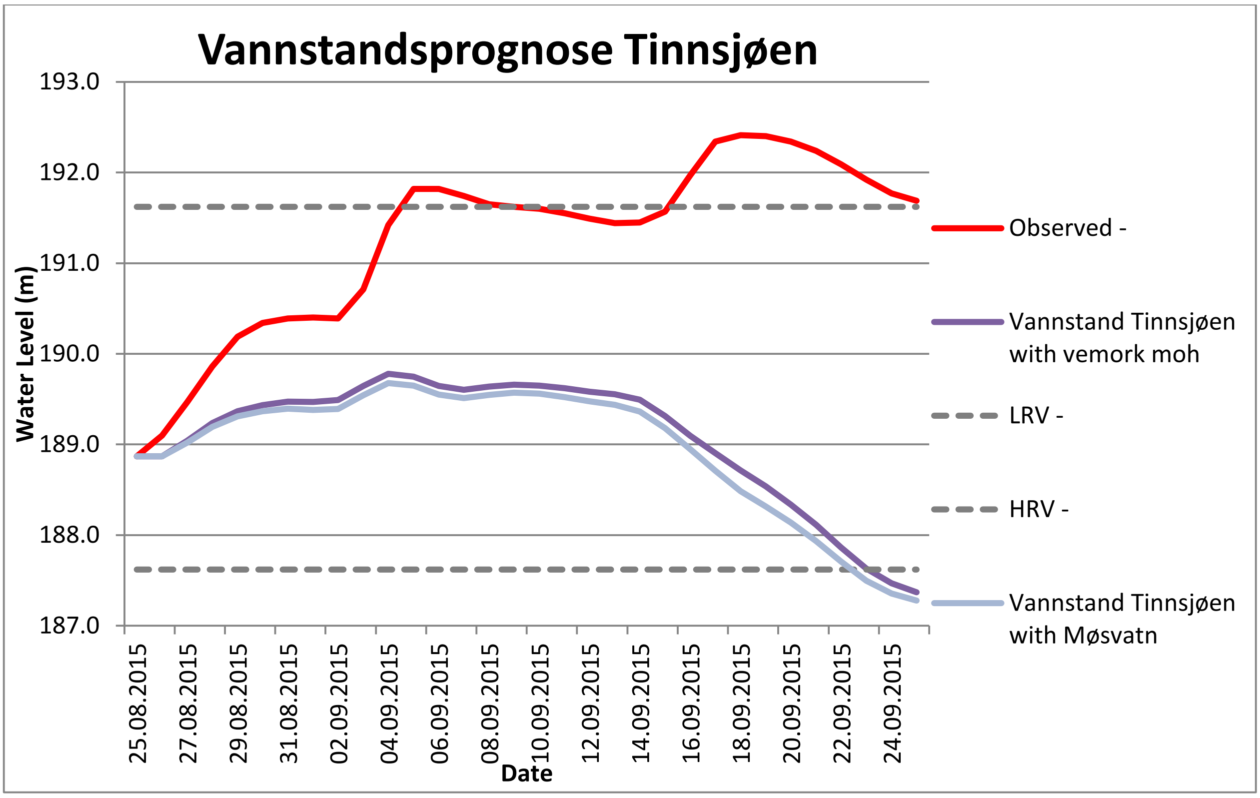


Figure 8-23: FMTV simulation using Skarsfoss outlet for a large flood period in 2015

With the increase in runoff beyond medium flood, the simulation results obtained by selecting Skarsfoss become less satisfactory. Figure 8-21, Figure 8-22 and Figure 8-23 show improvement in simulated water level than before but it is far from being satisfactory for the researcher. So, it is necessary to do further study for improvement of simulation results.

8.3. Simulation results by considering spill and intake capacity

FMTV model seems to be neglecting spill from brook intakes. It tries to balance all other extra flows by representing with local inflow. The study was done to study if the inclusion of spill from dam and brook intakes along the tunnel will provide an improvement in the simulation results. It was seen that there seems to be no spill from the dam for small and medium flood event. It was also observed that during small flood, intake capacities of brook intakes will be almost zero. During the large flood, it was considered that tunnel would be full, so the capacity of brook intake is considered as spill whereas for medium flood events intake capacity is considered as an inclusion to flow to the power plant.

Re-simulation for large flood events was performed, with inclusion of capacity of brook intake. In our study area, it is seen that inclusion of spill from Skarsfoss dam and brook intakes from Møsvatn and Mår hydropower system affect Tinnsjø and spill from Vrangfoss affect Norsjø, so re-simulation was performed for Tinnsjø and Vrangfoss during large flood. Re-simulation was also carried out for medium flood event when inflow from brook intakes seems to be large.

8.3.1. Tinnsjø

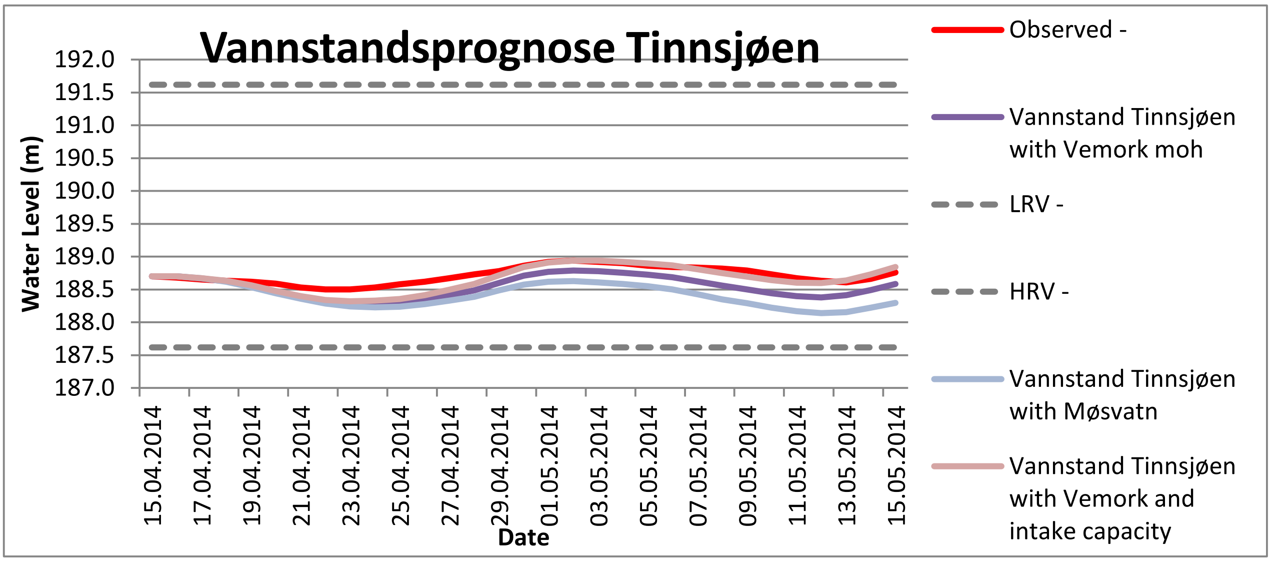


Figure 8-24: FMTV simulation considering spill from Skarsfoss and Brook intake capacity for medium flood event in 2014

There is no spill from dam during medium flood, but the contribution from five brook intakes in headrace tunnel from Mår helps in achieving better simulation result. Figure 8-24 shows simulated water level is coinciding with observed runoff after including inflow from brook intakes and also after changing Møsvatn outlet to Skarsfoss outlet.

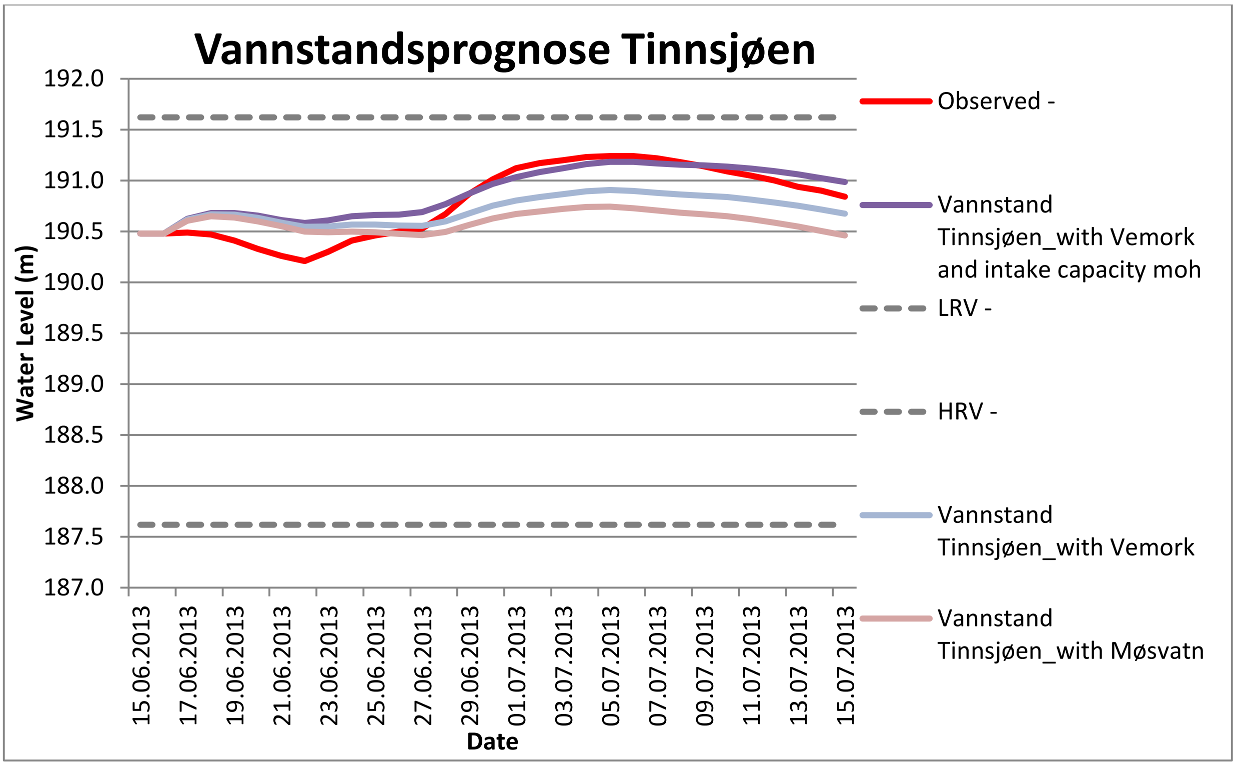


Figure 8-25: FMTV simulation result considering spill from Skarsfoss and Brook intake capacity for large flood event in 2013

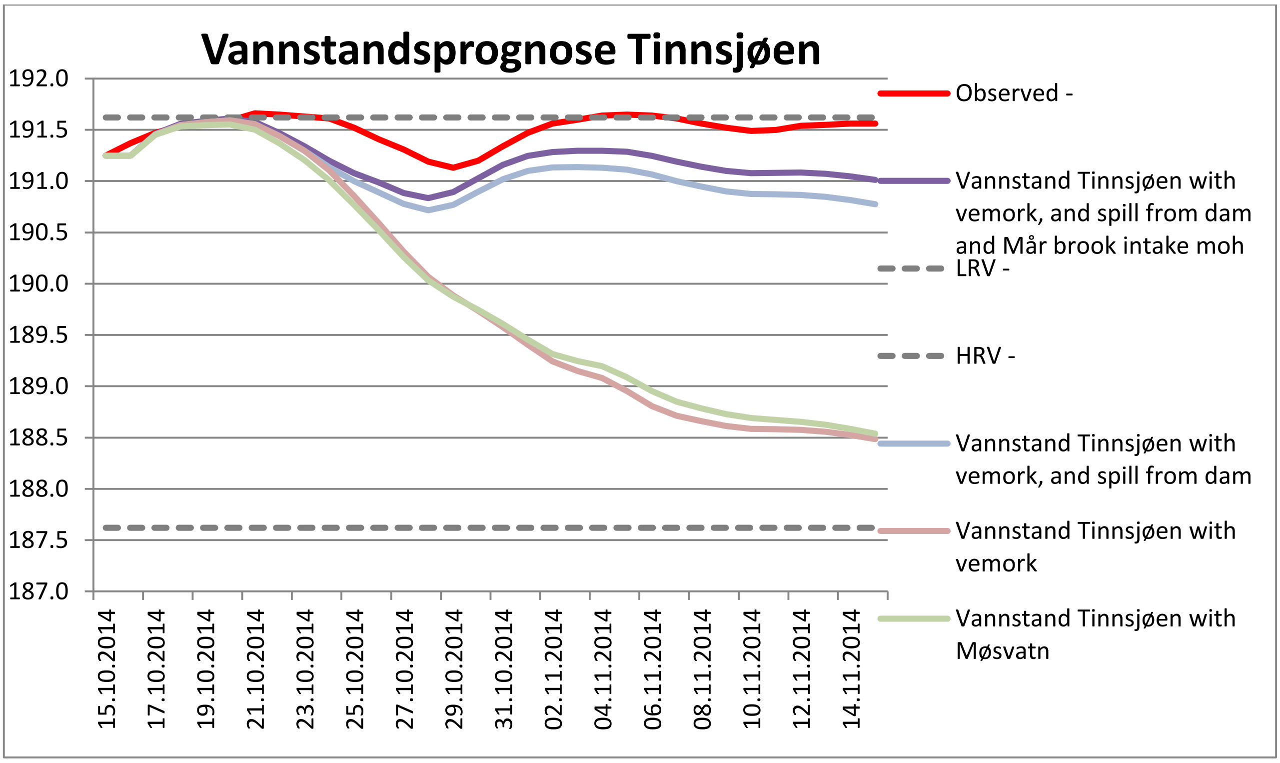


Figure 8-26: FMTV simulation result considering spill from Skarsfoss and Brook intake capacity for large flood event in 2014

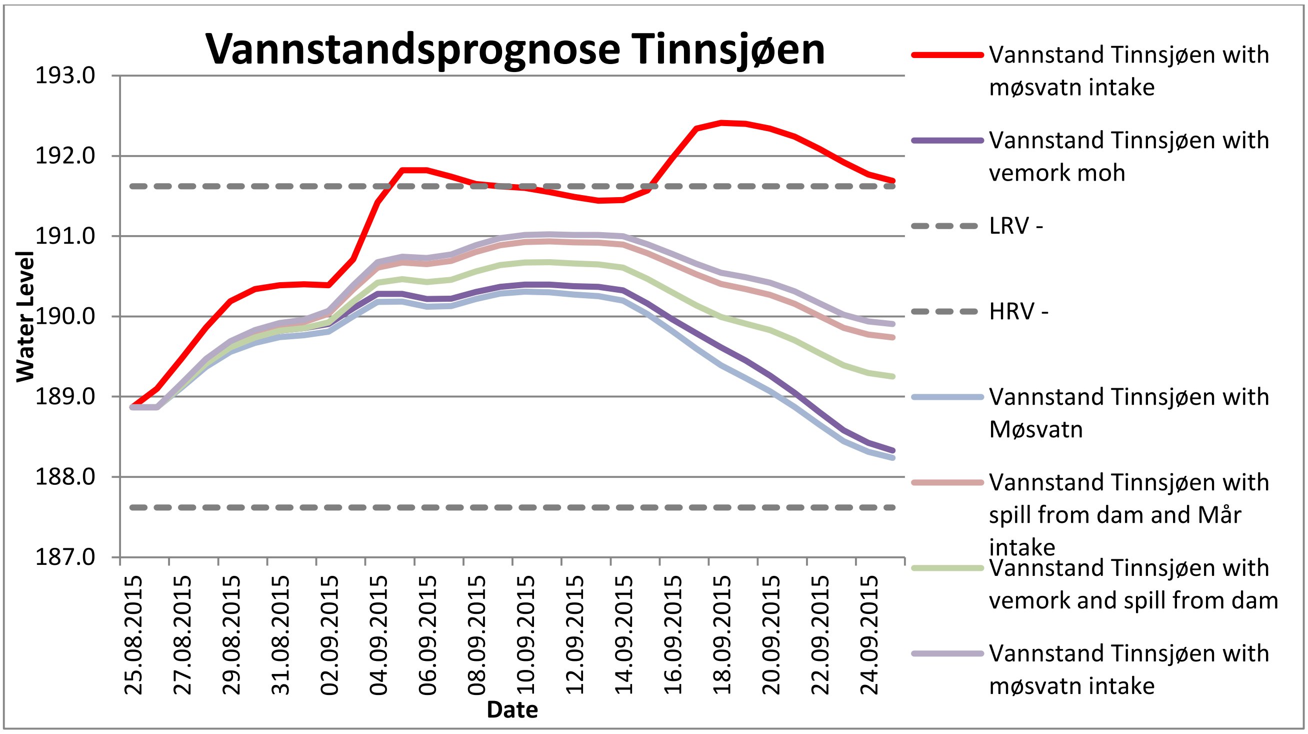


Figure 8-27: FMTV simulation results considering spill from Skarsfoss and Brook intake capacity for large flood event in 2015

The consideration of capacity of brook intakes along tunnel from Mår seems to be significant addition for a flood event in 2013 as shown by the result in Figure 8-25. During the period of large flood, simulated runoff match with observed runoff. It is expected to have a better result for large flood events in 2014 and 2015, but addition of spill from book intakes from Mår does not seem sufficient to see the obtained simulation result satisfactory as seen in Figure 8-26 and Figure 8-27.

Furthermore, spill from dam is added to the outlet from Skarsfoss and simulation was carried out with the model. The combination of spill from intakes and dam shows significant improvement in the result as seen in Figure 8-26 and Figure 8-27. In addition, it was expected to obtain further improvement in the result by including spill from brook intakes along headrace tunnel from Møsvatn, but improvement is tiny visible in Figure 8-27.

8.3.2 Norsjø

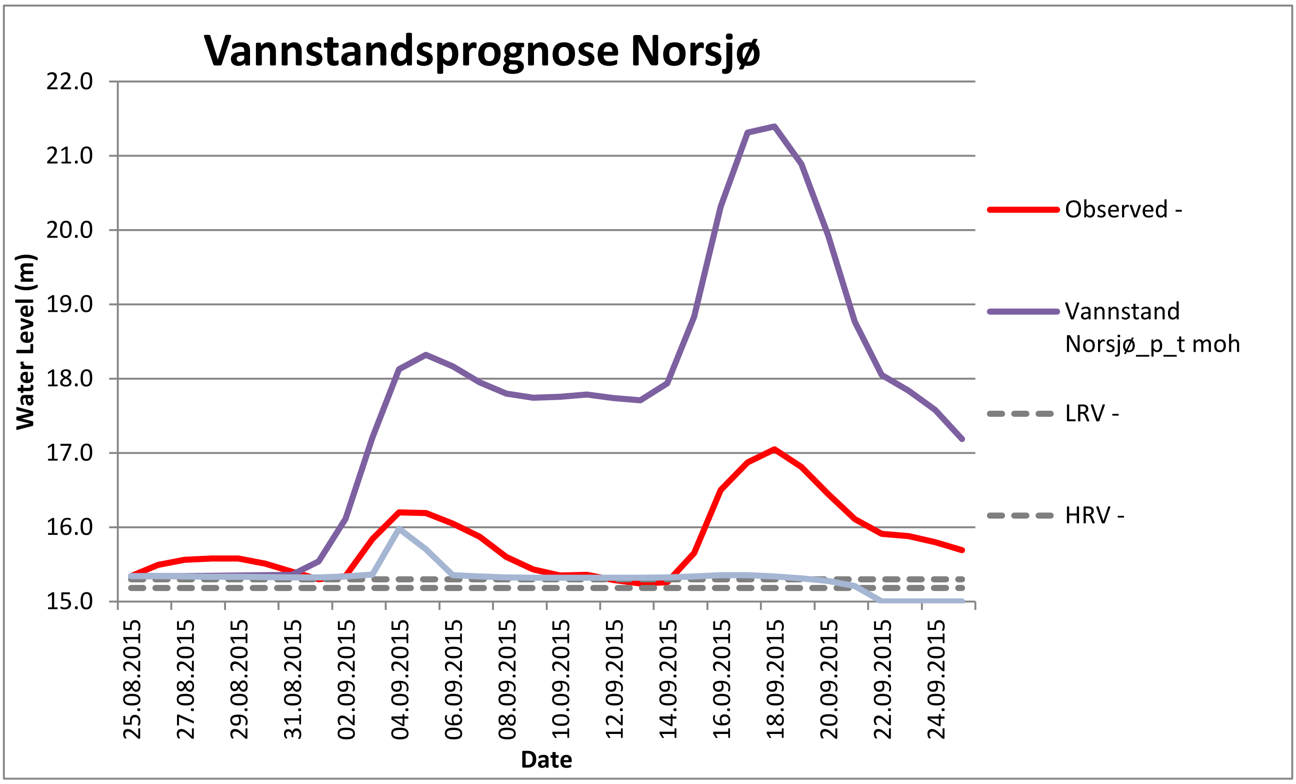


Figure 8-28: FMTV simulation result for Norsjø after considering Spill from Vrangfoss in 2015

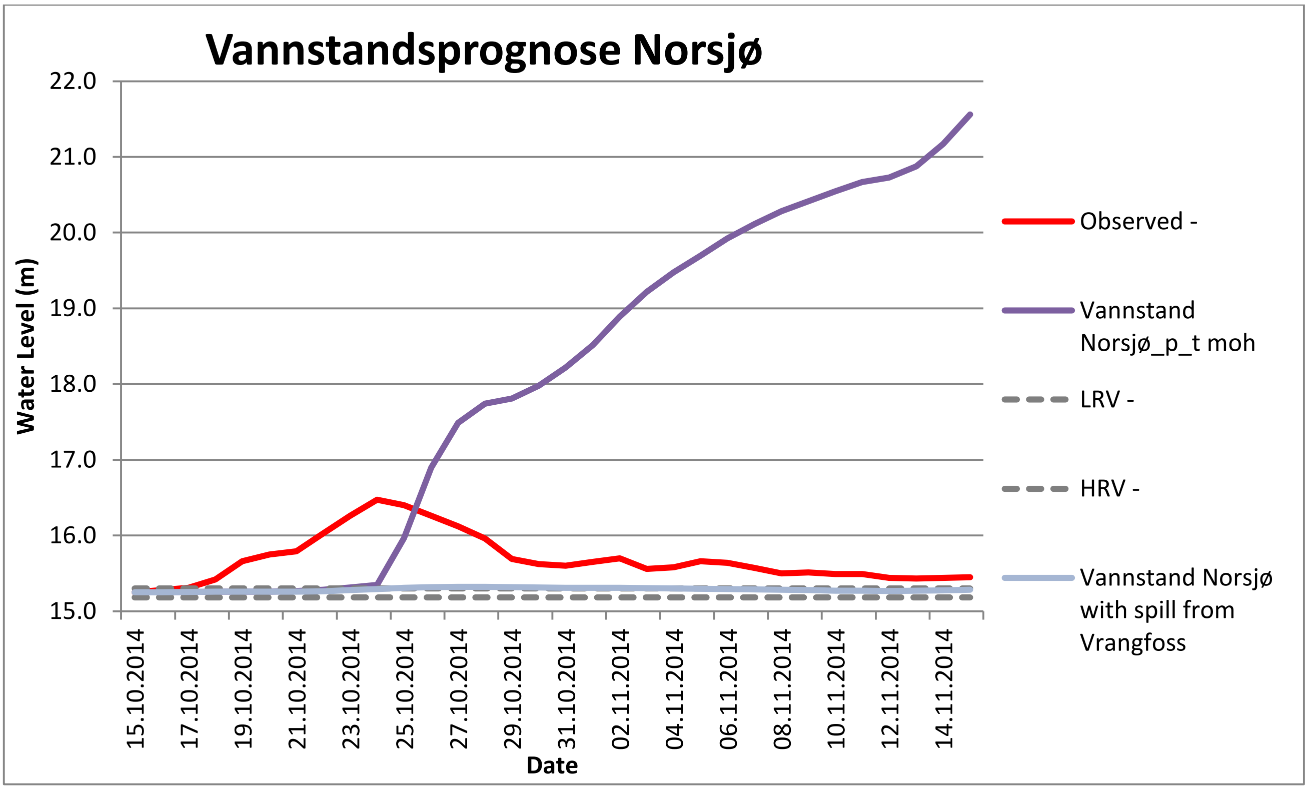


Figure 8-29: FMTV simulation result for Norsjø after including Spill from Vrangfoss in 2014

Figure 8-28 and Figure 8-29 present the fact that for Norsjø, FMTV model is overestimating the upcoming inflow after inclusion of spill from Vrangfoss resulting in rising of simulated runoff too above the permissible limit.

8.4. Discussion:

The simulation result for various flood events in three years period from 2013 to 2015 provides mixed results for four reservoirs during reservoir routing. The model seems to be providing success for Tinnsjø and Hjellevatn but for Norsjø and Heddalsvatn, the model appears to be underperforming as the variation in simulated water level for different flood events were registered. The detail discussion for all four reservoirs can give more insight to result and cause of errors in the model for its underperformance.

8.4.1. Tinnsjø

The simulation results provided by the model for small flood events and medium flood events is good with some inflow missing. The improvement in simulation results was obtained after changing Møsvatn outlet to Skarsfoss outlet and considering brook intake capacity in calculation as seen in Figure 8-19 and Figure 8-24.

The simulation result for large flood event in 2013 is good after inclusion of spill from brook intakes in Mår hydropower system and using outflow from Skarsfoss as seen in Figure 8-25. But the result for large flood event in 2014 and 2015 doesn’t look satisfactory after inclusion of these two factors as seen in Figure 8-26 and Figure 8-27. The simulation was further carried out by the inclusion of spill from Skarsfoss dam with presently considered outlet. The result shows great improvement as the gap between simulated water level and observed water level narrows down. Even after inclusion of these factors during large flood simulated water level is below observed water level as seen in Figure 8-26 and Figure 8-27 which is clear sign of local inflow to Tinnsjø is being underestimated by FMTV model.

During Large flood event in 2015, spill from brook intakes of Møsvatn hydropower system was also included during simulation and improvement was viewed. The improvement is not so satisfactory, so it is recommended not to consider spill from brook intakes in headrace tunnel from Møsvatn during further study on the topic.

8.4.2. Heddalsvatn

The model is giving good simulation results for small and medium flood events for all three years as seen in Figure 8-4, and Figure 8-10. During small flood the simulated water level seems to be little below observed which hints that some local inflows to the Heddalsvatn is not considered by model. During medium flood the simulated water level appears to be little above observed showing that the model is estimating bit more local inflows than actually coming into the reservoir as no spill from upstream reservoirs needs to be considered due to presence of gauging stations. During large floods, the model seems to be performing excellent except at the peak point of the flood in 2015 when the water level rose 2.1m above HRWL. The reason behind these mixed results can be the lack of gauging station in Sauarelva. The model has its capacity curve for calculation depending on the water level at Heddalsvatn and Norsjø. It can be said that the capacity curve provided in model works well as the pattern of simulated water level is same as observed water level. Some adjustment in scaling factor can remove the deficits being faced during simulation of Heddalsvatn.

8.4.3. Norsjø

The model is giving bad simulation results for Norsjø. During the small flood, the model shows simulated water level is far below observed water level. During medium flood, the models show simulated water level far above observed water level. During the large flood, the model seems to be missing some inflows but after adding spill from Vrangfoss, it overestimates simulated runoff which seems strange as seen in Figure 8-28 and Figure 8-29. The reason behind this can be an error in data received or error within the software. The task was to check whether the software is performing well. So, manual reservoir routing was carried out for large flood events in 2014 and 2015. The result was compared with the result from FMTV and shown in figures below.

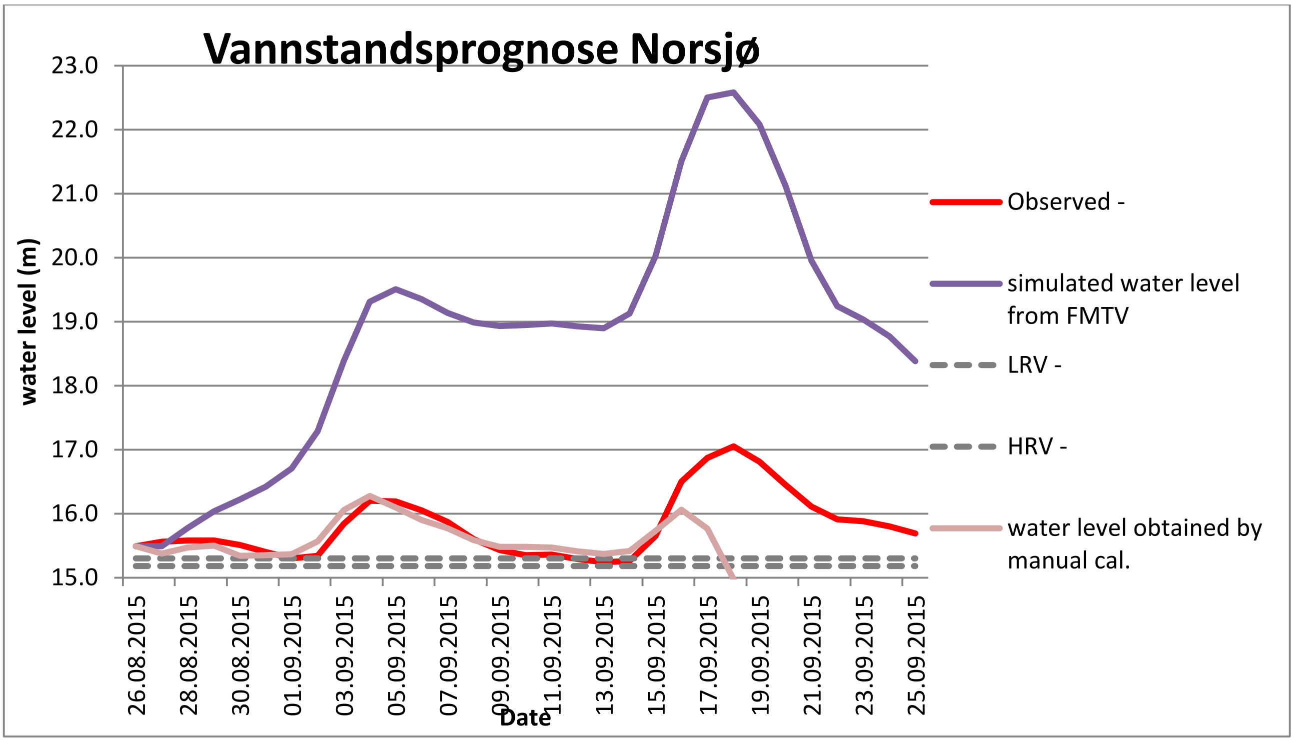


Figure 8-30: Simulation result from FMTV and manual calculation in 2015.

Figure 8-30: Simulation result from FMTV and manual calculation in 2015. shows water level obtained from the manual calculation is matching with observed water level but for later stage manual calculation fails to forecast flood. This might be due to unavailability of spill data from Skotfoss. Farelva station receives water from Falkumelva so cannot be directly used as an outlet from Norsjø. For same data as used for manual calculation of water level, FMTV is providing high simulated water level than observed water level which represents there exists error in the software.

The calculation was checked further for large flood event in 2014. The result obtained from manual calculation is combined with the result from FMTV and presented below.

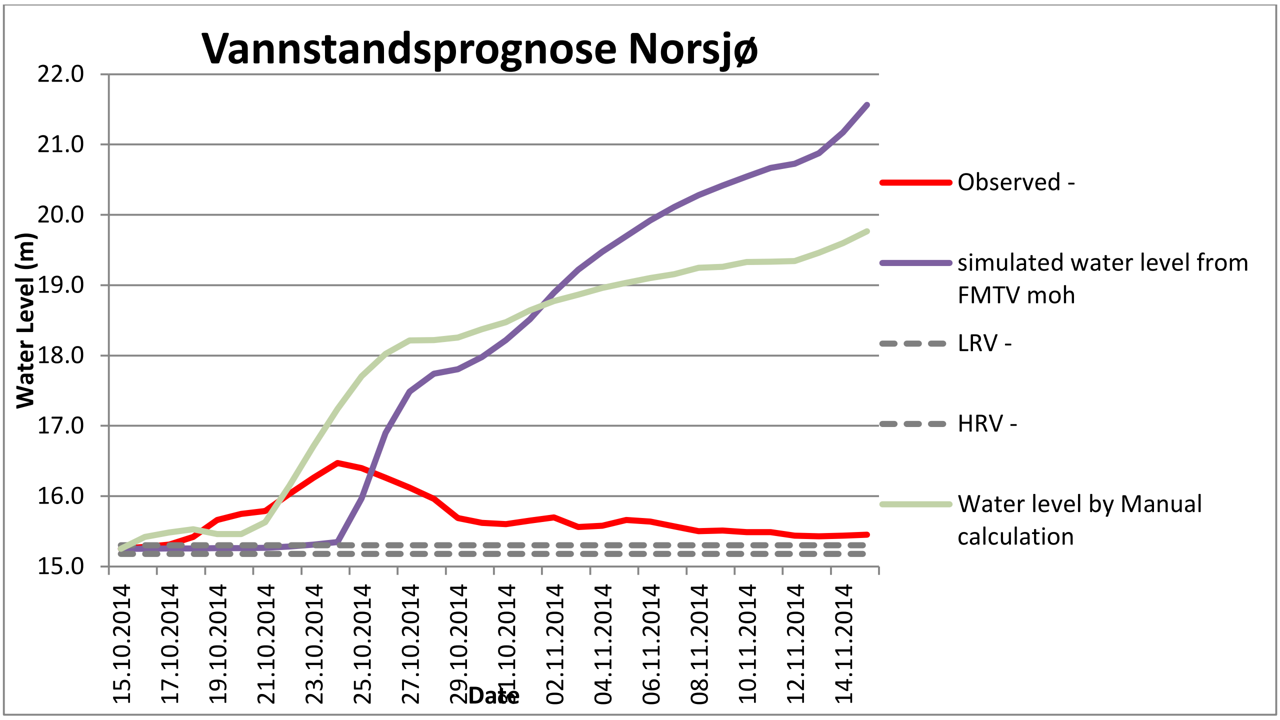


Figure 8-31: Simulation result from FMTV and manual calculation for large flood event in 2014

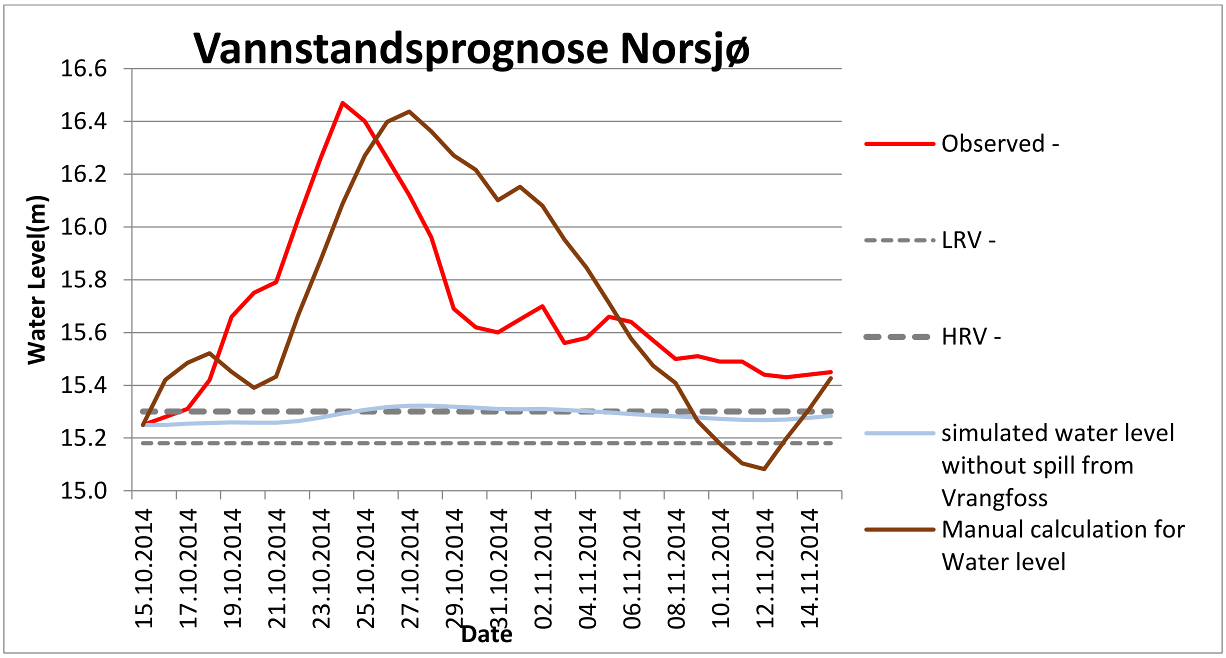


Figure 8-32: Simulation result from FMTV and manual calculation for large flood event in 2014

Figure 8-31 shows both simulation results from FMTV and manual calculation is over observed level but manually obtained simulated water level is lower than the result obtained from FMTV. This can be the result of large inflow or less outflow. So, it might be due to inproper data from Skotfoss or large inflow from Sauarelva and Vrangfoss. The data obtained for Vrangfoss was tested without spill in FMTV and manual calculation, and the outcome was presented in Figure 8-32.

The result after exclusion of spill from Vrangfoss dam provides doubt on data received for Vrangfoss. After exclusion of spill, the result looks good for simulated water level obtained by manual calculation. However, for same data provided, FMTV fails to give the result as provided by manual calculation. This is the clear sign that codes or outlet curve and volume curve in FMTV for Norsjø must be updated or changed.

8.4.4. Hjellevatn

The simulation results show that during all flood events the result provided by the model is not satisfactory as seen in Figure 8-18, Figure 8-12, and Figure 8-6. The reason can be the absence of gauging stations downstream and data unavailability from power plants in Hjellevatn. The only way to consider water level at Hjellevatn is by considering inlet=outlet. It is necessary to do detail study about the possibility of measuring water flow at downstream. The control of flood in upstream with good prediction of runoff from FMTV can be helpful in controlling flood at Hjellevatn. It is seen from site visit it is impossible to put gauging station in the downstream of the reservoir so the best way to manage flood at Hjellevatn is controlling flood by reservoir routing of upstream reservoirs.

9. Manual Calculation of Local Inflows

The simulation results show that during large flood event after inclusion of spill from brook intakes and dam, inflow is still missing as simulated water level seems to be lower than observed water level. The local inflows are calculated in the model by scaling from calibrated catchments. So, the manual calculation of local inflow is done and compared with local inflows being considered by the model. It is not deemed necessary to calculate local inflow to Heddalsvatn as result provided by FMTV is excellent. For Hjellevatn, there is no outflow data from Hjellevatn, so calculation of local inflow to Hjellevatn was not considered.

The inflow from Mår and Møsvatn with spill from dam and brook intakes is considered for calculation of inflow. The calculation of inflow is done by using water balance equation. The detail calculation is shown in Appendix G(Table)- 1.

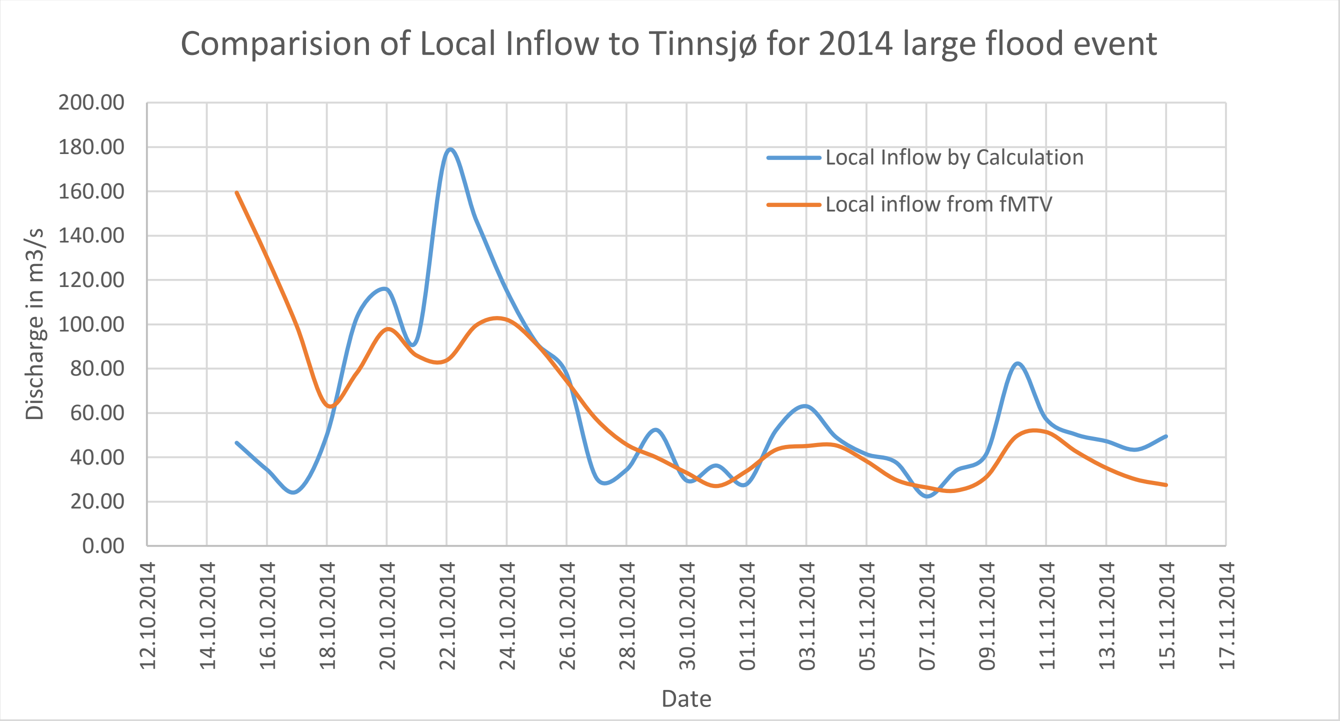


Figure 9-1: Local Inflow provided by Manual Calculation and FMTV model for a large flood event in 2014

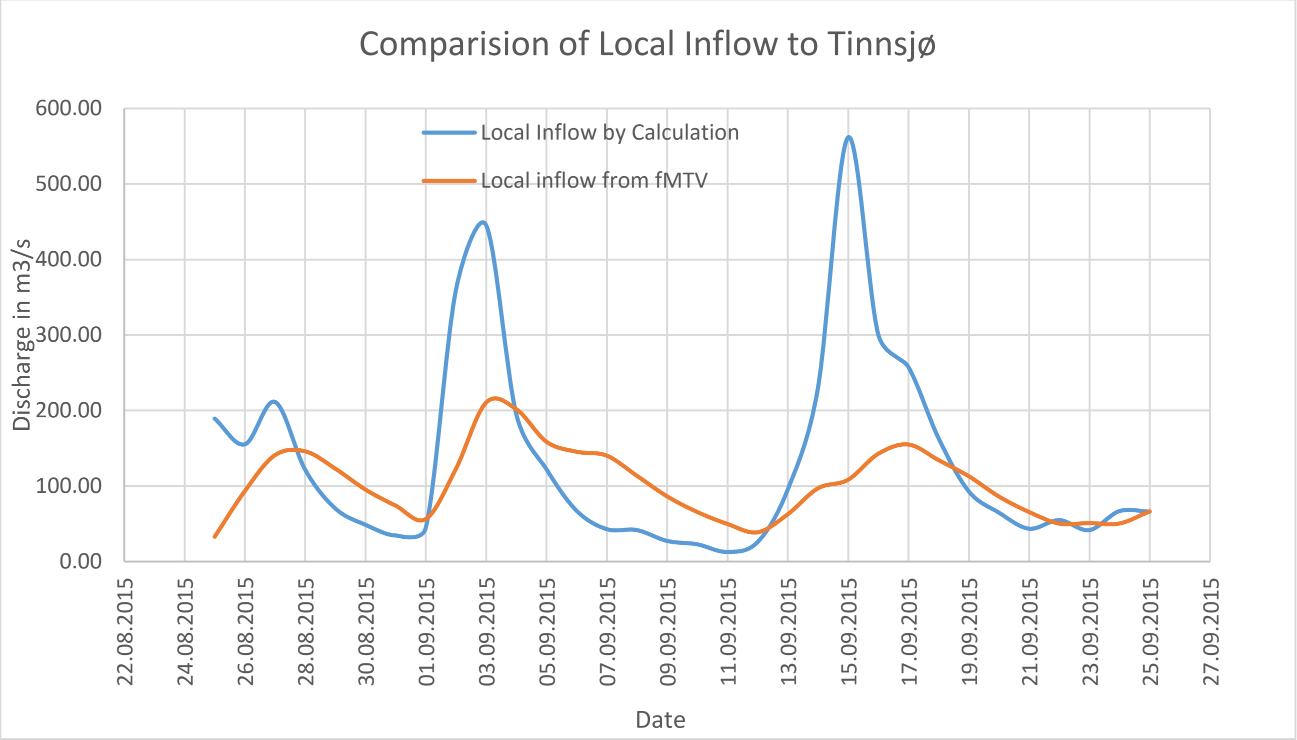


Figure 9-2: Local Inflow provided by Manual Calculation and FMTV model for a large flood event in 2014

It is clear from Figure 9-1 and Figure 9-2, there needs an adjustment for local inflow in the model. The model is underestimating the local inflow and adjustment in scaling factor can solve this problem. It might also be necessary to select another catchment instead of Austbygdåi for scaling to get a better result.

During large flood events, the simulation results for Heddalsvatn is promising so it was assumed that the outlet to Sauarelva is considered accurately by the model and the runoff for Sauarelva obtained from Software is used to find Local inflow at Norsjø. The detail calculation of local inflow to Norsjø is presented in Appendix G(Table)- 2 with runoff for Sauarelva obtained from FMTV model.

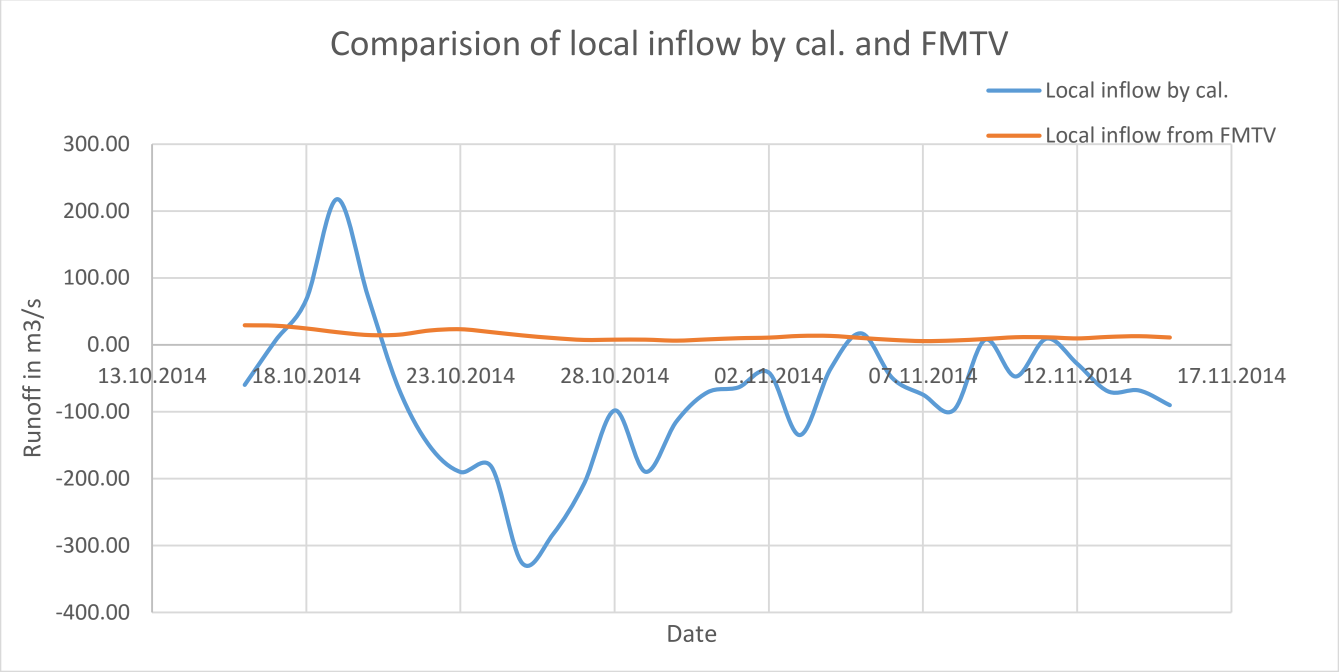


Figure 9-3: Local Inflow Provided by Manual Calculation and Norsjø during large flood in 2014

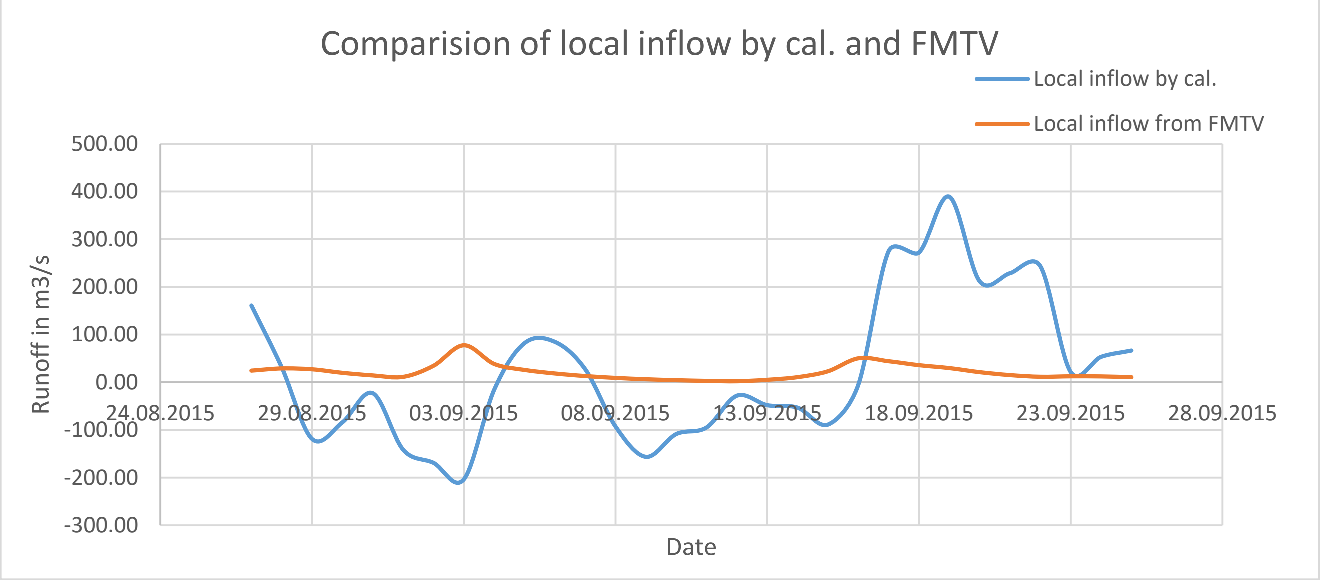


Figure 9-4: Local Inflow Provided by Manual Calculation and Norsjø during large flood in 2015

The local inflow calculated by the manual method ends up with a lot of negative values for large flood events in 2014 and 2015, which raise questions regarding accuracy on data received. A possible reason can be the Skotfoss might not be recording spill to Norsjø and can also be incorrect data for Vrangfoss as discussed in chapter 8.4.3. Another reason behind this can be the mistaken inflow from Sauarelva, which is considered with the belief that the model is providing good runoff for Sauarelva as simulation result for Heddalsvatn is good.

10. CONCLUSION AND RECOMMENDATION

10.1. Conclusion

FMTV model is designed to optimize the operation of hydropower plant by controlling water level keeping a highest possible reservoir level for maximum energy storage, and lowest possible level to store and reduce floods. In 2015, the model failed to live up to its main task of planning reservoir operation and flood routing which triggered the need of improvement in the model.

The main aim of the study is to find whether inclusion of flood spill along headrace tunnels and diversions will help to improve flood forecasting simulation results in the model. Data were collected from NVE, Statkraft, and Hydro Power Company for input in the model. It was also an important task to calculate capacities of brook intakes in the model. During the process, the decision was made to use outlet from Skarsfoss dam downstream of Møsvatn dam as inflow to Tinnsjø. The simulation was performed for historical flood events with existing data and new data believed to improve the simulation results by using FMTV model.

The results show that the model is performing well for Tinnsjø and Heddalsvatn during large and medium flood events. The simulation results for Tinnsjø is better after selecting Skarsfoss outlet instead of Møsvatn during these flood events. The inclusion of spill from dam and brook intakes along headrace tunnel improved the flood forecasting simulation results during large flood events for Tinnsjø. The final result obtained still have some flow missing which is due to underestimation of local flow by the model during large flood events. For Heddalsvatn, the simulation results seem to be good for all flood events, but it is a good idea to do further study in scaling factors for better results. The model fails to provide good flood forecasting simulation results for Norsjø even after inclusion of spill from Vrangfoss as inflow to Norsjø. The reason for this is an error in FMTV model which suggest a revision of outlet curve and volume curve being used by the model is necessary. The local inflows computed with existing data also seem to have negative values providing doubt over the existing data. The flow from Sauarelva is believed to be actual flow trusting simulation results provided by the model for Heddalsvatn which can also be source of error for these negative inflows in Norsjø during manual calculation. The flood forecasting results for Hjellevatn for all flood events show that the model is impossible to provide reliable results until there is a good reliable data station available upstream and equally important to have some way of measurement of outflow in the downstream.

In conclusion, the replacement of outflow from Møsvatn dam to Skarsfoss dam as inflow to Tinnsjø seems to provide good simulation results for Tinnsjø. The spill along headrace tunnel appears to be a major reason behind underperformance of FMTV model. It is necessary to include these spill during any attempt to improve the model further.

10.2. Recommendations

The recommendations based on the present study experience are:

1. It is a need to redefine the scaling factor for predicting actual local inflows to the reservoirs. For Tinnsjø and Heddalsvatn the re-adjustment of scaling factor can prove sufficient but for Norsjø and Hjellevatn brief study is necessary.
2. FMTV model seems to have failed completely for Norsjø. It has encountered error, so it is a need to revise outlet curve and volume curve. It is also necessary to repair and update the model for new changes before re-use of this software.
3. It is important to change Møsvatn tapping with Skarsfoss tapping as water from Møsvatn spill, and Frøystul power plant ends up in Skarsfoss dam and result are better when considering Skarsfoss tapping.
4. It is important to consider spill from brook intakes from Mår hydropower system during flood forecasting simulation in future.

REFERENCES

Alfredsen, K., et al. (2008). A Flood-Forecasting System for Skiensvassdraget, Norway. S. M. G. Oli Gretar Blöndal Sveinsson, and Sigurlaug Gunnlaugsdottir. Reyjavik, Iceland, Norwegian University of Science and Technology, NVE, ØTB. **2**.

Alfredsen, K. and B. Sæther (2000). An object-oriented application framework for building water resource information and planning tools applied to a flood analysis system. Environmental Modelling and Software**:** 215-224.

Atlas (2016). 1000 arsflom, NVE**:** Vassatlas for Telemark.

Bergström, S. and A. Forsman (1973). "Development of a conceptual deterministic rainfall-runoff model." Hydrology Research **4**(3): 147-170.

Booch, G. (1996). Object Oriented Analysis and Design with Applications. Redwood City, CA.

Council, W. T. (2016). "Facts about Telemark and Norway." Retrieved 02.05.2016, 2016, from http://www.vest-telemark.no/Aktoer/123/Schoolproject/Learn-about-Norway-and-Telemark/Facts-about-Telemark-and-Norway.

Fjeld, M. and S. Aam (1980). "An implementation of estimation techniques to a hydrological model for prediction of runoff to a hydroelectric power station." Automatic Control, IEEE Transactions on **25**(2): 151-163.

Gamma, E., Helm, R., Johnson, R., Vlissides, J. (1995). Design Patterns. Reading, Mass.

Killingtveit, Å. and N.R.Sælthun (1995). Hydrology. Hydropower Development. D. K. Lysne. N-7034 Trondheim, Norwegian Institute of Technology: Division of Hydraulic Engineering. **7:** 103-125, 127-137.

Lysne, D. K., et al. (2003). Hydraulic design, Norwegian University of Science and Technology, Department of Hydraulic and Environmental Engineering.

Mahat, V. (2006). Flood Forecasting Model for the Telemark Water Course, NTNU. **Masters:** 96.

Maidment, D., Mays, L. Chow, V. (1988.). Applied Hydrology. McGraw Hill, New York.

Marahatta, S. (2015). Impact of Climate Change on Hydropower Potential in the Koshi Basin, Nepal. Hydraulic and Environmental Engineering. Trondheim, Norwegian University of Science and Technology. **Masters:** 88.

NVE, A. (2015). "Vassdrag - Nedbørfelt - Regine-enhet." Retrieved 24.04.2016, from http://atlas.nve.no/SilverlightViewer/?Viewer=NVEAtlas.

NVE, A. (2016). "Vannkraft- Utbygd vannkraft database." Retrieved 24/02/2016, from http://atlas.nve.no/SilverlightViewer/?Viewer=NVEAtlas.

NVE, A. (2016). "Vassdrag-Innsjødatabase." Retrieved 24.04.2015, from http://atlas.nve.no/SilverlightViewer/?Viewer=NVEAtlas.

Samuels, P. G. (1999). River Basin Modelling, Management and Flood Mitigation. Report SR 551. HR Wallingford, UK.**:** 1.

Shreedhar, M. (2004). Modelling Uncertainty in Flood Forecasting Systems. Netherland, Delft University of Technology. **Doctor:** 146.

Sæther, B. (1996). An object-oriented toolkit for time series handling. Proceedings of the Second International Conference on Hydroinformatics, Zurich, Switzerland, September.

Ødegård, N. (1996). Mår Kraftverk Bekkeinntakene på Tilløåstunnelen - Kapasitetsvurdering, Adv. Engergi-og Vassdragsutbygging**:** 14.

APPENDICES

Appendix A: Volume and Outlet Curve for Norsjø, and Gauging Stations

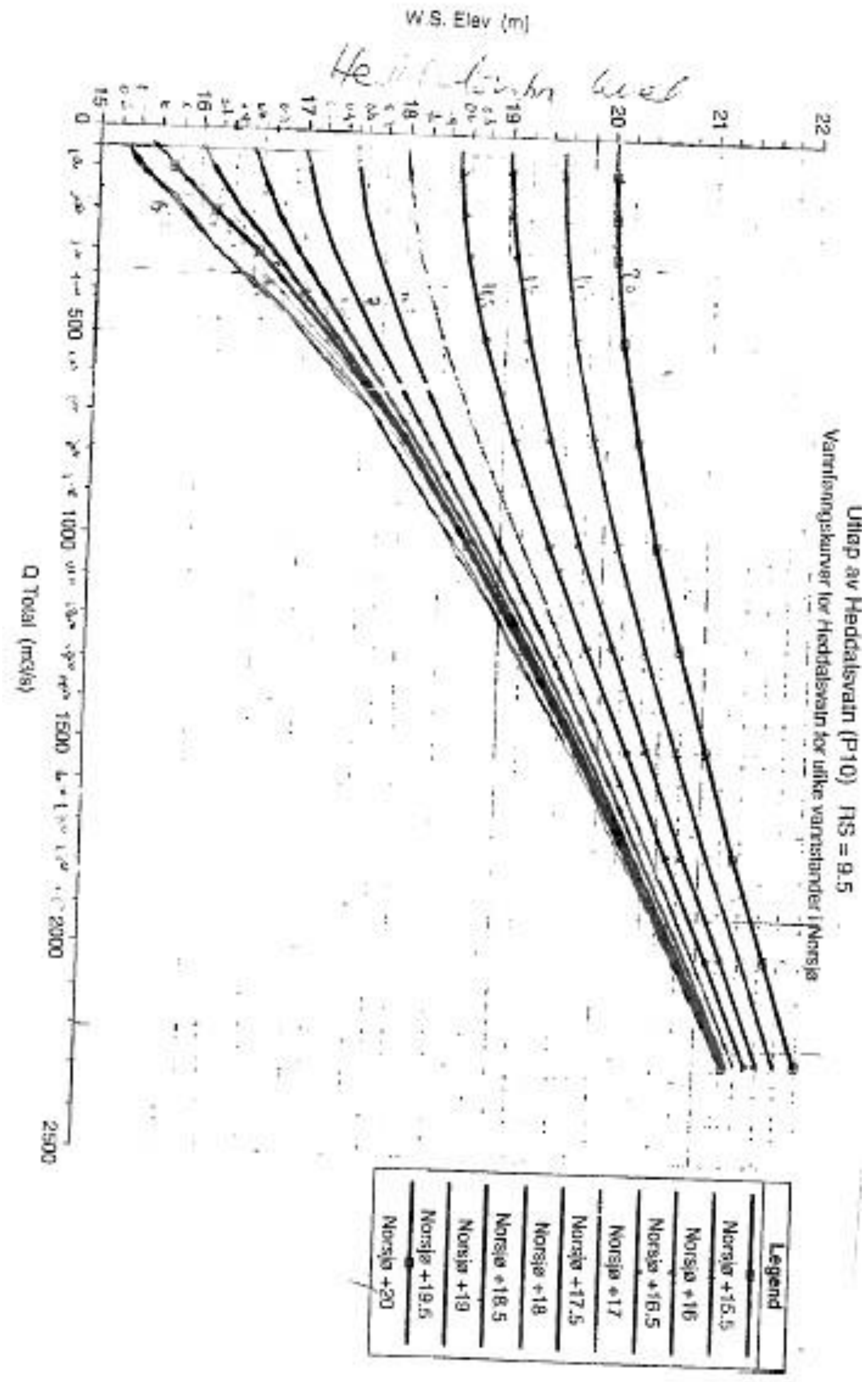
Appendix A (Table)- 1: Relation for Volume and Outlet Curve for Norsjø

Table:Relation for Volume Curve for Norsjø	
Water Level	Volume
(m)	(m^3)
15	0
15.15	0
15.24	13310000
15.36	139500000
19.3	240000000
23.3	480000000

Table: Relation for Outlet Curve for Norsjø	
Water Level	Outlet
(m)	(m^3/s)
15.15	0
15.21	0
15.32	384
15.97	1000
17.07	1500
17.6	2000
18.28	2500
18.9	3000

TAppendix A (Table)- 2: Gauging Station with their code

Station	**Code**
Kirkevoll Bru	16.23.0
Strengen	16.142.0
Møsvatn Langhol	16.19.0
Omnesfoss	16.10.0
Hagadrag	16.51.0
Skotfoss	16.133.0
Farelva	16.497.0
Nottoden	16.1.0



Appendix A- 1: Discharge in Saurelva depending on Norsjø and Hjellevatn water level.

Appendix B: Runoff Calculation

Appendix B(Table)- 1. Calculation of Runoff of Skotfoss from Falkumelva

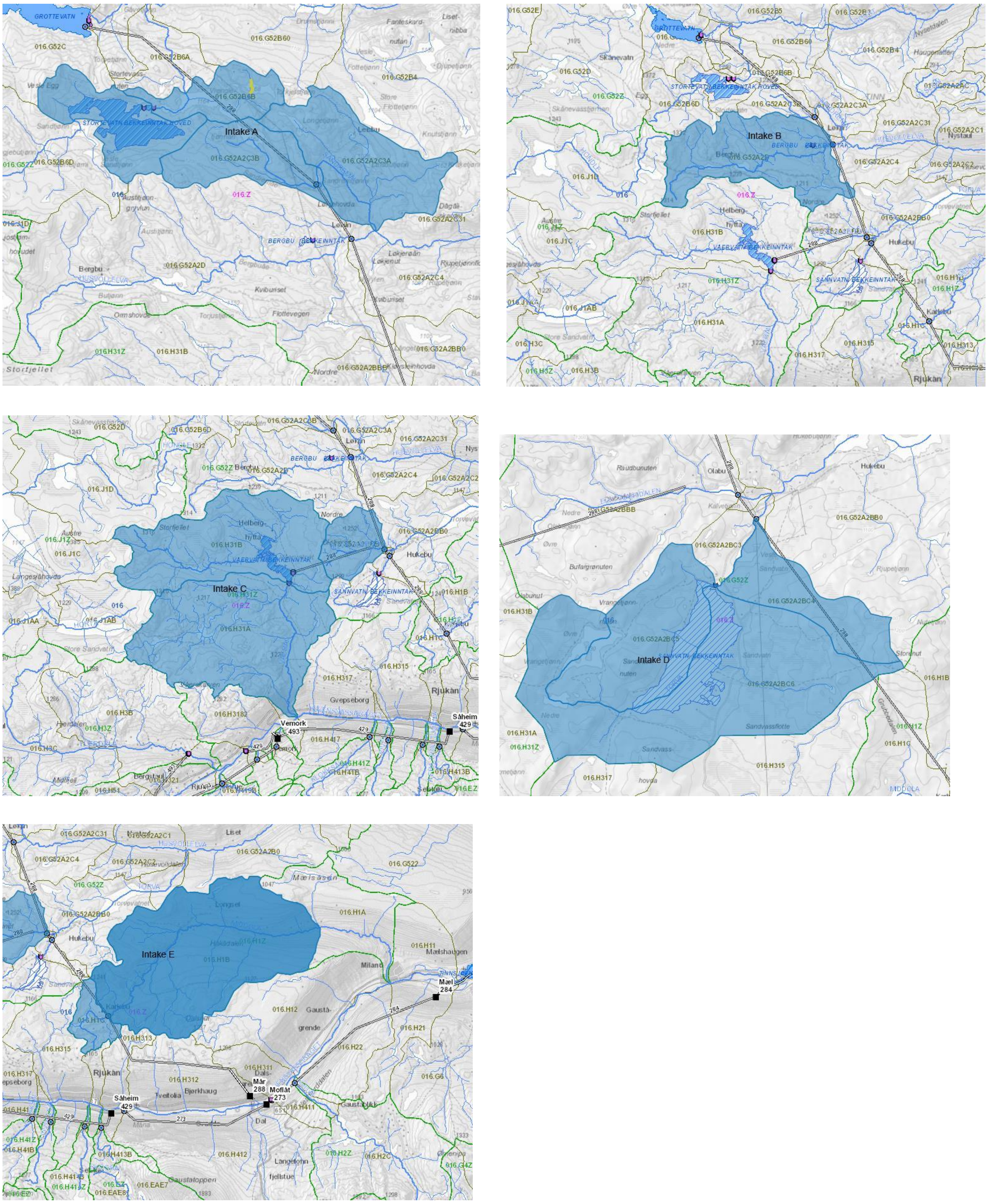
Date	Skotfoss tapping	Kileåi Runoff	Falkumelva Runoff	Hjellevatn Tapping
	(m3/s)	(m3/s)	(m3/s)	(m3/s)
01.01.2013	240	0.9	2.44	242.44
02.01.2013	238.17	0.9	2.44	240.61
03.01.2013	236.33	0.9	2.44	238.77
04.01.2013	234.5	0.9	2.44	236.94
05.01.2013	232.67	1	2.72	235.39
06.01.2013	230.83	1	2.72	233.55
07.01.2013	229	1	2.72	231.72
08.01.2013	265	1	2.72	267.72
09.01.2013	290	1	2.72	292.72
10.01.2013	300	0.9	2.44	302.44
11.01.2013	290	0.9	2.44	292.44
12.01.2013	285	0.8	2.17	287.17
13.01.2013	300	0.7	1.90	301.90
14.01.2013	288	0.7	1.90	289.90
15.01.2013	287	0.7	1.90	288.90
16.01.2013	294	0.6	1.63	295.63
17.01.2013	283	0.6	1.63	284.63
18.01.2013	289	0.6	1.63	290.63
19.01.2013	283	0.6	1.63	284.63
20.01.2013	285	0.6	1.63	286.63
21.01.2013	291	0.5	1.36	292.36
22.01.2013	310	0.5	1.36	311.36
23.01.2013	298	0.5	1.36	299.36
24.01.2013	283	0.5	1.36	284.36
25.01.2013	268	0.4	1.09	269.09
26.01.2013	250	0.4	1.09	251.09
27.01.2013	242	0.5	1.36	243.36
28.01.2013	277	0.5	1.36	278.36
29.01.2013	283	0.5	1.36	284.36
30.01.2013	290	0.5	1.36	291.36
31.01.2013	247	0.5	1.36	248.36

Gauged Station	**Catchment Area (Km2)**	**Specific Runoff**
Austbygdåi	344.6	24.77
Hørte	157	
Kileåi	118.5	20.11
Falkumelva	304.16	21.28
Scaling factor K		2.72

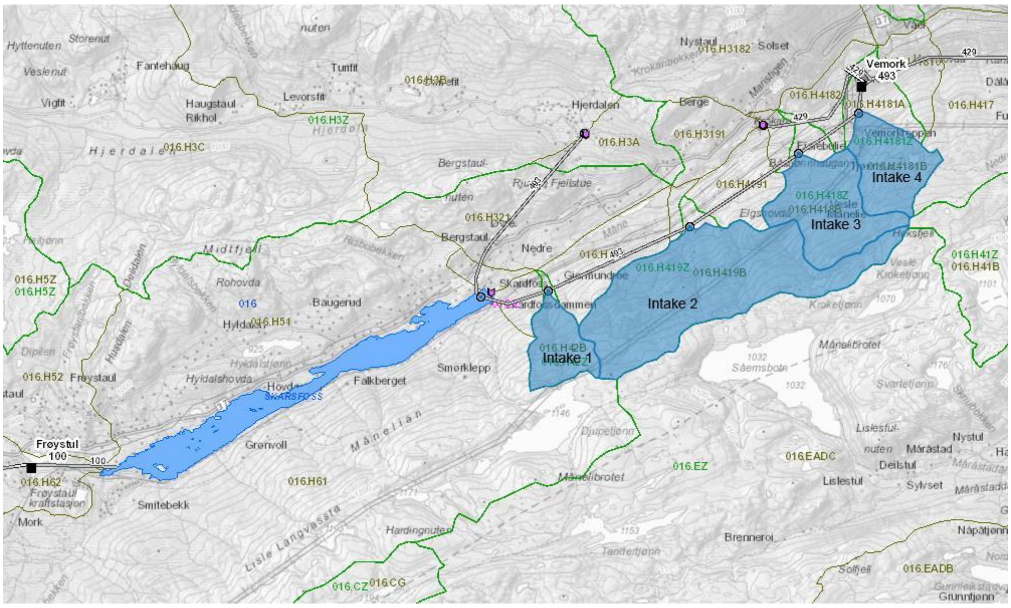
Falkumelva Runoff = K* Kileåi Runoff

Hjellevatn Tapping= Falkumelva +skotfoss

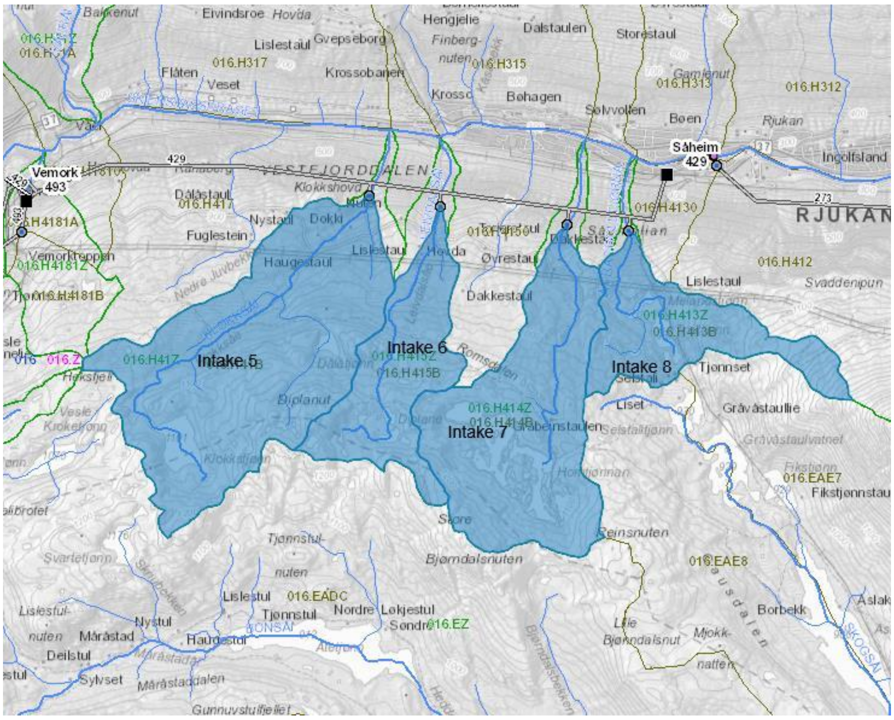
Appendix C: Brook Intakes



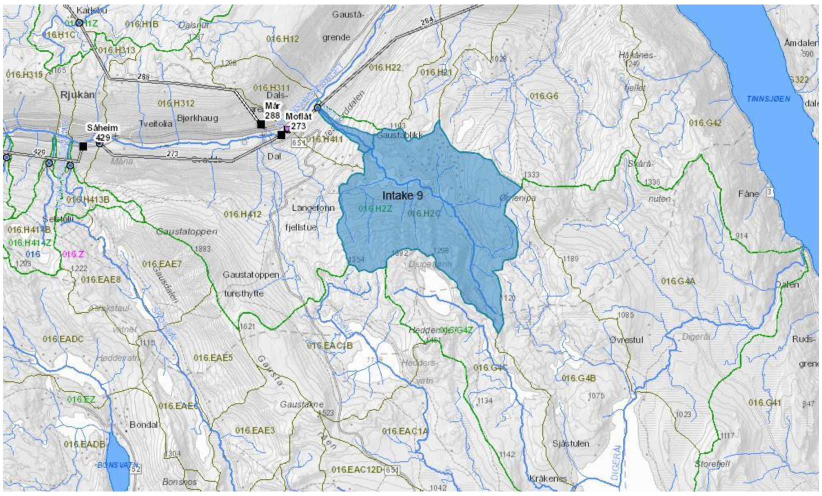
Appendix C 1: Intakes with Catchment along Headrace Tunnel from Mårvatn to Mår Power Plant



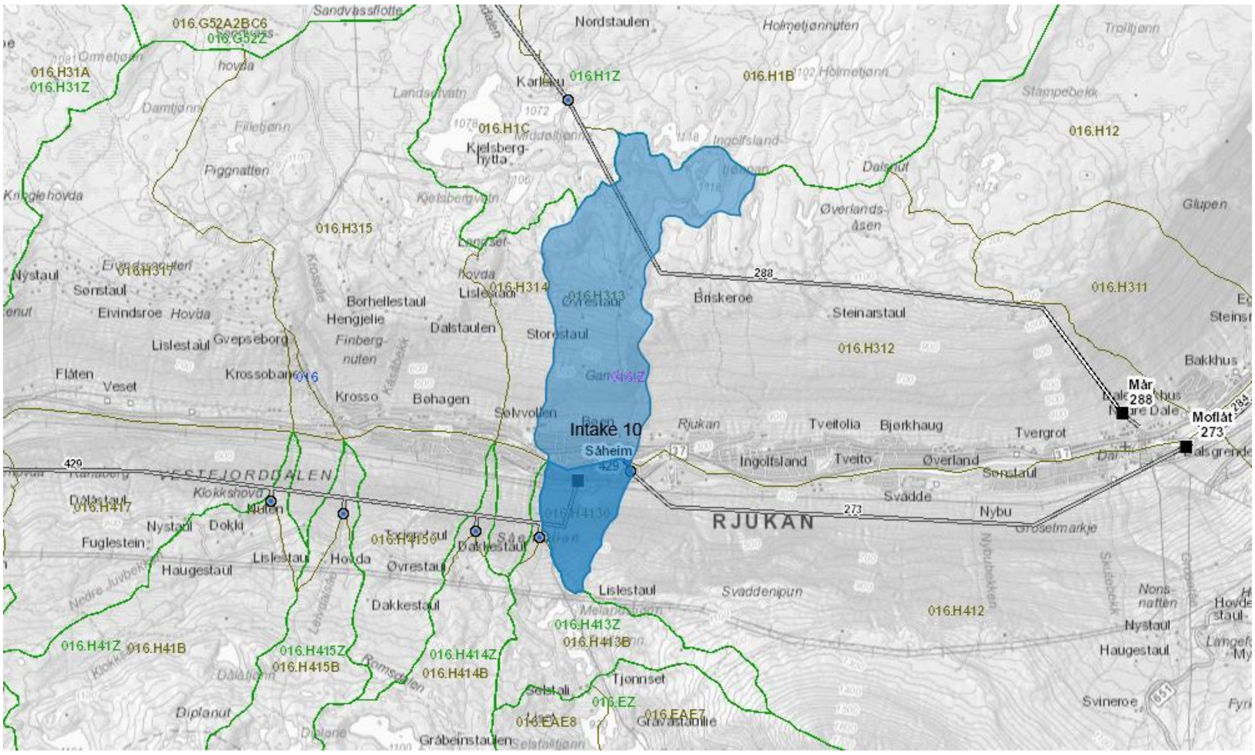
Appendix C 2: Intakes along Tunnel from Frøystul to Vemork Power Plant



Appendix C 3: Intakes along Vemork to Såheim Power Plant



Appendix C 4: Intakes along Moflåt to Møel Power Plant



Appendix C 5: Intake along Såheim to Moflåt

Intake A = Scaling Factor * Austbygdåi

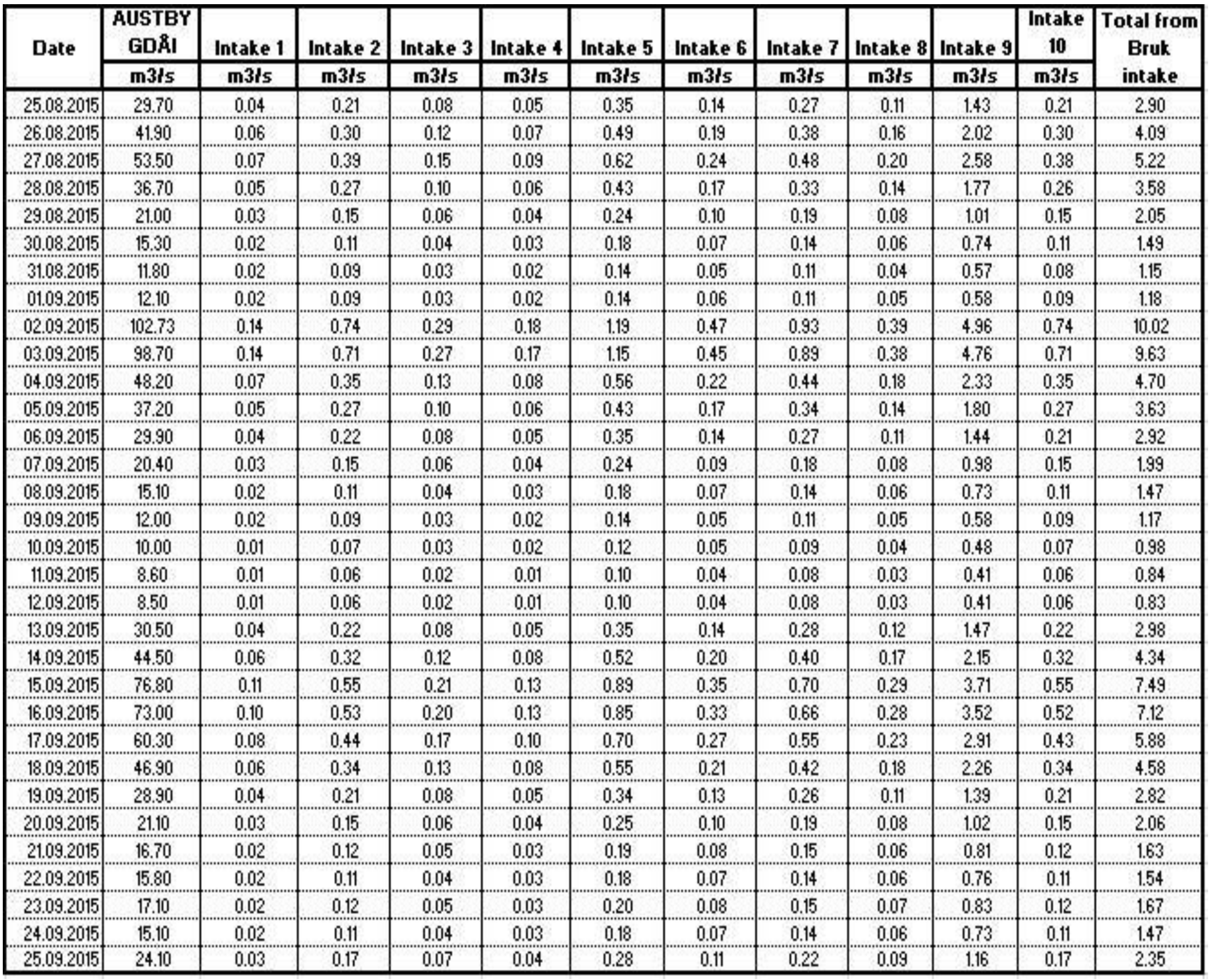
Total=Intake A + Intake B + Intake C +Intake D + Intake E

Appendix C(Table)- 1: Intake capacity of Brook Intake along headrace tunnel in Mår

Date	AUSTBYGDÅI	Intake A	Intake B	Intake C	Intake D	Intake E	Total from Brook intake (m3/s)
	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	
25.08.2015	29.70	0.856	1.083	3.471	0.327	2.641	8.377
26.08.2015	41.90	1.207	1.527	4.896	0.462	3.726	11.819
27.08.2015	53.50	1.542	1.950	6.252	0.590	4.757	15.091
28.08.2015	36.70	1.058	1.338	4.289	0.405	3.263	10.352
29.08.2015	21.00	0.605	0.765	2.454	0.231	1.867	5.923
30.08.2015	15.30	0.441	0.558	1.788	0.169	1.360	4.316
31.08.2015	11.80	0.340	0.430	1.379	0.130	1.049	3.328
01.09.2015	12.10	0.349	0.441	1.414	0.133	1.076	3.413
02.09.2015	102.73	2.961	3.745	12.005	1.132	9.135	28.978
03.09.2015	98.70	2.844	3.598	11.534	1.088	8.777	27.841
04.09.2015	48.20	1.389	1.757	5.633	0.531	4.286	13.596
05.09.2015	37.20	1.072	1.356	4.347	0.410	3.308	10.493
06.09.2015	29.90	0.862	1.090	3.494	0.330	2.659	8.434
07.09.2015	20.40	0.588	0.744	2.384	0.225	1.814	5.754
08.09.2015	15.10	0.435	0.550	1.765	0.166	1.343	4.259
09.09.2015	12.00	0.346	0.437	1.402	0.132	1.067	3.385
10.09.2015	10.00	0.288	0.364	1.169	0.110	0.889	2.821
11.09.2015	8.60	0.248	0.313	1.005	0.095	0.765	2.426
12.09.2015	8.50	0.245	0.310	0.993	0.094	0.756	2.398
13.09.2015	30.50	0.879	1.112	3.564	0.336	2.712	8.603
14.09.2015	44.50	1.282	1.622	5.200	0.490	3.957	12.552
15.09.2015	76.80	2.213	2.799	8.975	0.846	6.829	21.663
16.09.2015	73.00	2.104	2.661	8.531	0.805	6.491	20.591
17.09.2015	60.30	1.738	2.198	7.047	0.665	5.362	17.009
18.09.2015	46.90	1.352	1.709	5.481	0.517	4.170	13.229
19.09.2015	28.90	0.833	1.053	3.377	0.319	2.570	8.152
20.09.2015	21.10	0.608	0.769	2.466	0.233	1.876	5.952
21.09.2015	16.70	0.481	0.609	1.952	0.184	1.485	4.711
22.09.2015	15.80	0.455	0.576	1.846	0.174	1.405	4.457
23.09.2015	17.10	0.493	0.623	1.998	0.188	1.521	4.823
24.09.2015	15.10	0.435	0.550	1.765	0.166	1.343	4.259
25.09.2015	24.10	0.695	0.878	2.816	0.266	2.143	6.798

Intake 1= Scaling Factor *Austbygdåi Runoff

Appendix C(Table)- 2: Intake capacity of Brook Intake along headrace tunnel in Møsvatn



Date	AUSTBY GDÅI	Intake 1	Intake 2	Intake 3	Intake 4	Intake 5	Intake 6	Intake 7	Intake 8	Intake 9	Intake 10	Total from Bruk intake
	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	m3/s	
25.08.2015	29.70	0.04	0.21	0.08	0.05	0.35	0.14	0.27	0.11	1.43	0.21	2.90
26.08.2015	41.90	0.06	0.30	0.12	0.07	0.49	0.19	0.38	0.16	2.02	0.30	4.09
27.08.2015	53.50	0.07	0.39	0.15	0.09	0.62	0.24	0.48	0.20	2.58	0.38	5.22
28.08.2015	36.70	0.05	0.27	0.10	0.06	0.43	0.17	0.33	0.14	1.77	0.26	3.58
29.08.2015	21.00	0.03	0.15	0.06	0.04	0.24	0.10	0.19	0.08	1.01	0.15	2.05
30.08.2015	15.30	0.02	0.11	0.04	0.03	0.18	0.07	0.14	0.06	0.74	0.11	1.49
31.08.2015	11.80	0.02	0.09	0.03	0.02	0.14	0.05	0.11	0.04	0.57	0.08	1.15
01.09.2015	12.10	0.02	0.09	0.03	0.02	0.14	0.06	0.11	0.05	0.58	0.09	1.18
02.09.2015	102.73	0.14	0.74	0.29	0.18	1.19	0.47	0.93	0.39	4.96	0.74	10.02
03.09.2015	98.70	0.14	0.71	0.27	0.17	1.15	0.45	0.89	0.38	4.76	0.71	9.63
04.09.2015	48.20	0.07	0.35	0.13	0.08	0.56	0.22	0.44	0.18	2.33	0.35	4.70
05.09.2015	37.20	0.05	0.27	0.10	0.06	0.43	0.17	0.34	0.14	1.80	0.27	3.63
06.09.2015	29.90	0.04	0.22	0.08	0.05	0.35	0.14	0.27	0.11	1.44	0.21	2.92
07.09.2015	20.40	0.03	0.15	0.06	0.04	0.24	0.09	0.18	0.08	0.98	0.15	1.99
08.09.2015	15.10	0.02	0.11	0.04	0.03	0.18	0.07	0.14	0.06	0.73	0.11	1.47
09.09.2015	12.00	0.02	0.09	0.03	0.02	0.14	0.05	0.11	0.05	0.58	0.09	1.17
10.09.2015	10.00	0.01	0.07	0.03	0.02	0.12	0.05	0.09	0.04	0.48	0.07	0.98
11.09.2015	8.60	0.01	0.06	0.02	0.01	0.10	0.04	0.08	0.03	0.41	0.06	0.84
12.09.2015	8.50	0.01	0.06	0.02	0.01	0.10	0.04	0.08	0.03	0.41	0.06	0.83
13.09.2015	30.50	0.04	0.22	0.08	0.05	0.35	0.14	0.28	0.12	1.47	0.22	2.98
14.09.2015	44.50	0.06	0.32	0.12	0.08	0.52	0.20	0.40	0.17	2.15	0.32	4.34
15.09.2015	76.80	0.11	0.55	0.21	0.13	0.89	0.35	0.70	0.29	3.71	0.55	7.49
16.09.2015	73.00	0.10	0.53	0.20	0.13	0.85	0.33	0.66	0.28	3.52	0.52	7.12
17.09.2015	60.30	0.08	0.44	0.17	0.10	0.70	0.27	0.55	0.23	2.91	0.43	5.88
18.09.2015	46.90	0.06	0.34	0.13	0.08	0.55	0.21	0.42	0.18	2.26	0.34	4.58
19.09.2015	28.90	0.04	0.21	0.08	0.05	0.34	0.13	0.26	0.11	1.39	0.21	2.82
20.09.2015	21.10	0.03	0.15	0.06	0.04	0.25	0.10	0.19	0.08	1.02	0.15	2.06
21.09.2015	16.70	0.02	0.12	0.05	0.03	0.19	0.08	0.15	0.06	0.81	0.12	1.63
22.09.2015	15.80	0.02	0.11	0.04	0.03	0.18	0.07	0.14	0.06	0.76	0.11	1.54
23.09.2015	17.10	0.02	0.12	0.05	0.03	0.20	0.08	0.15	0.07	0.83	0.12	1.67
24.09.2015	15.10	0.02	0.11	0.04	0.03	0.18	0.07	0.14	0.06	0.73	0.11	1.47
25.09.2015	24.10	0.03	0.17	0.07	0.04	0.28	0.11	0.22	0.09	1.16	0.17	2.35

Appendix D: Procedure to use FMTV and Dataset for FMTV

Appendix D1

Procedure for simulating historical events with FMTV

To run a simulation for a historical flood-event you must first define:

- the start date of the flood event,
- the end date of the flood event,
- the start date for the HBV-run-up period before the flood event,
- the start date for the Reservoir-run-up period
- the end date for the Reservoir-run-up period
- the start date for the Reservoir-forecast period
- the end date for the Reservoir-forecast period

The end dates for the HBV-runup and forecast periods can be long after the end-date of the flood event you want to simulate. The HBV- simulations must only cover from before the start of the flood event (typically from the start of the previous hydrological year) to after the end of the flood event.

All three HBV-forecasts (for Austbygdaai, Hoerte, and Kilaai) must be simulated with identical Run-up periods that starts before the beginning of flood event and ends after the end of the flood event.

Run-up period and forecast period for the lake level simulation must thereafter be specified. The simulated HBV-data is then loaded into the dialog, and the rest of the columns must be filled with the data you prepare before the lake level simulation can be run.

In this procedure I describe how to do a historical simulation of the September 2015 flood-event, as an example. Here I assume:

- start date of the flood event = 04.09.2015,
- end date of the flood event = 24.09.2015,
- start date for the HBV-run-up period before the flood event = 01.09.2014,
- start date for the Reservoir-run-up period = 04.09.2015,
- end date for the Reservoir-run-up period = 14.09.2015,
- start date for the Reservoir-forecast period = 15.09.2015,
- end date for the Reservoir-forecast period = 24.09.2015,

Other flood events can be simulated in the same manner, only changing the dates.

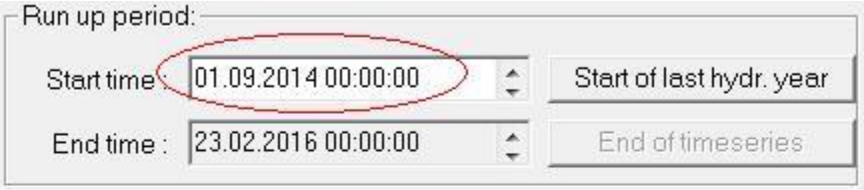
Procedure:

1. Start FMTV by doubleclicking on the -icon.
2. Load setup by clicking on Oppsett (Setup) and then Åpne (Open) and selecting the file *Telemarksvassdraget.hpm* under the setup-folder.

3. Then select Prognoser Tilsig (Forecast inflow) and Run to the right of the first cactchment (Austbygdaai).

4) Select Forecast in the main HBV-window.

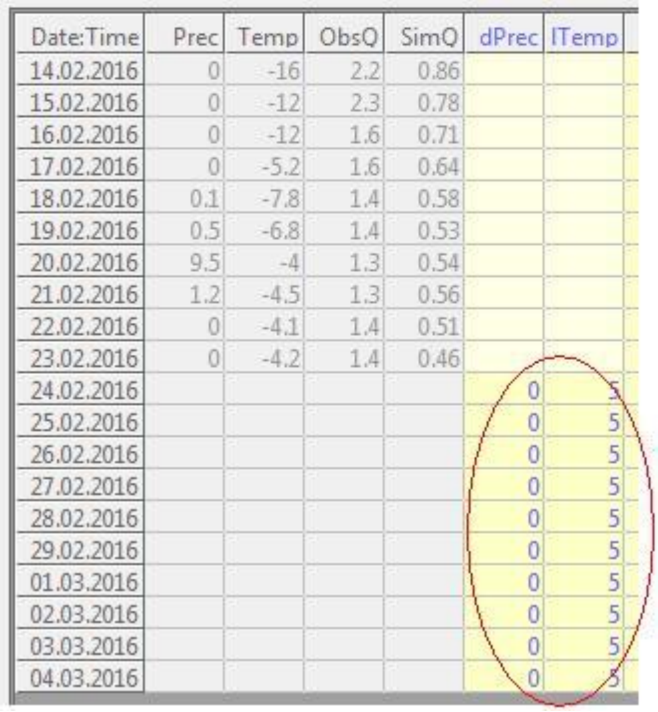
5) In the “Run Predictions” dialog you must specify a Run-up period that starts before the beginning of the flood event (typically at the beginning of the hydrological year, the year before the event).


Run up period:
Start time 01.09.2014 00:00:00
End time : 23.02.2016 00:00:00

For the time being the “End date” will just have to be kept at the last timestep in the input-file. (This doesn’t matter since this will be past the end of the flood-event, but if it turns out to be a problem I will look at this later.)

The other dates can be left at their default values.

6) In the columns for forecasted precip and temp, you just fill in dummy values for the forecast period.



Date:Time	Prec	Temp	ObsQ	SimQ	dPrec	lTemp
14.02.2016	0	-16	2.2	0.86		
15.02.2016	0	-12	2.3	0.78		
16.02.2016	0	-12	1.6	0.71		
17.02.2016	0	-5.2	1.6	0.64		
18.02.2016	0.1	-7.8	1.4	0.58		
19.02.2016	0.5	-6.8	1.4	0.53		
20.02.2016	9.5	-4	1.3	0.54		
21.02.2016	1.2	-4.5	1.3	0.56		
22.02.2016	0	-4.1	1.4	0.51		
23.02.2016	0	-4.2	1.4	0.46		
24.02.2016					0	5
25.02.2016					0	5
26.02.2016					0	5
27.02.2016					0	5
28.02.2016					0	5
29.02.2016					0	5
01.03.2016					0	5
02.03.2016					0	5
03.03.2016					0	5
04.03.2016					0	5

This is because it is not the period from the end of the data-series and onwards that is of interest to us now.

7) The click on Run forecasts to generate the forecast-simulation file (wich is input to the hydraulic model)

8) Repeat steps 3 – 7 for the two other catchments, Hoerte and Kilaai, so that you create forecast-simulation files with exactly the same start-dates and end-dates for all the three catchments.

9) Close the "Prognoser Tilsig"-dialog, and go back to FMTV-main window.

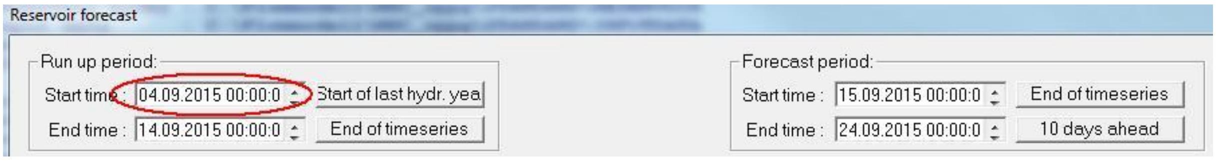
10) Then select Prognoser Magasin (Forecast Reservoir) to open the "Reservoir Forecast"-dialog.

11) If your HBV-forecasting now is performed correctLY, you should see identical "Runup-from", "Runup to" and "Forecast to" dates in the input consistency-control frame, like is shown below:

HBV prognoser:

	Runup from :	Runup to :	Forecast to :	High prc ☑	Low prc ☑	High tmp ☑	Low tmp ☑	Prediction years:
Austbygdaai	01.09.2014	24.02.2016	05.03.2016	✓	✓	✓	✓	
Hoerte	01.09.2014	24.02.2016	05.03.2016	✓	✓	✓	✓	
Kilaai	01.09.2014	24.02.2016	05.03.2016	✓	✓	✓	✓	
-								
-								

12) Then specify the start time for the Reservoir-run-up period (a date that is after the start of the HBV-run-up period and before the start of the flood event).

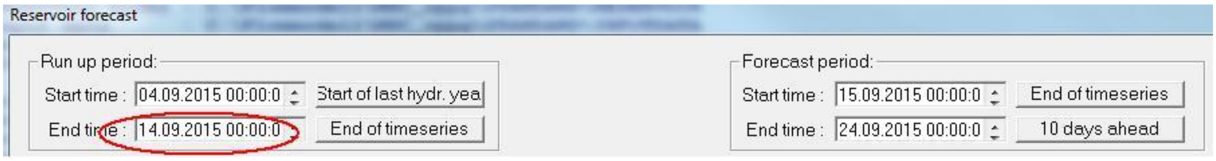


Reservoir forecast

Run up period:
Start time : 04.09.2015 00:00:0
End time : 14.09.2015 00:00:0

Forecast period:
Start time : 15.09.2015 00:00:0
End time : 24.09.2015 00:00:0

13) Specify the end time for the Reservoir-run-up period (the date of the start of the flood event).

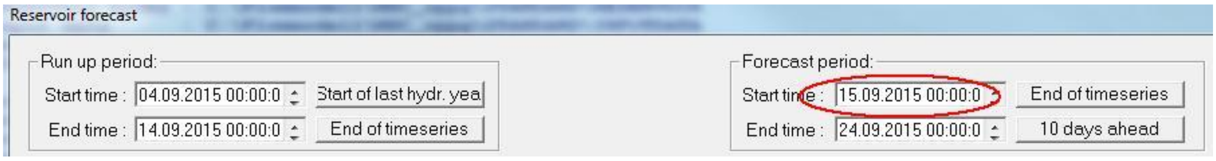


Reservoir forecast

Run up period:
Start time : 04.09.2015 00:00:0
End time : 14.09.2015 00:00:0

Forecast period:
Start time : 15.09.2015 00:00:0
End time : 24.09.2015 00:00:0

14) The start time for the Reservoir-forecast will automatically be set to the next day.

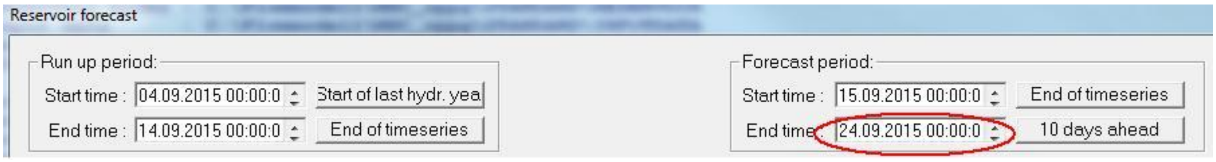


Reservoir forecast

Run up period:
Start time : 04.09.2015 00:00:0
End time : 14.09.2015 00:00:0

Forecast period:
Start time : 15.09.2015 00:00:0
End time : 24.09.2015 00:00:0

15) Specify the end time for the Reservoir--forecast period (f.ex. the date of the end of the flood event or later (but not later than the end date of the HBV-runup-period)).



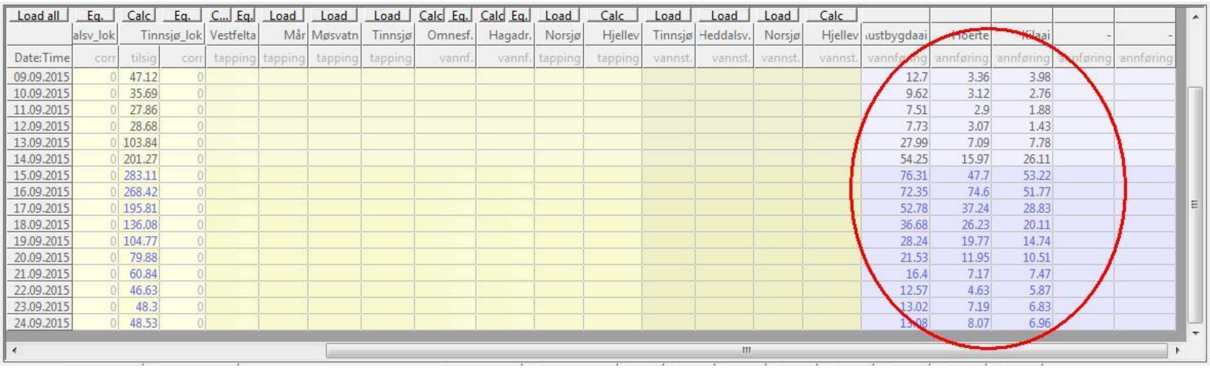
Reservoir forecast

Run up period:
Start time : 04.09.2015 00:00:0
End time : 14.09.2015 00:00:0

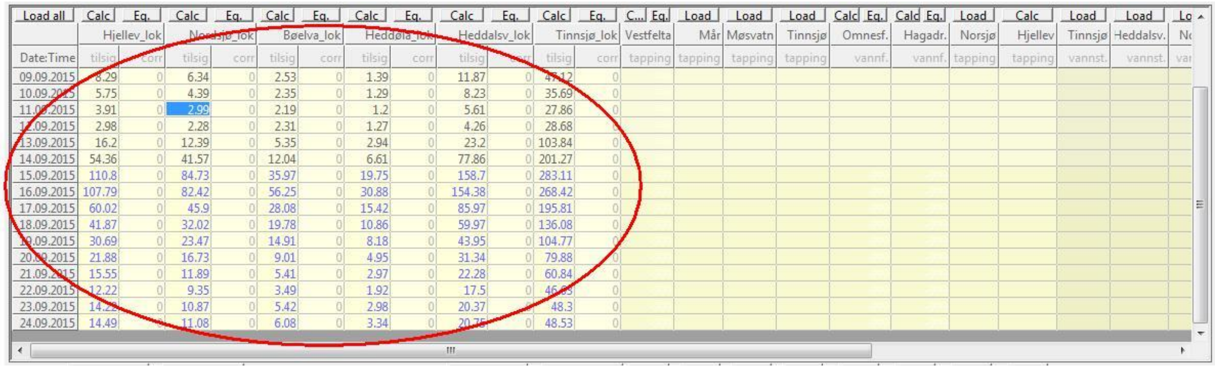
Forecast period:
Start time : 15.09.2015 00:00:0
End time : 24.09.2015 00:00:0

NB! Move out of the date-time field when finished typing in the end-date so that the new date specification becomes activated and the reservoir-input-data table below is rezised according to the length of the runup and forecast periods specified (i.e. click someplace outside the date-time field or hit the Tab-key to move on to the next control).

16) Then click on Load all (left corner above the table). The simulated HBV-runoffs from the three catchments will then be loaded into the columns to the extreme right in the table (scroll horizontally to the right to see the HBV-flow values).



	alsv_lok	Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø	Heddalsv.	Norsjø	Hjellev	ustbygdaai	Hoerte	Kilaai	-	-
Date:Time	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.	vannst.	vannst.	vannst.	vannføring	annføring	annføring	annføring	annføring
09.09.2015	0	47.12	0													12.7	3.36	3.98		
10.09.2015	0	35.69	0													9.62	3.12	2.76		
11.09.2015	0	27.86	0													7.51	2.9	1.88		
12.09.2015	0	28.68	0													7.73	3.07	1.43		
13.09.2015	0	103.84	0													27.99	7.09	7.78		
14.09.2015	0	201.27	0													54.25	15.97	26.11		
15.09.2015	0	283.11	0													76.31	47.7	53.22		
16.09.2015	0	268.42	0													72.35	74.6	51.77		
17.09.2015	0	195.81	0													52.78	37.24	28.83		
18.09.2015	0	136.08	0													36.68	26.23	20.11		
19.09.2015	0	104.77	0													28.24	19.77	14.74		
20.09.2015	0	79.88	0													21.53	11.95	10.51		
21.09.2015	0	60.84	0													16.4	7.17	7.47		
22.09.2015	0	46.63	0													12.57	4.63	5.87		
23.09.2015	0	48.3	0													13.02	7.19	6.83		
24.09.2015	0	48.53	0													13.08	8.07	6.96		

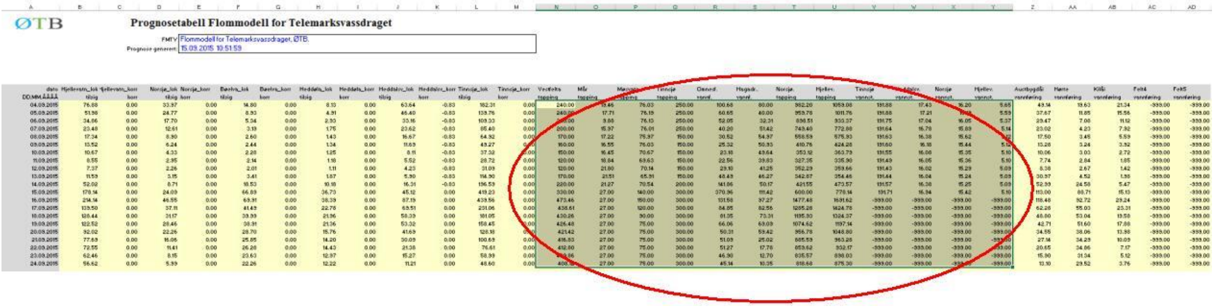


	Hjellev_lok		Norsjø_lok		Bøelva_lok		Heddøla_lok		Heddalsv_lok		Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø	Heddalsv.
Date:Time	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.	vannst.
09.09.2015	8.29	0	6.34	0	2.53	0	1.39	0	11.87	0	47.12	0										
10.09.2015	5.75	0	4.39	0	2.35	0	1.29	0	8.23	0	35.69	0										
11.09.2015	3.91	0	2.99	0	2.19	0	1.2	0	5.61	0	27.86	0										
12.09.2015	2.98	0	2.28	0	2.31	0	1.27	0	4.26	0	28.68	0										
13.09.2015	16.2	0	12.39	0	5.35	0	2.94	0	23.2	0	103.84	0										
14.09.2015	54.36	0	41.57	0	12.04	0	6.61	0	77.86	0	201.27	0										
15.09.2015	110.8	0	84.73	0	35.97	0	19.75	0	158.7	0	283.11	0										
16.09.2015	107.79	0	82.42	0	56.25	0	30.88	0	154.38	0	268.42	0										
17.09.2015	60.02	0	45.9	0	28.08	0	15.42	0	85.97	0	195.81	0										
18.09.2015	41.87	0	32.02	0	19.78	0	10.86	0	59.97	0	136.08	0										
19.09.2015	30.69	0	23.47	0	14.91	0	8.18	0	43.95	0	104.77	0										
20.09.2015	21.88	0	16.73	0	9.01	0	4.95	0	31.34	0	79.88	0										
21.09.2015	15.55	0	11.89	0	5.41	0	2.97	0	22.28	0	60.84	0										
22.09.2015	12.22	0	9.35	0	3.49	0	1.92	0	17.5	0	46.63	0										
23.09.2015	14.22	0	10.87	0	5.42	0	2.98	0	20.37	0	48.3	0										
24.09.2015	14.49	0	11.08	0	6.08	0	3.34	0	20.75	0	48.53	0										

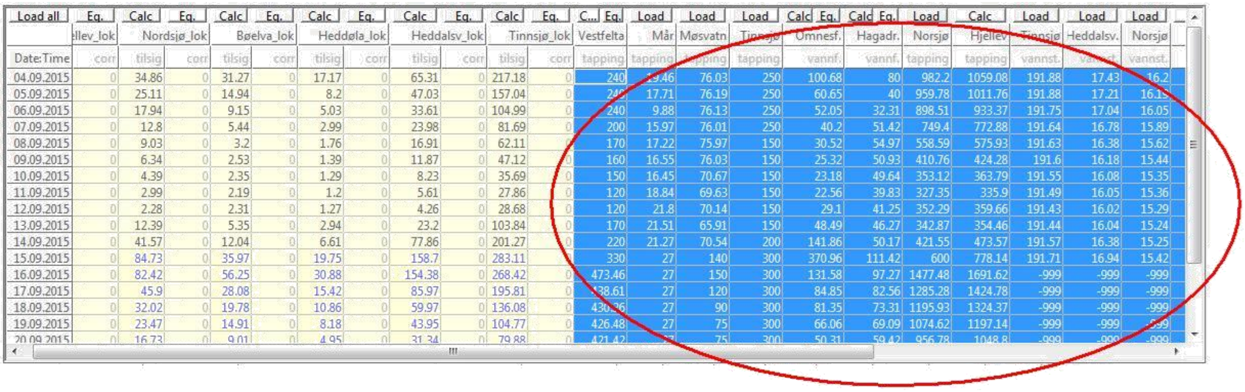
Also the flow values for the unregulated sub-catchments in the water system is filled in (left columns in the table). These values are scaled from the HBV-flow series.

17) The remaining columns (with yellow color) must be filled with data that you have prepared. For the September 2015 flood event this is easy since some flood-simulation reports have been stored and made available. In this example I use: FMTV_PROGNOSE20150918091415.xlsx.

18) Open FMTV_PROGNOSE20150918091415.xlsx and go to the "Tabell" sheet. Copy the columns "Vestfelta-tapping" (column N) to "Hjellev.-vannst" (column Y). (See also point 26.)



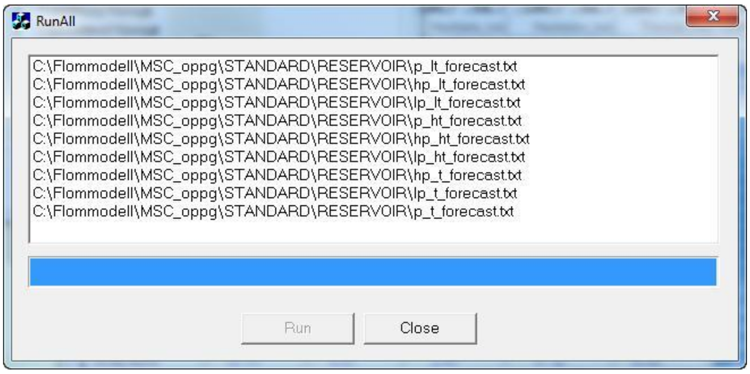
19) Paste the values into the table in the table in the "Reservoir forecast" dialog (i.e. select the upper left cell of those columns and hit SHIFT-Insert).



	llev_lok	Nordsjø_lok		Bøelva_lok		Heddøla_lok		Heddalsv_lok		Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø	Heddalsv.	Norsjø
Date:Time	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.	vannst.	vannst.
04.09.2015	0	34.86	0	31.27	0	17.17	0	65.31	0	217.18	0	240	19.46	76.03	250	100.68	80	982.2	1059.08	191.88	17.43	16.2
05.09.2015	0	25.11	0	14.94	0	8.2	0	47.03	0	157.04	0	240	17.71	76.19	250	60.65	40	959.78	1011.76	191.88	17.21	16.15
06.09.2015	0	17.94	0	9.15	0	5.03	0	33.61	0	104.99	0	240	9.88	76.13	250	52.05	32.31	898.51	933.37	191.75	17.04	16.05
07.09.2015	0	12.8	0	5.44	0	2.99	0	23.98	0	81.69	0	200	15.97	76.01	250	40.2	51.42	749.4	772.88	191.64	16.78	15.89
08.09.2015	0	9.03	0	3.2	0	1.76	0	16.91	0	62.11	0	170	17.22	75.97	150	30.52	54.97	558.59	575.93	191.63	16.38	15.62
09.09.2015	0	6.34	0	2.53	0	1.39	0	11.87	0	47.12	0	160	16.55	76.03	150	25.32	50.93	410.76	424.28	191.6	16.18	15.44
10.09.2015	0	4.39	0	2.35	0	1.29	0	8.23	0	35.69	0	150	16.45	70.67	150	23.18	49.64	353.12	363.79	191.55	16.08	15.35
11.09.2015	0	2.99	0	2.19	0	1.2	0	5.61	0	27.86	0	120	18.84	69.63	150	22.56	39.83	327.35	335.9	191.49	16.05	15.36
12.09.2015	0	2.28	0	2.31	0	1.27	0	4.26	0	28.68	0	120	21.8	70.14	150	29.1	41.25	352.29	359.66	191.43	16.02	15.29
13.09.2015	0	12.39	0	5.35	0	2.94	0	23.2	0	103.84	0	170	21.51	65.91	150	48.49	46.27	342.87	354.46	191.44	16.04	15.24
14.09.2015	0	41.57	0	12.04	0	6.61	0	77.86	0	201.27	0	220	21.27	70.54	200	141.86	50.17	421.55	473.57	191.57	16.38	15.25
15.09.2015	0	84.73	0	35.97	0	19.75	0	158.7	0	283.11	0	330	27	140	300	370.96	111.42	600	778.14	191.71	16.94	15.42
16.09.2015	0	82.42	0	56.25	0	30.88	0	154.38	0	268.42	0	473.46	27	150	300	131.58	97.27	1477.48	1691.62	-999	-999	-999
17.09.2015	0	45.9	0	28.08	0	15.42	0	85.97	0	195.81	0	438.61	27	120	300	84.85	82.56	1285.28	1424.78	-999	-999	-999
18.09.2015	0	32.02	0	19.78	0	10.86	0	59.97	0	136.08	0	430.26	27	90	300	81.35	73.31	1195.93	1324.37	-999	-999	-999
19.09.2015	0	23.47	0	14.91	0	8.18	0	43.95	0	104.77	0	426.48	27	75	300	66.06	69.09	1074.62	1197.14	-999	-999	-999
20.09.2015	0	16.73	0	9.01	0	4.95	0	31.34	0	79.88	0	421.42	[illegible]	75	300	50.31	59.42	956.78	1048.8	-999	-999	-999

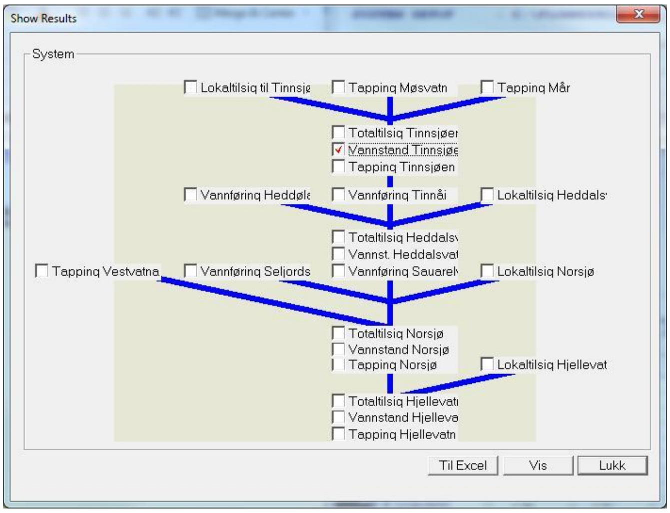
20) The data are now filled in, and you can perform a Lake-level simulation by clicking on Beregn vannstander (calculate water levels), and then on Run in the hydraulic model window.

21) After the hydraulic model has completed the window should look like this:



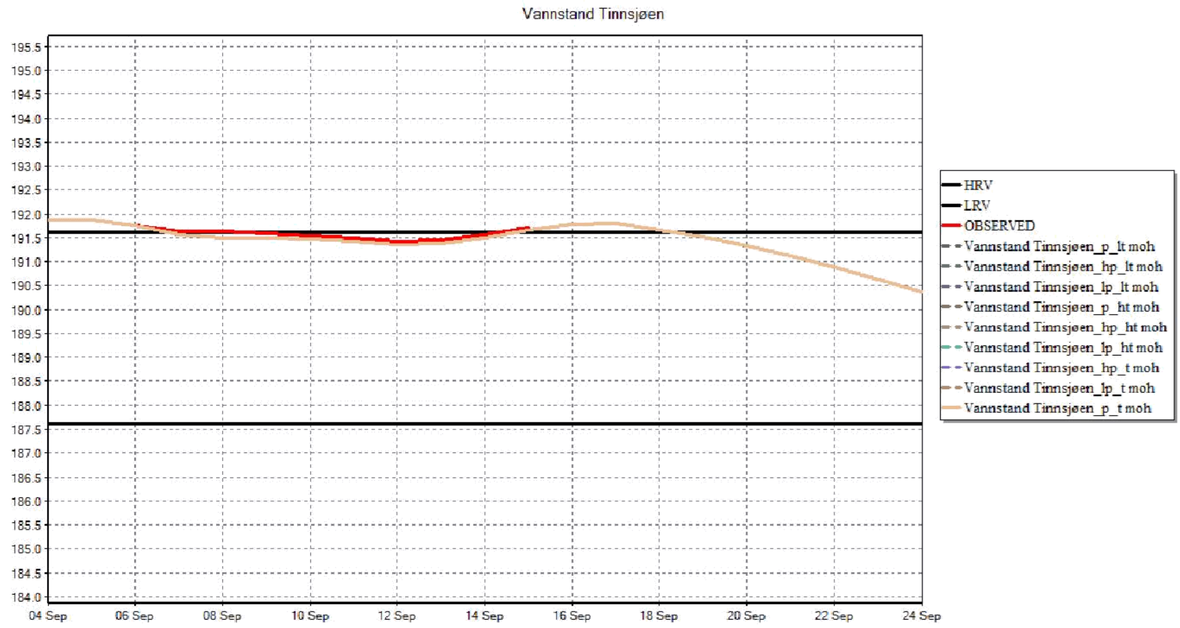
```
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\p_lt_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\hp_lt_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\lp_lt_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\p_ht_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\hp_ht_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\lp_ht_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\hp_t_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\lp_t_forecast.txt
C:\Flommodell\MSC_oppg\STANDARD\RESERVOIR\p_t_forecast.txt
```

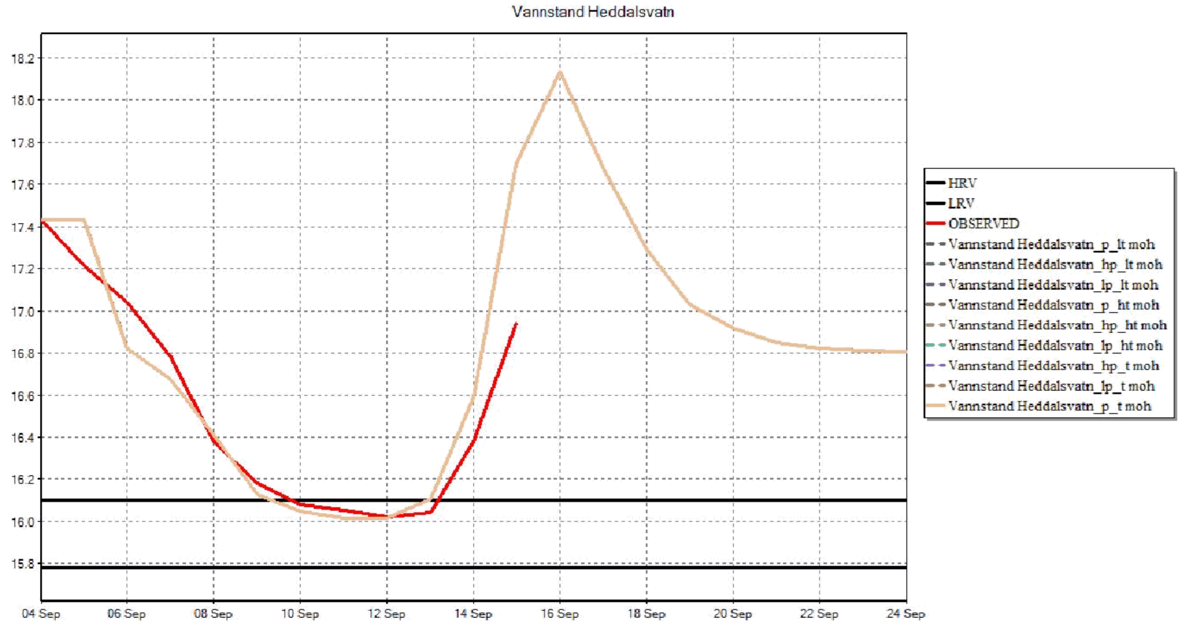
22) Close the window. You can now view the simulated results by selecting output variables in the “Show Results”–dialog.



☐ Lokaltilsig til Tinnsjø
☐ Tapping Møsvatn
☐ Tapping Mår
☐ Totaltilsig Tinnsjøen
☑ Vannstand Tinnsjøe
☐ Tapping Tinnsjøen
☐ Vannføring Heddøle
☐ Vannføring Tinnåi
☐ Lokaltilsig Heddals
☐ Totaltilsig Heddalsv
☐ Vannst. Heddalsvat
☐ Tapping Vestvatna
☐ Vannføring Seljords
☐ Vannføring Sauareł
☐ Lokaltilsig Norsjø
☐ Totaltilsig Norsjø
☐ Vannstand Norsjø
☐ Tapping Norsjø
☐ Lokaltilsig Hjellevat
☐ Totaltilsig Hjellevatı
☐ Vannstand Hjelleva
☐ Tapping Hjellevatn

23) For instance, the development in Lake Tinnsjøen and Lake Heddalsvatn for this example becomes like is shown below:

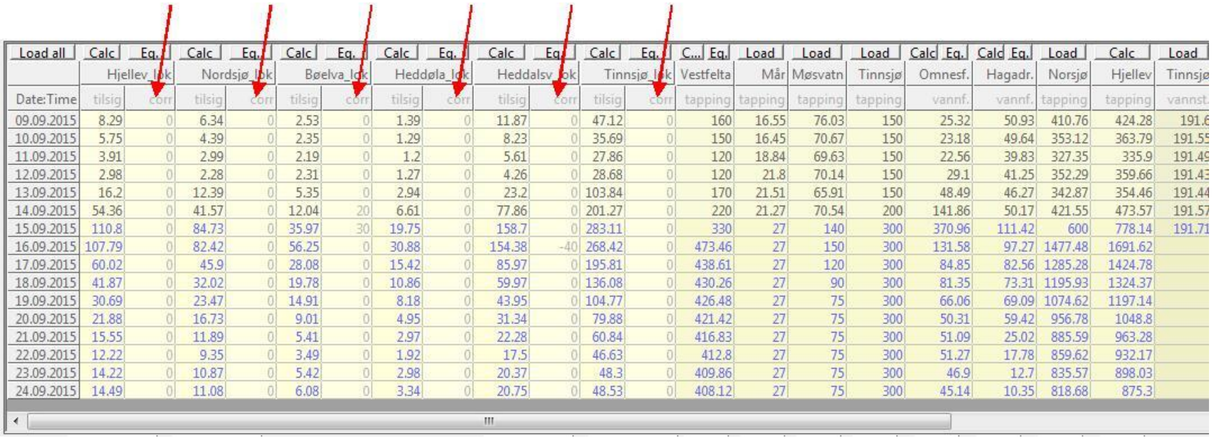




24) Unfortunately the data in the “Reservoir forecast” dialog will not be stored when you close the dialog. To save the setup you must therefore create a “Flood-simulation report”. You do this by closing “Show Results”, and then click on  (create report) in the “Reservoir forecast” dialog. A similar file to FMTV_PROGNOSE20150918091415.xlsx is then created, only that the time tag in the file name becomes the current time and the data in the file becomes your new simulated data. The file will be stored in the ..\OUTPUTDATA\ folder under the model setup. If you want to resimulate this setup on a later time, you will have to reload it into the “Reservoir Forecast”-dialog, like is described in this procedure.

25) In the example described in step 18 to 24, the simulation was conducted on the HBV-simulated runoff, without corrections. Often it is necessary to correct on the unregulated inflow, in order to obtain accordance between simulated and observed lake levels up to the start of the forecast period. This is done by adding or subtracting discharge in the “corr” columns to the right of the

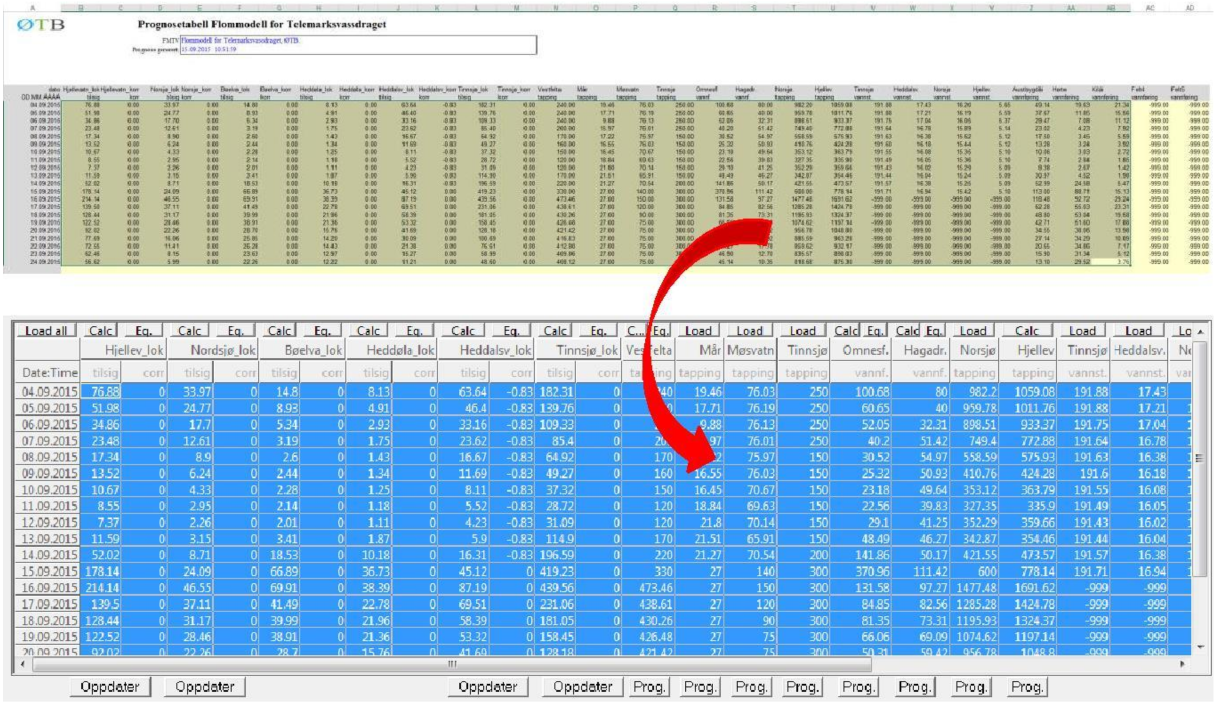
sub-catchment-flow columns in the table.



Load all	Calc	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	C... Eq.	Load	Load	Load	Calc Eq.	Calc Eq.	Load	Calc	Load
	Hjellev_lok		Nordsjø_lok		Bøelva_lok		Heddøla_lok		Heddalsv_lok		Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø
Date:Time	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.
09.09.2015	8.29	0	6.34	0	2.53	0	1.39	0	11.87	0	47.12	0	160	16.55	76.03	150	25.32	50.93	410.76	424.28	191.6
10.09.2015	5.75	0	4.39	0	2.35	0	1.29	0	8.23	0	35.69	0	150	16.45	70.67	150	23.18	49.64	353.12	363.79	191.55
11.09.2015	3.91	0	2.99	0	2.19	0	1.2	0	5.61	0	27.86	0	120	18.84	69.63	150	22.56	39.83	327.35	335.9	191.49
12.09.2015	2.98	0	2.28	0	2.31	0	1.27	0	4.26	0	28.68	0	120	21.8	70.14	150	29.1	41.25	352.29	359.66	191.43
13.09.2015	16.2	0	12.39	0	5.35	0	2.94	0	23.2	0	103.84	0	170	21.51	65.91	150	48.49	46.27	342.87	354.46	191.44
14.09.2015	54.36	0	41.57	0	12.04	20	6.61	0	77.86	0	201.27	0	220	21.27	70.54	200	141.86	50.17	421.55	473.57	191.57
15.09.2015	110.8	0	84.73	0	35.97	30	19.75	0	158.7	0	283.11	0	330	27	140	300	370.96	111.42	600	778.14	191.71
16.09.2015	107.79	0	82.42	0	56.25	0	30.88	0	154.38	-40	268.42	0	473.46	27	150	300	131.58	97.27	1477.48	1691.62	
17.09.2015	60.02	0	45.9	0	28.08	0	15.42	0	85.97	0	195.81	0	438.61	27	120	300	84.85	82.56	1285.28	1424.78	
18.09.2015	41.87	0	32.02	0	19.78	0	10.86	0	59.97	0	136.08	0	430.26	27	90	300	81.35	73.31	1195.93	1324.37	
19.09.2015	30.69	0	23.47	0	14.91	0	8.18	0	43.95	0	104.77	0	426.48	27	75	300	66.06	69.09	1074.62	1197.14	
20.09.2015	21.88	0	16.73	0	9.01	0	4.95	0	31.34	0	79.88	0	421.42	27	75	300	50.31	59.42	956.78	1048.8	
21.09.2015	15.55	0	11.89	0	5.41	0	2.97	0	22.28	0	60.84	0	416.83	27	75	300	51.09	25.02	885.59	963.28	
22.09.2015	12.22	0	9.35	0	3.49	0	1.92	0	17.5	0	46.63	0	412.8	27	75	300	51.27	17.78	859.62	932.17	
23.09.2015	14.22	0	10.87	0	5.42	0	2.98	0	20.37	0	48.3	0	409.86	27	75	300	46.9	12.7	835.57	898.03	
24.09.2015	14.49	0	11.08	0	6.08	0	3.34	0	20.75	0	48.53	0	408.12	27	75	300	45.14	10.35	818.68	875.3	

Updating the model to correct start levels in the lakes is an iterative process, where you correct the flow values, and then resimulated, lokk at the results, correct the flow values again and resimulate again, and so on, till a good agreement between observed and simulated water levels is obtained.

26) If the simulation setup from FMTV_PROGNOSE20150918091415.xlsx is to be repeated entirely, i.e. perform an identical simulation, all values (column B to column AB) in the Flood simulation report must be copied into the table in the Reservoir Forecast dialog.



Prognosetabell Flommodell for Telemarksvassdraget

FMTV: Flommodell for Telemarksvassdraget, ØTB.
Prognose generert: 15.09.2015 10:51:59

Load all	Calc	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	C... Eq.	Load	Load	Load	Calc Eq.	Calc Eq.	Load	Calc	Load	Load
	Hjellev_lok		Nordsjø_lok		Bøelva_lok		Heddøla_lok		Heddalsv_lok		Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø	Heddalsv.
Date:Time	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.	vannst.
04.09.2015	76.88	0	33.97	0	14.8	0	8.13	0	63.64	-0.83	182.31	0	[illegible]	19.46	76.03	250	100.68	80	982.2	1059.08	191.88	17.43
05.09.2015	51.98	0	24.77	0	8.93	0	4.91	0	46.4	-0.83	139.76	0	[illegible]	17.71	76.19	250	60.65	40	959.78	1011.76	191.88	17.21
06.09.2015	34.86	0	17.7	0	5.34	0	2.93	0	33.16	-0.83	109.33	0	[illegible]	9.88	76.13	250	52.05	32.31	898.51	933.37	191.75	17.04
07.09.2015	23.48	0	12.61	0	3.19	0	1.75	0	23.62	-0.83	85.4	0	[illegible]	[illegible]	76.01	250	40.2	51.42	749.4	772.88	191.64	16.78
08.09.2015	17.34	0	8.9	0	2.6	0	1.43	0	16.67	-0.83	64.92	0	170	[illegible]	75.97	150	30.52	54.97	558.59	575.93	191.63	16.38
09.09.2015	13.52	0	6.24	0	2.44	0	1.34	0	11.69	-0.83	49.27	0	160	16.55	76.03	150	25.32	50.93	410.76	424.28	191.6	16.18
10.09.2015	10.67	0	4.33	0	2.28	0	1.25	0	8.11	-0.83	37.32	0	150	16.45	70.67	150	23.18	49.64	353.12	363.79	191.55	16.08
11.09.2015	8.55	0	2.95	0	2.14	0	1.18	0	5.52	-0.83	28.72	0	120	18.84	69.63	150	22.56	39.83	327.35	335.9	191.49	16.05
12.09.2015	7.37	0	2.26	0	2.01	0	1.11	0	4.23	-0.83	31.09	0	120	21.8	70.14	150	29.1	41.25	352.29	359.66	191.43	16.02
13.09.2015	11.59	0	3.15	0	3.41	0	1.87	0	5.9	-0.83	114.9	0	170	21.51	65.91	150	48.49	46.27	342.87	354.46	191.44	16.04
14.09.2015	52.02	0	8.71	0	18.53	0	10.18	0	16.31	-0.83	196.59	0	220	21.27	70.54	200	141.86	50.17	421.55	473.57	191.57	16.38
15.09.2015	178.14	0	24.09	0	66.89	0	36.73	0	45.12	0	419.23	0	330	27	140	300	370.96	111.42	600	778.14	191.71	16.94
16.09.2015	214.14	0	46.55	0	69.91	0	38.39	0	87.19	0	439.56	0	473.46	27	150	300	131.58	97.27	1477.48	1691.62	-999	-999
17.09.2015	139.5	0	37.11	0	41.49	0	22.78	0	69.51	0	231.06	0	438.61	27	120	300	84.85	82.56	1285.28	1424.78	-999	-999
18.09.2015	128.44	0	31.17	0	39.99	0	21.96	0	58.39	0	181.05	0	430.26	27	90	300	81.35	73.31	1195.93	1324.37	-999	-999
19.09.2015	122.52	0	28.46	0	38.91	0	21.36	0	53.32	0	158.45	0	426.48	27	75	300	66.06	69.09	1074.62	1197.14	-999	-999
20.09.2015	92.02	0	22.26	0	28.7	0	15.76	0	41.69	0	128.18	0	421.42	27	75	300	50.31	59.42	956.78	1048.8	-999	-999

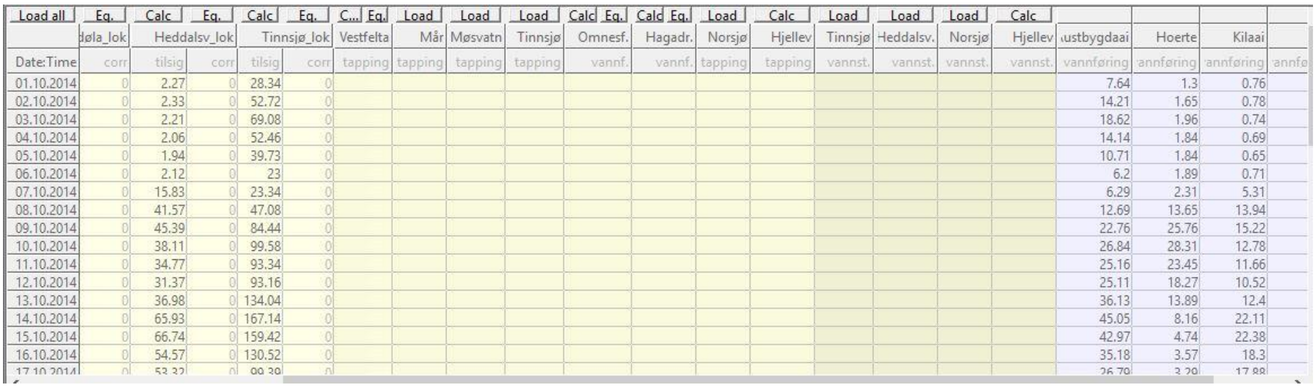
27) This procedure should work for all recent flood events during the last 5 – 10 years (I have tested it back to 2011). However for events even further back, the HBV-runup period becomes very long (see point 5), and I expect that it may become impractical to carry out the HBV-steps (or even that it will hang or crash). I will look for a solution to this, for instance to reprogram the HBV-model so that and earlier date than present time can be specified as the end-time of the run-up period. But I will need some more time for this, so you will have to concentrate on the later flood-events until then.

Trond

Appendix D2

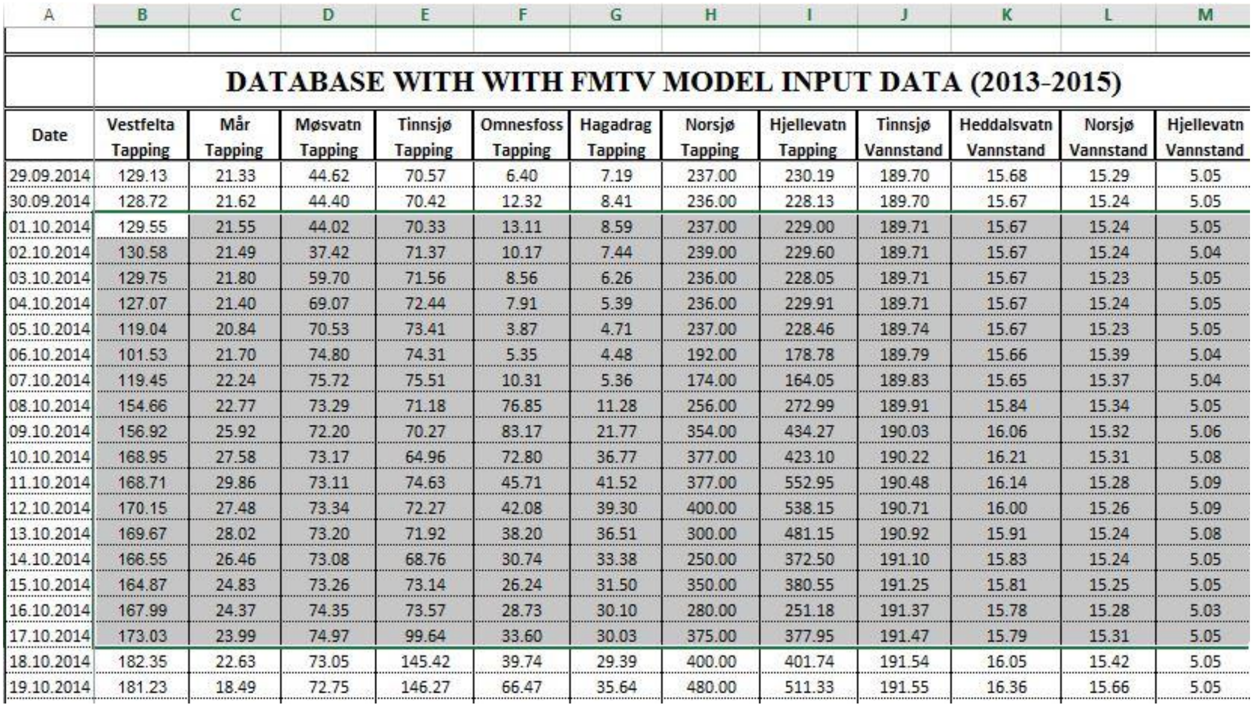
Procedure for using Dataset for FMTV model.

1. Follow Step 1 to 17 from file ‘Procedure for Simulating Historical floods with FMTV.xlsx’. The simulated HBV-runoff for three catchments will be filled in extreme right and flow values for unregulated sub-catchments in water system will be filled in left column of the table. The columns between these two sections will be empty which needs to be filled manually.



Load all	Eq.	Calc	Eq.	Calc	Eq.	C... Eq.	Load	Load	Load	Calc Eq.	Calc Eq.	Load	Calc	Load	Load	Load	Calc				
	døla_lok	Heddalsv_lok		Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø	Heddalsv.	Norsjø	Hjellev	ustbygdaai	Hoerte	Kilaai	
Date:Time	corr	tilsig	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.	vannst.	vannst.	vannst.	vannføring	annføring	annføring	annfø
01.10.2014	0	2.27	0	28.34	0													7.64	1.3	0.76	
02.10.2014	0	2.33	0	52.72	0													14.21	1.65	0.78	
03.10.2014	0	2.21	0	69.08	0													18.62	1.96	0.74	
04.10.2014	0	2.06	0	52.46	0													14.14	1.84	0.69	
05.10.2014	0	1.94	0	39.73	0													10.71	1.84	0.65	
06.10.2014	0	2.12	0	23	0													6.2	1.89	0.71	
07.10.2014	0	15.83	0	23.34	0													6.29	2.31	5.31	
08.10.2014	0	41.57	0	47.08	0													12.69	13.65	13.94	
09.10.2014	0	45.39	0	84.44	0													22.76	25.76	15.22	
10.10.2014	0	38.11	0	99.58	0													26.84	28.31	12.78	
11.10.2014	0	34.77	0	93.34	0													25.16	23.45	11.66	
12.10.2014	0	31.37	0	93.16	0													25.11	18.27	10.52	
13.10.2014	0	36.98	0	134.04	0													36.13	13.89	12.4	
14.10.2014	0	65.93	0	167.14	0													45.05	8.16	22.11	
15.10.2014	0	66.74	0	159.42	0													42.97	4.74	22.38	
16.10.2014	0	54.57	0	130.52	0													35.18	3.57	18.3	
17.10.2014	0	53.32	0	99.39	0													26.79	3.29	17.88	

2. Open FMTV dataset for flood events.xls and go to ‘Table’ sheet.
3. Copy the columns ‘Vestfelta-tapping’ (column B) to ‘Hjellevatn Vannstand’ (Column M)

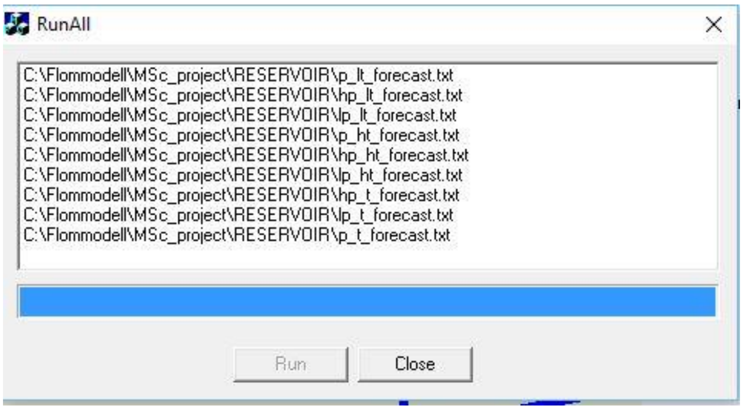


A	B	C	D	E	F	G	H	I	J	K	L	M
	DATABASE WITH WITH FMTV MODEL INPUT DATA (2013-2015)											
Date	**Vestfelta Tapping**	**Mår Tapping**	**Møsvatn Tapping**	**Tinnsjø Tapping**	**Omnesfoss Tapping**	**Hagadrag Tapping**	**Norsjø Tapping**	**Hjellevatn Tapping**	**Tinnsjø Vannstand**	**Heddalsvatn Vannstand**	**Norsjø Vannstand**	**Hjellevatn Vannstand**
29.09.2014	129.13	21.33	44.62	70.57	6.40	7.19	237.00	230.19	189.70	15.68	15.29	5.05
30.09.2014	128.72	21.62	44.40	70.42	12.32	8.41	236.00	228.13	189.70	15.67	15.24	5.05
01.10.2014	129.55	21.55	44.02	70.33	13.11	8.59	237.00	229.00	189.71	15.67	15.24	5.05
02.10.2014	130.58	21.49	37.42	71.37	10.17	7.44	239.00	229.60	189.71	15.67	15.24	5.04
03.10.2014	129.75	21.80	59.70	71.56	8.56	6.26	236.00	228.05	189.71	15.67	15.23	5.05
04.10.2014	127.07	21.40	69.07	72.44	7.91	5.39	236.00	229.91	189.71	15.67	15.24	5.05
05.10.2014	119.04	20.84	70.53	73.41	3.87	4.71	237.00	228.46	189.74	15.67	15.23	5.05
06.10.2014	101.53	21.70	74.80	74.31	5.35	4.48	192.00	178.78	189.79	15.66	15.39	5.04
07.10.2014	119.45	22.24	75.72	75.51	10.31	5.36	174.00	164.05	189.83	15.65	15.37	5.04
08.10.2014	154.66	22.77	73.29	71.18	76.85	11.28	256.00	272.99	189.91	15.84	15.34	5.05
09.10.2014	156.92	25.92	72.20	70.27	83.17	21.77	354.00	434.27	190.03	16.06	15.32	5.06
10.10.2014	168.95	27.58	73.17	64.96	72.80	36.77	377.00	423.10	190.22	16.21	15.31	5.08
11.10.2014	168.71	29.86	73.11	74.63	45.71	41.52	377.00	552.95	190.48	16.14	15.28	5.09
12.10.2014	170.15	27.48	73.34	72.27	42.08	39.30	400.00	538.15	190.71	16.00	15.26	5.09
13.10.2014	169.67	28.02	73.20	71.92	38.20	36.51	300.00	481.15	190.92	15.91	15.24	5.08
14.10.2014	166.55	26.46	73.08	68.76	30.74	33.38	250.00	372.50	191.10	15.83	15.24	5.05
15.10.2014	164.87	24.83	73.26	73.14	26.24	31.50	350.00	380.55	191.25	15.81	15.25	5.05
16.10.2014	167.99	24.37	74.35	73.57	28.73	30.10	280.00	251.18	191.37	15.78	15.28	5.03
17.10.2014	173.03	23.99	74.97	99.64	33.60	30.03	375.00	377.95	191.47	15.79	15.31	5.05
18.10.2014	182.35	22.63	73.05	145.42	39.74	29.39	400.00	401.74	191.54	16.05	15.42	5.05
19.10.2014	181.23	18.49	72.75	146.27	66.47	35.64	480.00	511.33	191.55	16.36	15.66	5.05

4. Paste the values in the table in ‘Reservor forecast’ dialog (i.e. Select the upper left cell of those columns and hit shift-insert or control-V.

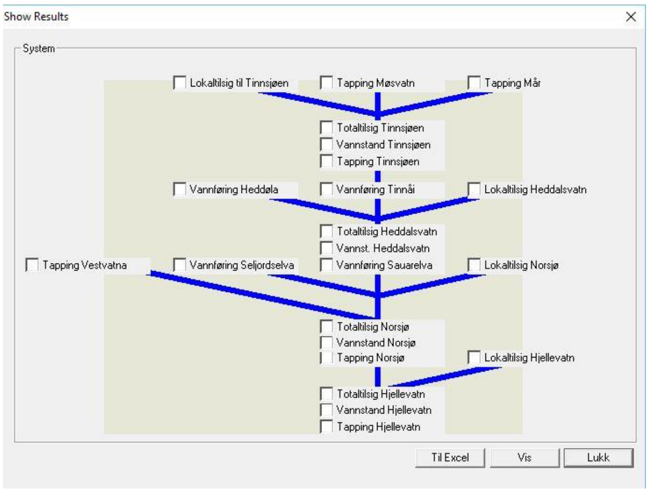
Load all	Eq.	Calc	Eq.	Calc	Eq.	Calc	Eq.	C... Eq.	Load	Load	Load	Calc Eq.	Calc Eq.	Load	Calc	Load	Load	Load	Calc		
	elva_lok	Heddøla_lok		Heddalsv_lok		Tinnsjø_lok		Vestfelta	Mår	Møsvatn	Tinnsjø	Omnesf.	Hagadr.	Norsjø	Hjellev	Tinnsjø	Heddalsv.	Norsjø	Hjellev	ustbygdaai	Hoerte
Date:Time	corr	tilsig	corr	tilsig	corr	tilsig	corr	tapping	tapping	tapping	tapping	vannf.	vannf.	tapping	tapping	vannst.	vannst.	vannst.	vannst.	vannføring	annføring
01.10.2014	0	0.54	0	2.27	0	28.34	0	129.55	21.55	44.02	70.33	13.11	8.59	237	229	189.71	15.67	15.24	5.05	7.64	1.3
02.10.2014	0	0.68	0	2.33	0	52.72	0	130.58	21.49	37.42	71.37	10.17	7.44	239	229.6	189.71	15.67	15.24	5.04	14.21	1.65
03.10.2014	0	0.81	0	2.21	0	69.08	0	129.75	21.8	59.7	71.56	8.56	6.26	236	228.05	189.71	15.67	15.23	5.05	18.62	1.96
04.10.2014	0	0.76	0	2.06	0	52.46	0	127.07	21.4	69.07	72.44	7.91	5.39	236	229.91	189.71	15.67	15.24	5.05	14.14	1.84
05.10.2014	0	0.76	0	1.94	0	39.73	0	119.04	20.84	70.53	73.41	3.87	4.71	237	228.46	189.74	15.67	15.23	5.05	10.71	1.84
06.10.2014	0	0.78	0	2.12	0	23	0	101.53	21.7	74.8	74.31	5.35	4.48	192	178.78	189.79	15.66	15.39	5.04	6.2	1.89
07.10.2014	0	0.96	0	15.83	0	23.34	0	119.45	22.24	75.72	75.51	10.31	5.36	174	164.05	189.83	15.65	15.37	5.04	6.29	2.31
08.10.2014	0	5.65	0	41.57	0	47.08	0	154.66	22.77	73.29	71.18	76.85	11.28	256	272.99	189.91	15.84	15.34	5.05	12.69	13.65
09.10.2014	0	10.66	0	45.39	0	84.44	0	156.92	25.92	72.2	70.27	83.17	21.77	354	434.27	190.03	16.06	15.32	5.06	22.76	25.76
10.10.2014	0	11.72	0	38.11	0	99.58	0	168.95	27.58	73.17	64.96	72.8	36.77	377	423.1	190.22	16.21	15.31	5.08	26.84	28.31
11.10.2014	0	9.71	0	34.77	0	93.34	0	168.71	29.86	73.11	74.63	45.71	41.52	377	552.95	190.48	16.14	15.28	5.09	25.16	23.45
12.10.2014	0	7.56	0	31.37	0	93.16	0	170.15	27.48	73.34	72.27	42.08	39.3	400	538.15	190.71	16	15.26	5.09	25.11	18.27
13.10.2014	0	5.75	0	36.98	0	134.04	0	169.67	28.02	73.2	71.92	38.2	36.51	300	481.15	190.92	15.91	15.24	5.08	36.13	13.89
14.10.2014	0	3.38	0	65.93	0	167.14	0	166.55	26.46	73.08	68.76	30.74	33.38	250	372.5	191.1	15.83	15.24	5.05	45.05	8.16
15.10.2014	0	1.96	0	66.74	0	159.42	0	164.87	24.83	73.26	73.14	26.24	31.5	350	380.55	191.25	15.81	15.25	5.05	42.97	4.74
16.10.2014	0	1.48	0	54.57	0	130.52	0	167.99	24.37	74.35	73.57	28.73	30.1	280	251.18	191.37	15.78	15.28	5.03	35.18	3.57
17.10.2014	0	1.36	0	53.32	0	99.39	0	173.03	23.99	74.97	99.64	33.6	30.03	375	377.95	191.47	15.79	15.31	5.05	26.79	3.29

5. All necessary data are filled now and the model is ready to perform lake level simulation by clicking Beregn vannstander and then click Run. The following display will be seen.



```
C:\Flommodell\MSc_project\RESERVOIR\p_lt_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\hp_lt_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\lp_lt_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\p_ht_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\hp_ht_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\lp_ht_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\hp_t_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\lp_t_forecast.txt
C:\Flommodell\MSc_project\RESERVOIR\p_t_forecast.txt
```

6. Close window. You can now view the simulated results by selecting output variables in 'show results'- dialog.



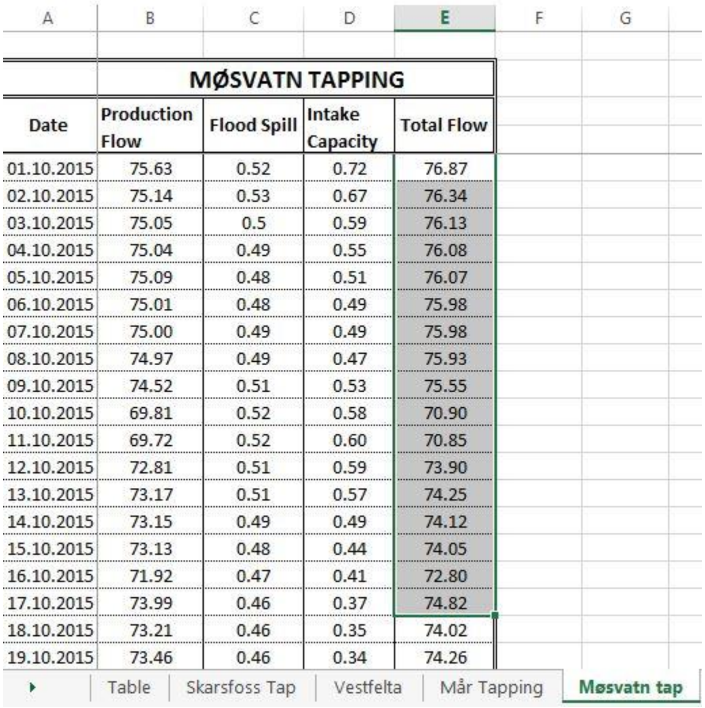
7. In order to the simulated result press  and the simulated water level for all reservoirs will be saved in C:\Flommodell\MSc_project\OUTPTDATA with name similar to FMTV_PROGNOSE20150918091415.xlsx

Procedure to run model with Møsvatn Tapping instead of Skarsfoss Tapping

1. Follow Step 1 to Step 4 from Procedure for dataset for FMTV model.

2. Open the FMTV set for flood event.xlsx go to sheet Møsvatn Tap.

3. Copy Total Flow (column E) for respective period or if you want to simulate flood without spill copy Produciton Flow (column B).



	MØSVATN TAPPING			
Date	Production Flow	Flood Spill	Intake Capacity	Total Flow
01.10.2015	75.63	0.52	0.72	76.87
02.10.2015	75.14	0.53	0.67	76.34
03.10.2015	75.05	0.5	0.59	76.13
04.10.2015	75.04	0.49	0.55	76.08
05.10.2015	75.09	0.48	0.51	76.07
06.10.2015	75.01	0.48	0.49	75.98
07.10.2015	75.00	0.49	0.49	75.98
08.10.2015	74.97	0.49	0.47	75.93
09.10.2015	74.52	0.51	0.53	75.55
10.10.2015	69.81	0.52	0.58	70.90
11.10.2015	69.72	0.52	0.60	70.85
12.10.2015	72.81	0.51	0.59	73.90
13.10.2015	73.17	0.51	0.57	74.25
14.10.2015	73.15	0.49	0.49	74.12
15.10.2015	73.13	0.48	0.44	74.05
16.10.2015	71.92	0.47	0.41	72.80
17.10.2015	73.99	0.46	0.37	74.82
18.10.2015	73.21	0.46	0.35	74.02
19.10.2015	73.46	0.46	0.34	74.26

4. Proceed form Step 4 to Step 7 to complete simulation.

Note: The data recorded in Table sheet is new data with spill from Skarsfoss and Vrangfoss recorded and also capacity of brook intakes for Mår hydropower system included. If you desire to do simulation without these values follow second procedure and selecting desired change in their respective sheet.

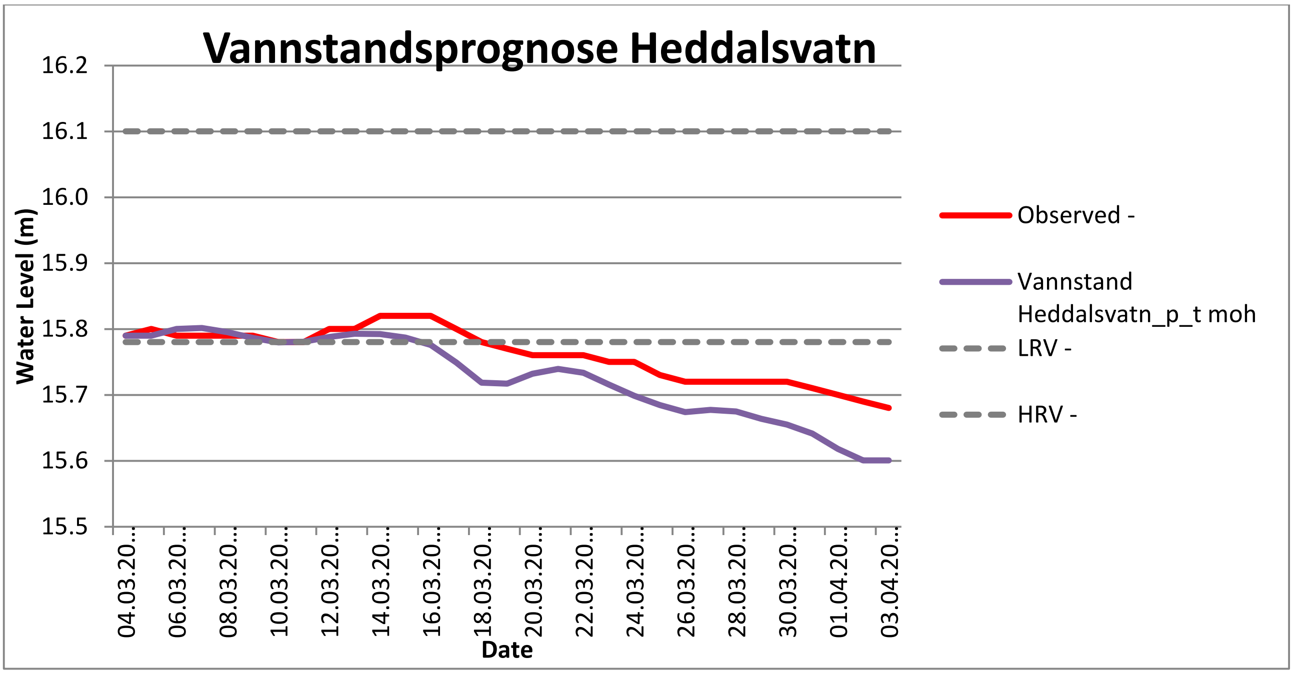
Appendix D(Table) 1: Free Parameters Set for three Catchments

S.N.	**Meaning**	**Symbol**	**Units**	**Range**	**Austbygdåi**	**Hørte**	**Kileåi**
1	Rainfall Correction	RCORR		1.05-1.2	0.812	1.062	1.062
2	Snowfall Correction	SCORR		1.15-1.5	1.168	1.016	1.016
3	Threshold Temperature Rain/Snow	TX	oC	-2 -1	0.511	-0.01	0.502
4	Temperature lapse rate for clear days	TCGRAD	oC /100m	-0.6- -1.0	-1	-1	-1
5	Temperature lapse rate during prec.	TPGRAD	oC /100m	-0.4--0.6	-0.5	-0.5	-0.5
6	Precipitaion Lapse rate	PGRAD	%/100m	1.0-1.10	5	5	5
7	Degree Day Factor	CX	mm/oC day	3.0-6.0	6.022	3.037	4.347
8	Threshold Temperature for Snowmelt	TS	oC	-1.0-2.0	-0.525	-1.85	1.202
9	Refreezing efficiency in Snow	CFR		0.0-0.01	0.01	0.01	0.005
10	Field Capacity in soil moisture zone	FC	mm	75-300	100.1	59.2	71.4
11	Parameter in soil moisture routine	BETA		1.0-4.0	0.765	1.137	3.274
12	Recession constant in upper zone	KUZ1	mm/day	0.1-0.5	0.27	0.49	0.331
13	Threshold	UZ1	mm	10-40	24.7	10.76	13.39
14	Recession constant in upper zone	KUZ	mm/day	0.05-0.15	0.077	0.064	0.042
15	Percolation	PERC	mm/day	0.5-1.0	0.1	1.58	0.73
16	Drainage Coeff.	KLZ	mm/day	0.005-0.002	0.057	0.051	0.042

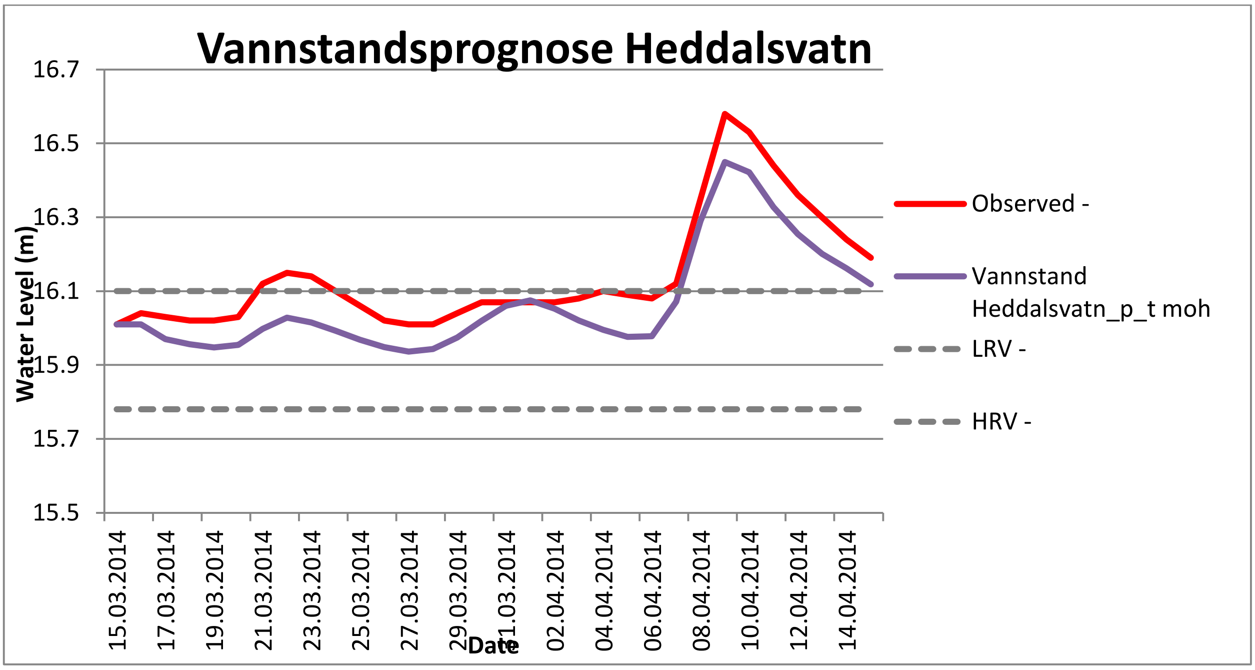
Appendix E: Simulation results for different flood events with FMTV

Small Flood Event

Heddalsvatn

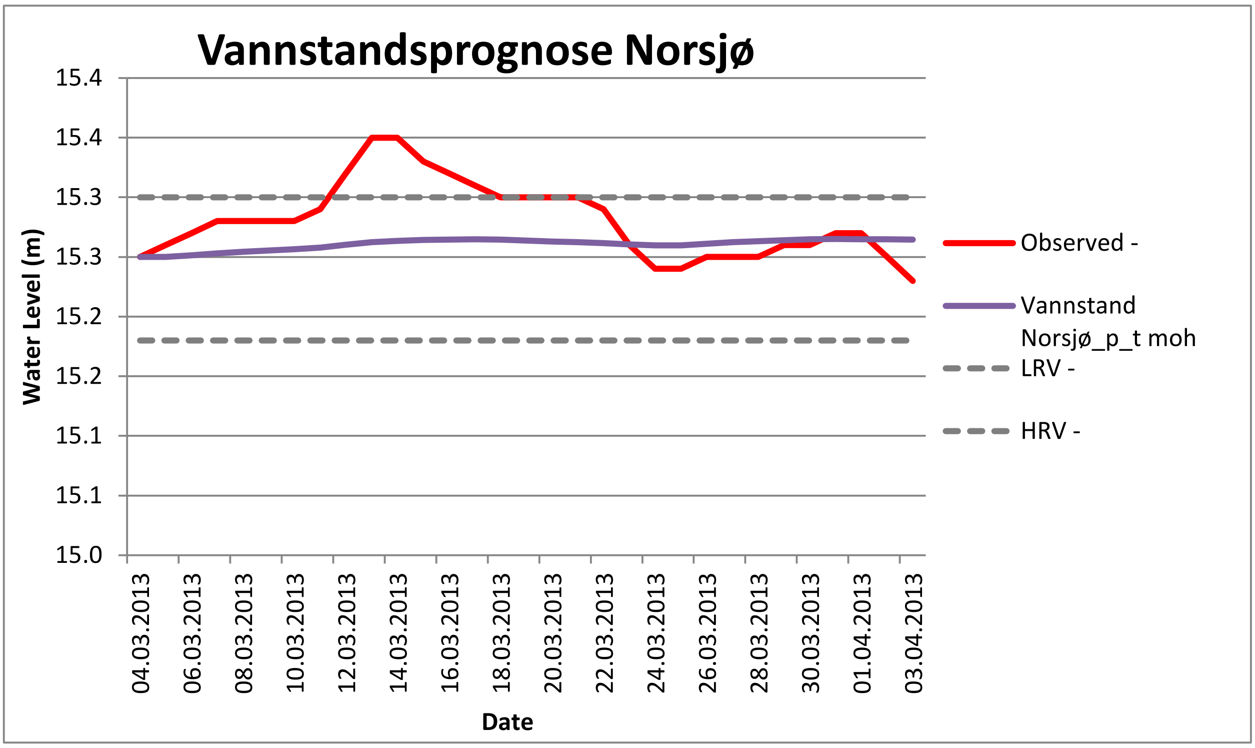


Appendix E 1: FMTV simulation result for a small flood period for Heddalsvatn in 2013

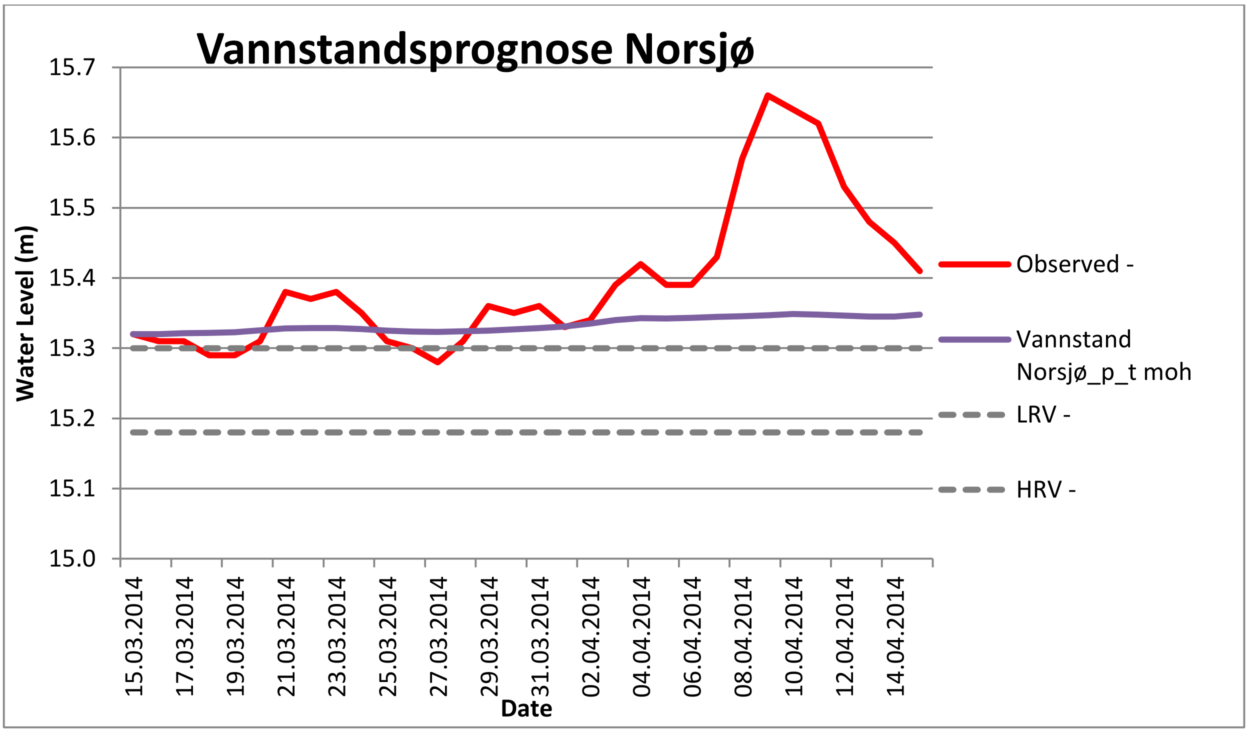


Appendix E 2: FMTV simulation result for a small flood period for Heddalsvatn in 2014

Norsjø

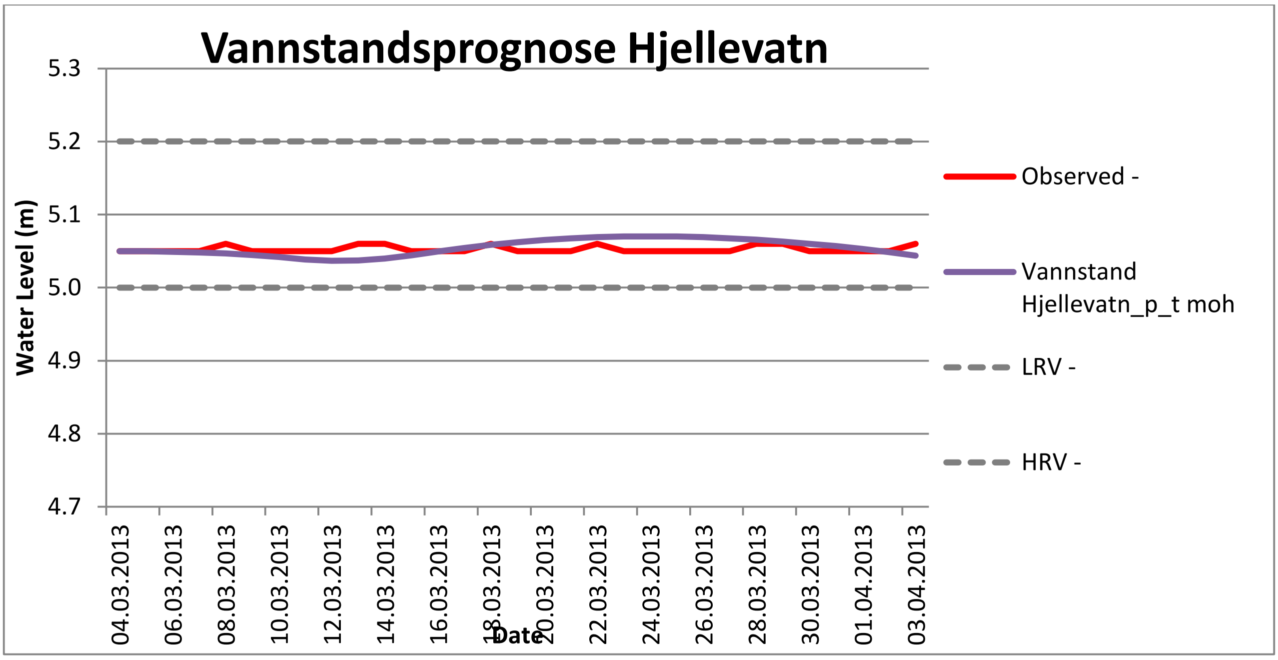


Appendix E 3: FMTV simulation result for a small flood period for Norsjø in 2013

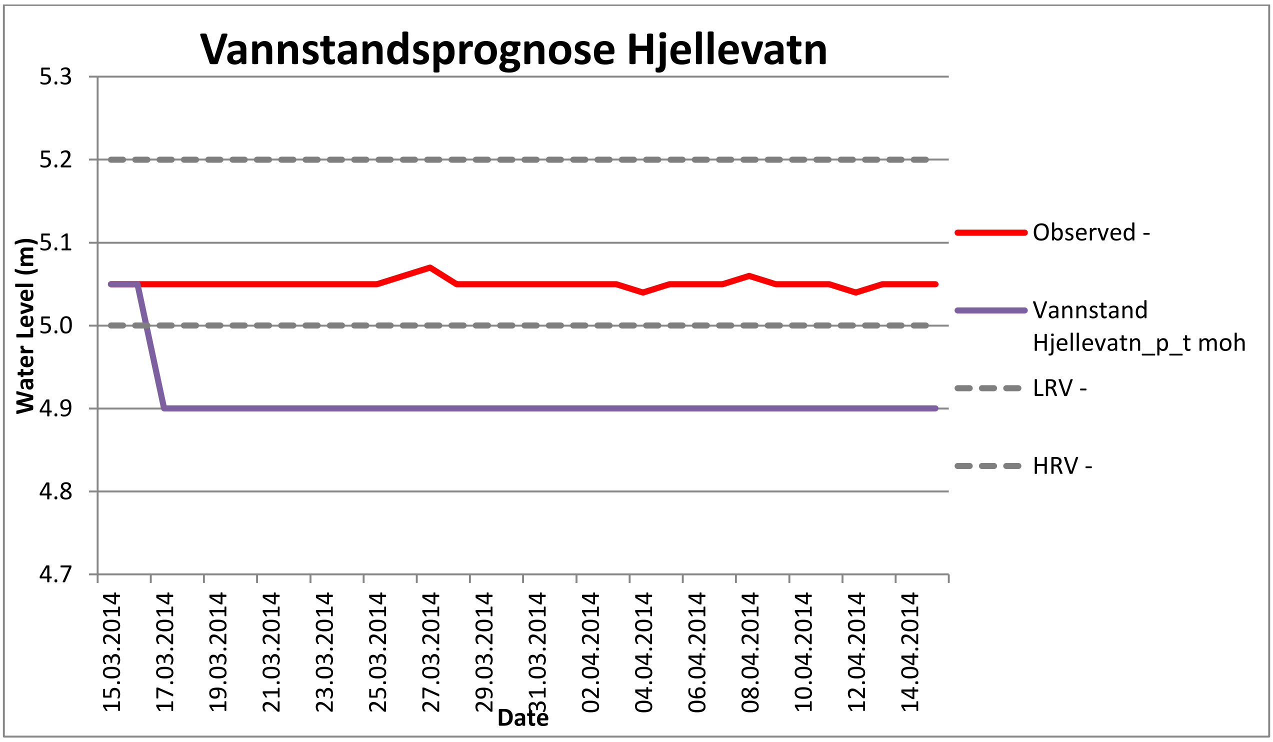


Appendix E 4: FMTV simulation result for a small flood period for Norsjø in 2014

Hjellevatn

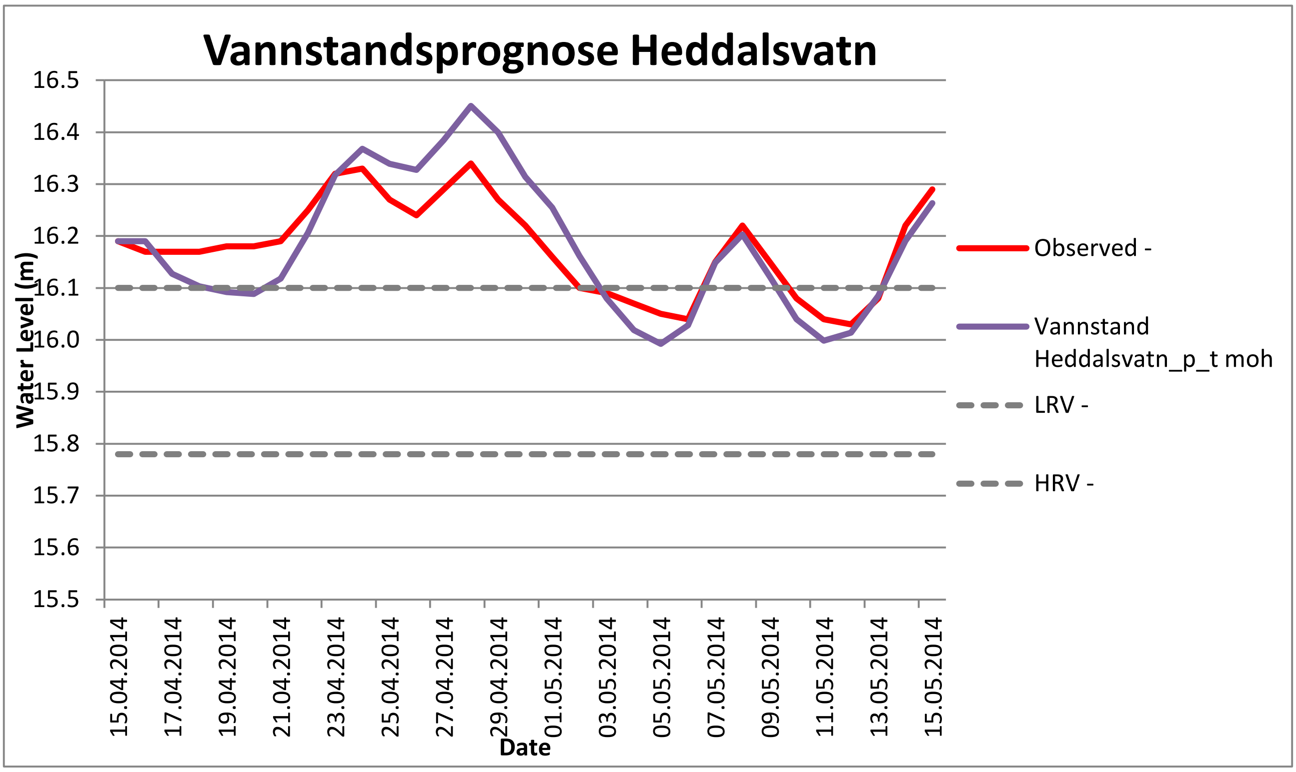


Appendix E 5: FMTV simulation result for a small flood period for Hjellevatn in 2013

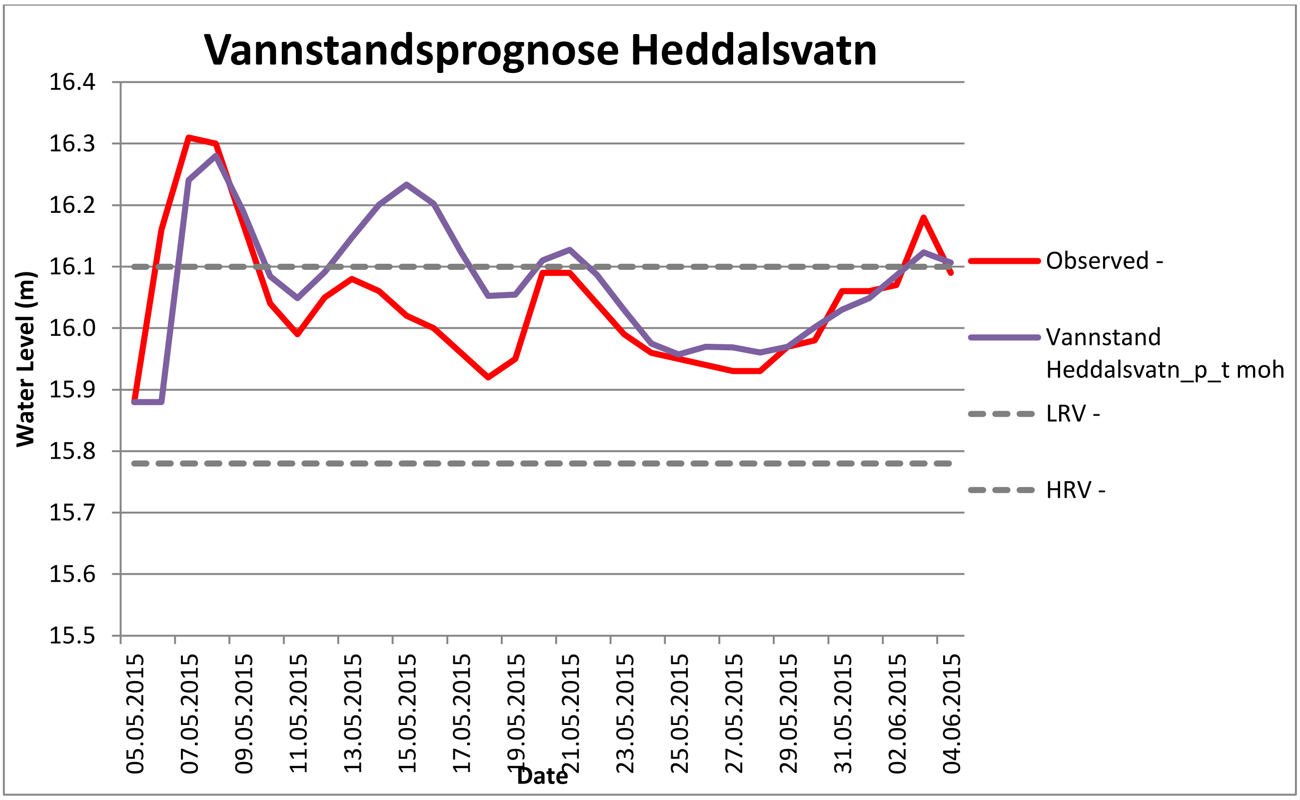


Appendix E 6: FMTV simulation result for a small flood period for Hjellevatn in 2014

Medium Flood Event
Heddalsvatn

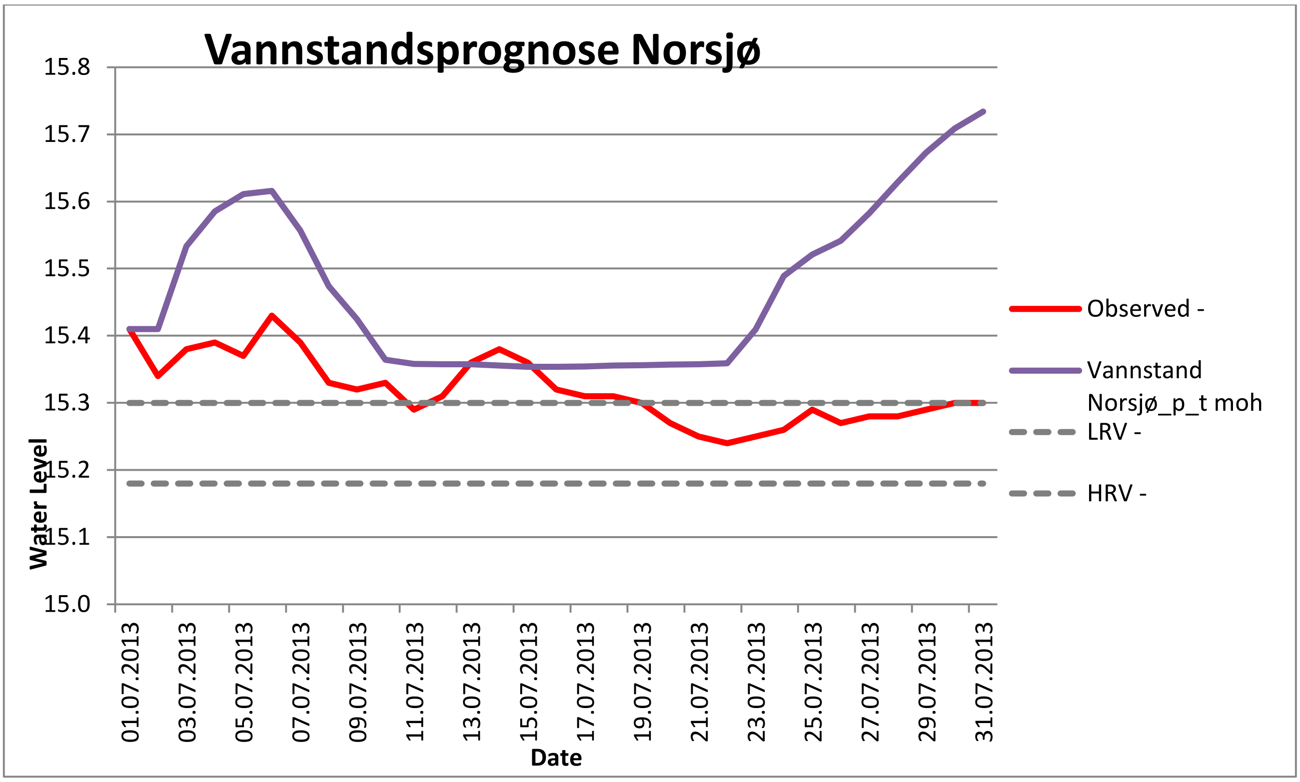


Appendix E 7: FMTV simulation result for a medium flood period for Heddalsvatn in 2014

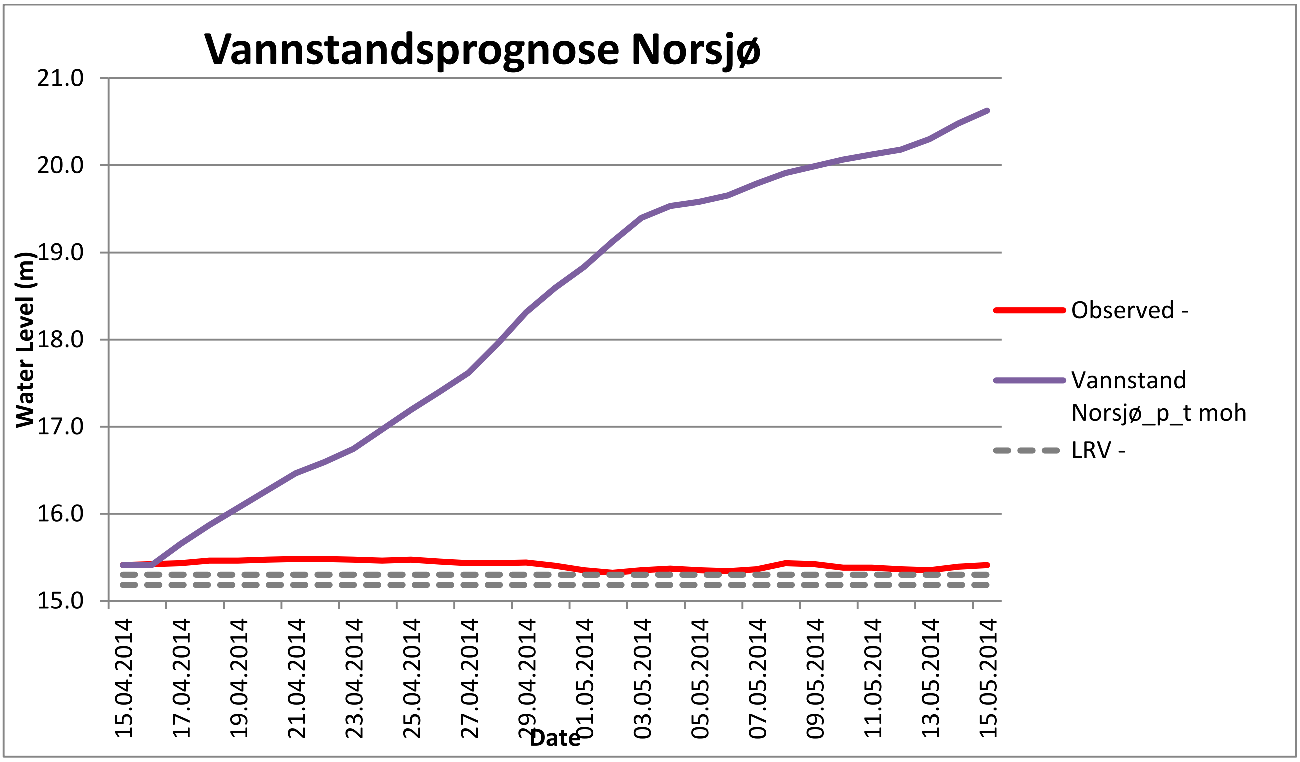


Appendix E 8: FMTV simulation result for a medium flood period for Heddalsvatn in 2015

Norsjø

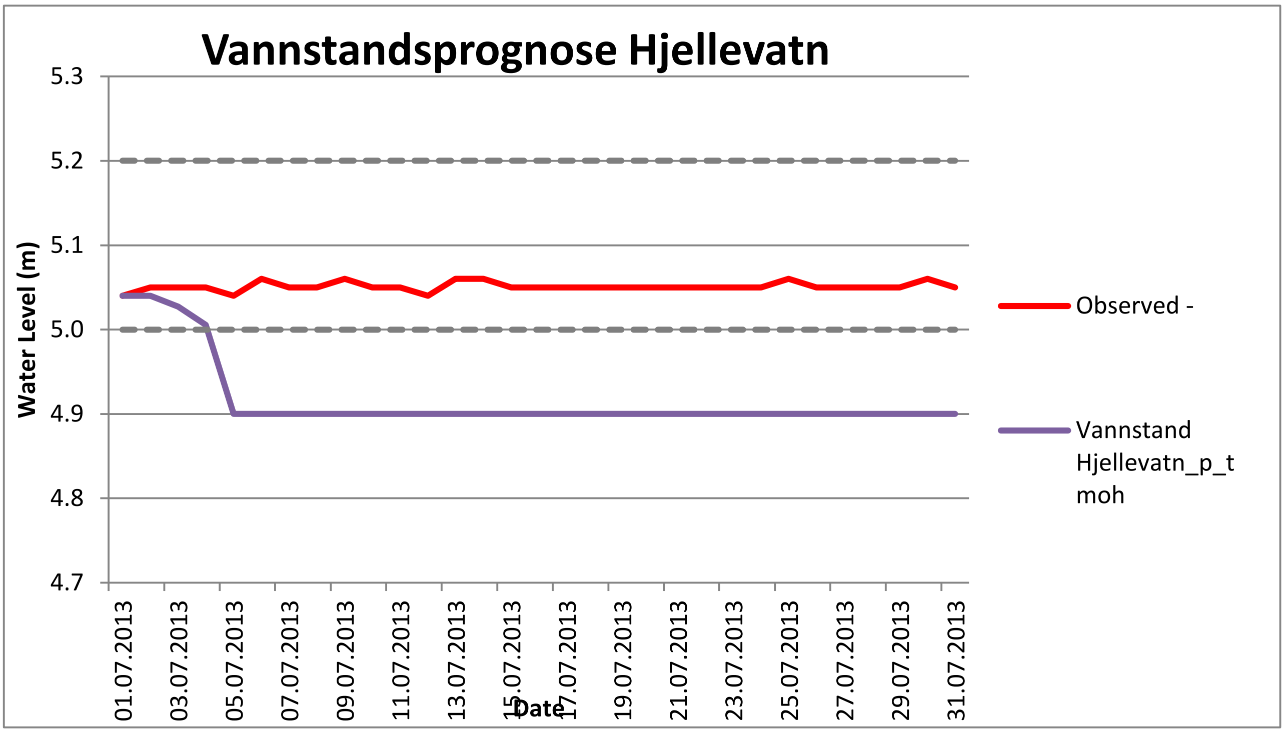


Appendix E 9: FMTV simulation result for a medium flood period for Norsjø in 2013

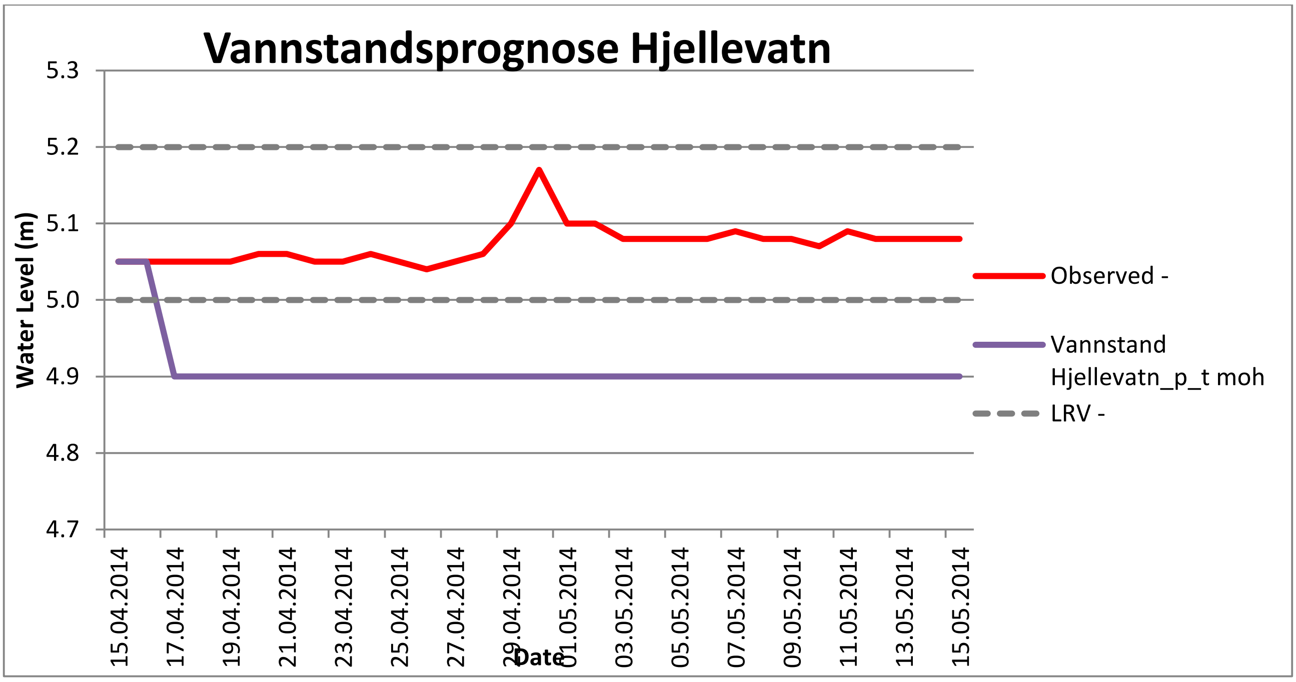


Appendix E 10: FMTV simulation result for a medium flood period for Norsjø in 2014

Hjellevatn



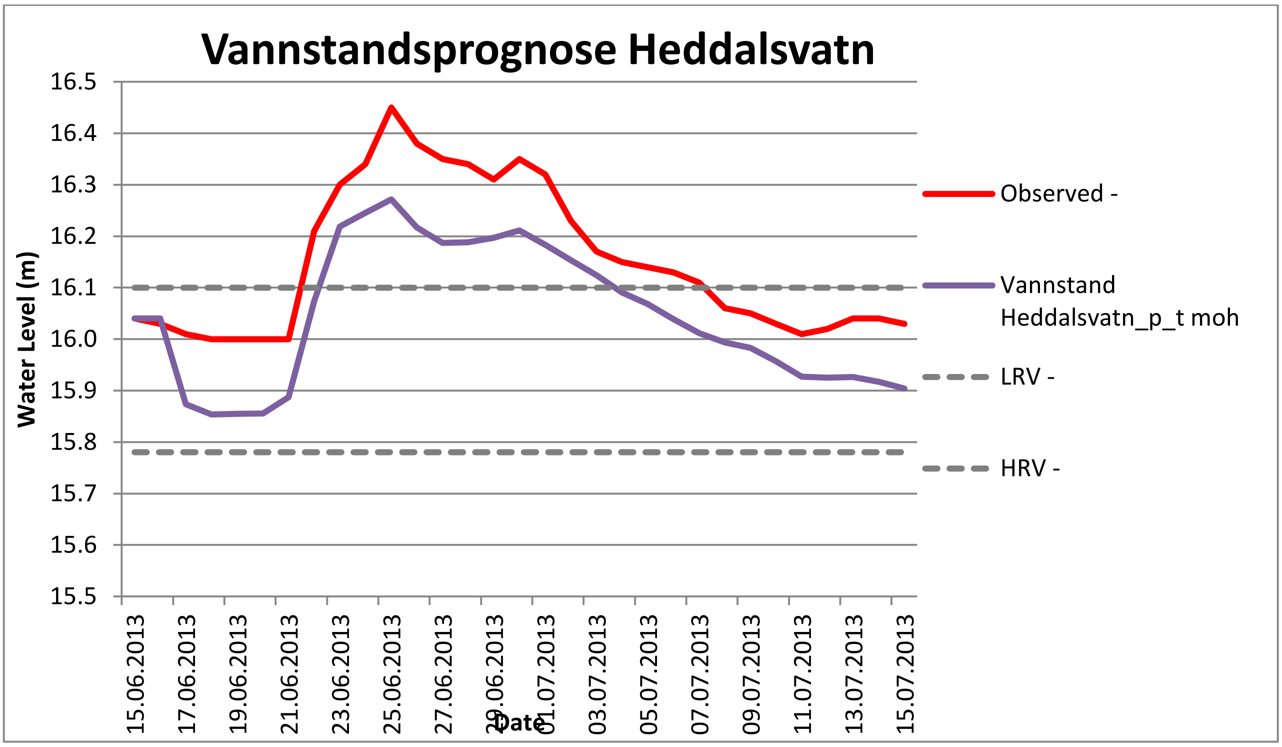
Appendix E 11: FMTV simulation result for a medium flood period for Hjellevatn in 2013



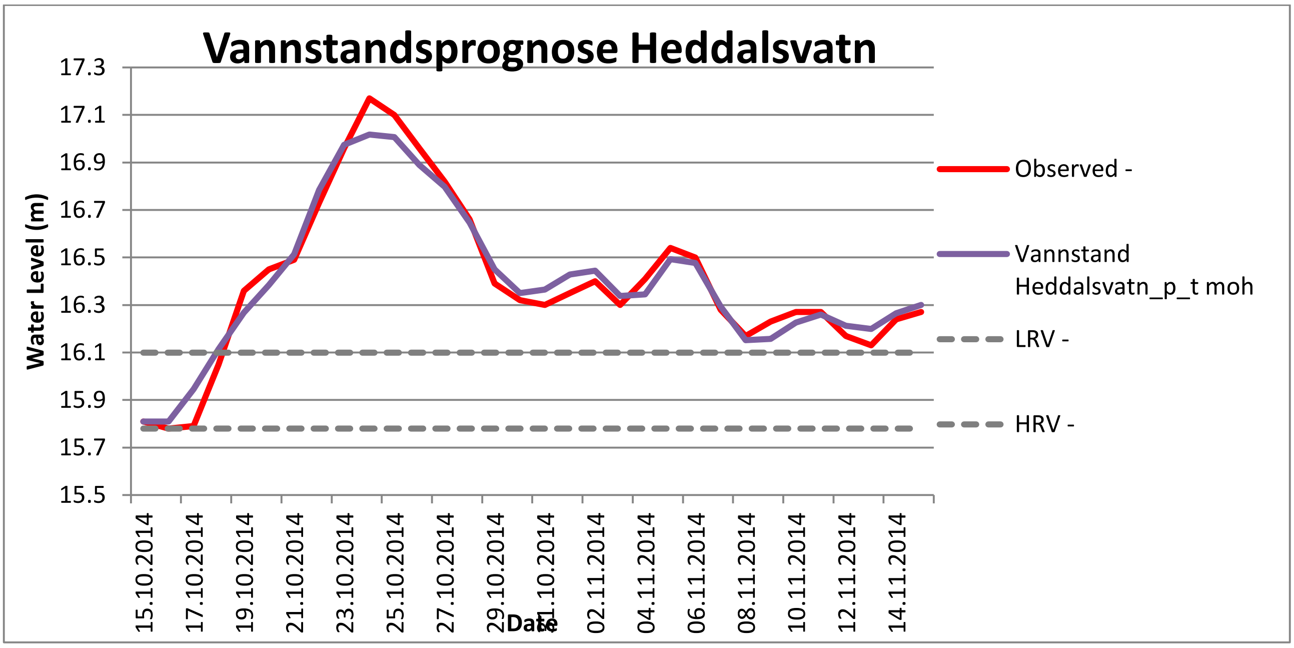
Appendix E 12: FMTV simulation result for a medium flood period for Hjellevatn in 2014

Large Flood Event

Heddalsvatn

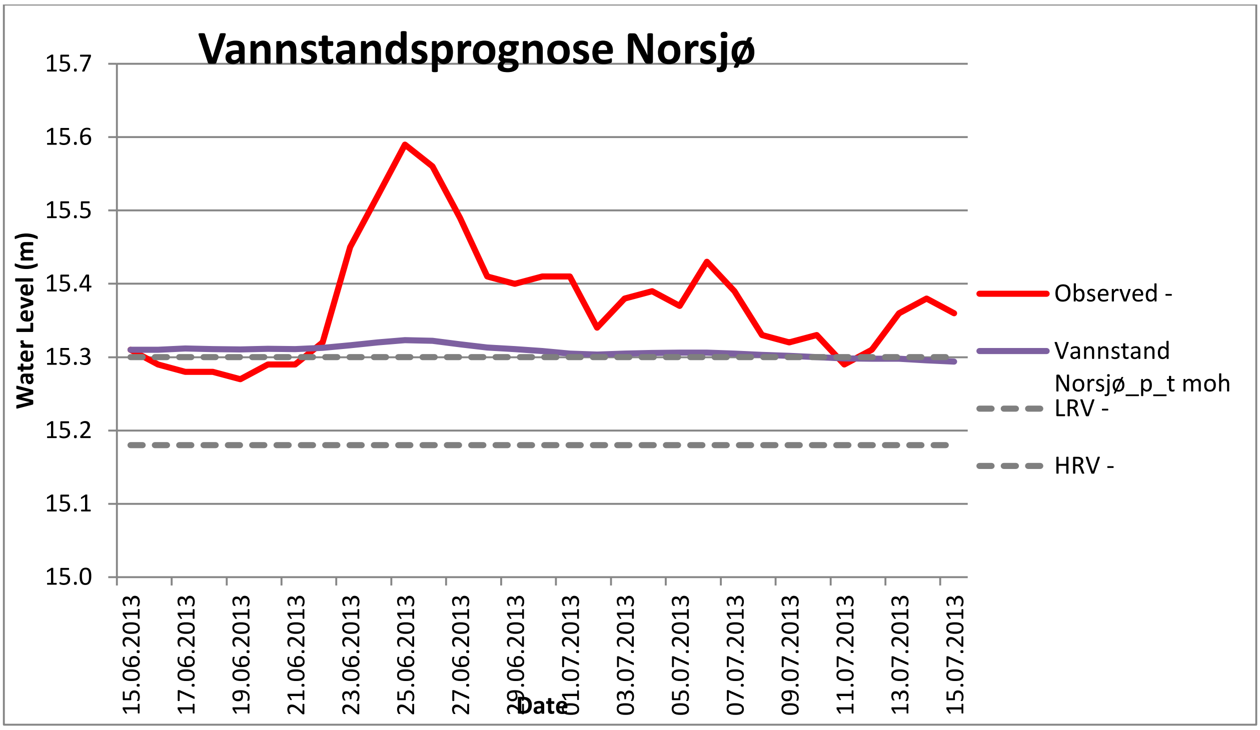


Appendix E 13: FMTV simulation result for a large flood period for Heddalsvatn for 2013

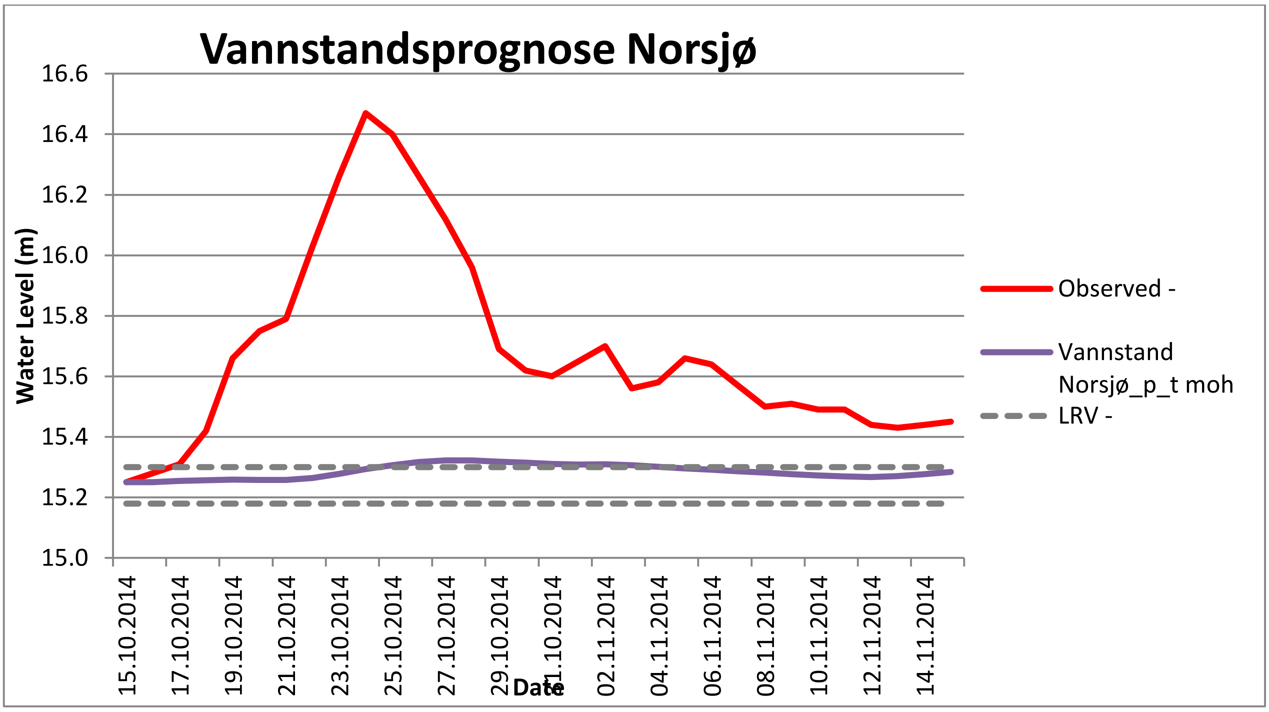


Appendix E 14: FMTV simulation result for a Large flood period for Heddalsvatn for 2014

Norsjø:

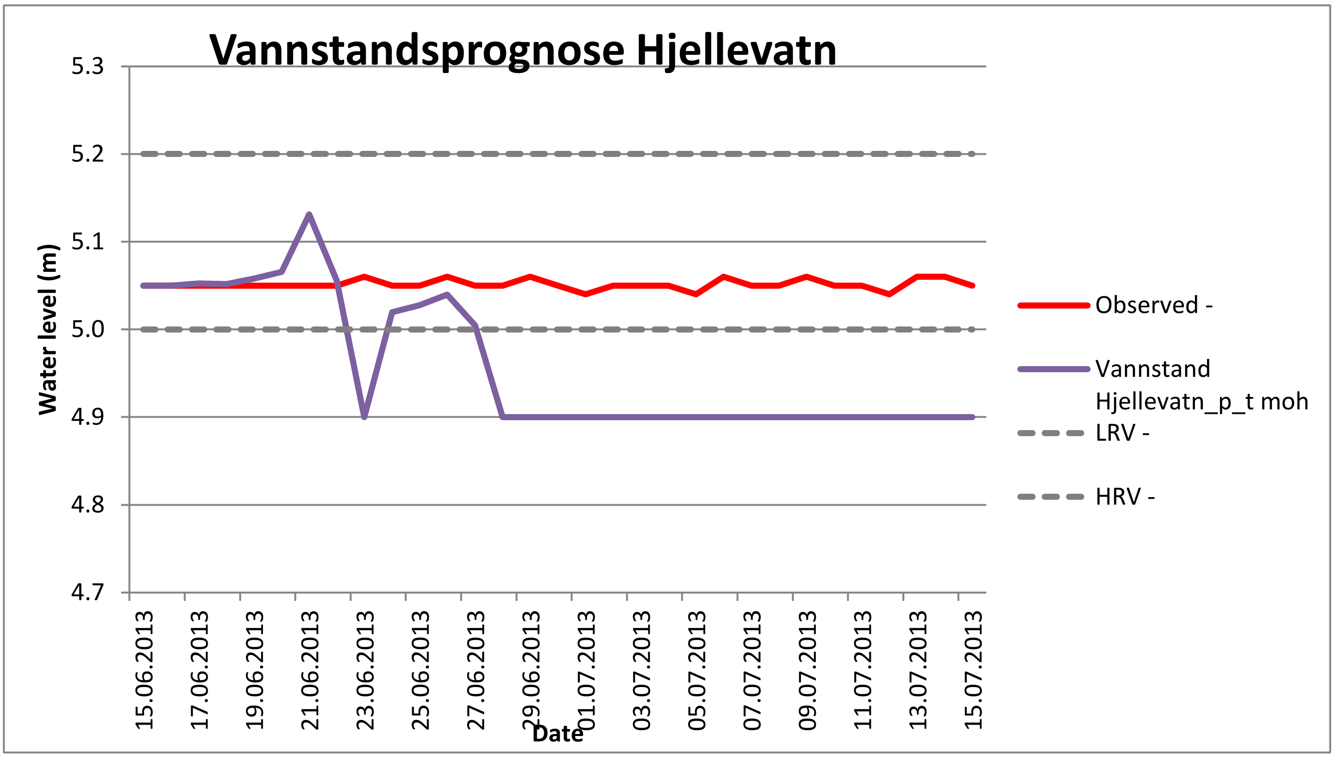


Appendix E 15: FMTV simulation result for a Large flood period for Norsjø for 2013

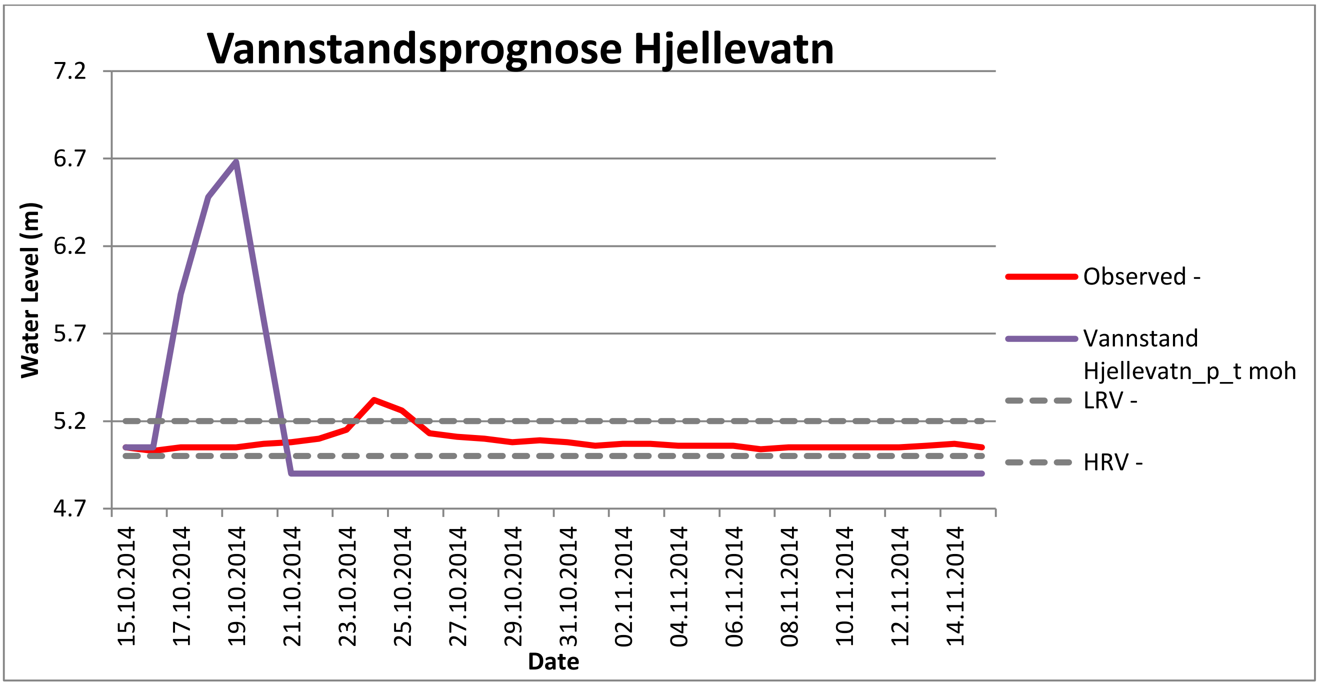


Appendix E 16: FMTV simulation result for a large flood period for Norsjø for 2014

Hjellevatn



Appendix E 17: FMTV simulation result for a large flood period for Hjellevatn for 2013



Appendix E 18: FMTV simulation result for a large flood period for Hjellevatn for 2014

Appendix F: Manual Routing of water level for Norsjø

Appendix F(Table)- 1: Manual Calculation of Water Level for Norsjø

Date	Sauarelva Runoff	Norsjø Tapping	Local flow from FMTV	Hagadrag	Vestfelta	Total Inflow	Volume Change(dv)	water level
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	mil. m^3	m
26.08.2015	168.00	483.70	17.93	68.79	153.59	408.31	-6.51	15.49
27.08.2015	264.00	650.38	24.47	97.87	189.45	575.79	-6.44	15.37
28.08.2015	338.00	618.81	29.04	120.85	192.54	680.43	5.32	15.47
29.08.2015	306.00	583.81	27.22	101.23	167.42	601.87	1.56	15.50
30.08.2015	182.40	576.83	19.88	78.85	195.66	476.79	-8.64	15.34
31.08.2015	222.00	504.42	14.50	61.32	213.59	511.41	0.60	15.35
01.09.2015	216.00	481.61	11.49	49.31	212.60	489.40	0.67	15.36
02.09.2015	360.00	554.34	34.55	100.10	188.99	683.64	11.17	15.57
03.09.2015	609.00	829.73	77.28	240.23	216.55	1143.06	27.07	16.06
04.09.2015	602.00	1032.91	38.45	222.21	308.31	1170.97	11.93	16.27
05.09.2015	400.00	1006.57	25.92	158.48	307.53	891.93	-9.90	16.09
06.09.2015	363.80	922.16	18.53	117.27	300.07	799.67	-10.58	15.90
07.09.2015	369.60	812.89	13.21	85.51	261.08	729.40	-7.21	15.77
08.09.2015	256.00	644.33	9.33	63.23	196.34	524.90	-10.32	15.58
09.09.2015	219.30	480.61	6.54	48.65	140.84	415.33	-5.64	15.48
10.09.2015	226.00	386.05	4.55	38.99	114.30	383.84	-0.19	15.48
11.09.2015	222.00	380.73	3.10	32.47	116.36	373.93	-0.59	15.47
12.09.2015	220.00	395.86	2.32	28.17	109.77	360.26	-3.08	15.41
13.09.2015	217.20	395.22	5.38	29.08	117.39	369.05	-2.26	15.37
14.09.2015	294.00	510.28	10.91	45.46	186.99	537.36	2.34	15.41
15.09.2015	510.00	769.45	23.10	115.09	321.83	970.02	17.33	15.73
16.09.2015	663.10	1231.06	50.10	199.11	531.95	1444.26	18.42	16.06
17.09.2015	568.80	1393.03	44.03	169.27	421.11	1203.21	-16.40	15.76
18.09.2015	437.30	1473.52	35.85	150.43	344.91	968.49	-43.63	14.97
19.09.2015	385.10	1362.11	29.79	113.08	333.75	861.72	-43.23	14.19
20.09.2015	326.00	1157.92	21.27	87.07	320.87	755.21	-34.79	13.56
21.09.2015	290.20	981.14	15.16	70.42	291.11	666.89	-27.15	13.07
22.09.2015	797.54	816.28	11.70	61.57	255.63	1126.44	26.80	13.55
23.09.2015	793.12	811.32	12.66	58.05	256.57	1120.40	26.70	14.04
24.09.2015	755.52	775.62	12.42	54.81	247.58	1070.33	25.46	14.50
25.09.2015	711.34	728.99	10.87	55.69	203.75	981.65	21.83	14.89

Total inflow = Sauarelva+Hagadrag+Vestfelta+Local Flow
Volume Change (dv)=(Total Inflow-Total Outflow)*86400/1000000
Water Level (L_2) = L_1+dv/55.15,
Area of Norsjø = 55.15 km^2

Appendix G: Manual calculation of local Inflow

Appendix G(Table)- 1: Manual local flow calculation for Tinnsjø

Date	Mår outflow	Skarsfoss outflow	Tinnsjø			Tinnsjø outflow	Local inflow by cal.	Local inflow from FMTV
			Water level	Volume	Storage			
	(m3/s)	(m3/s)	(m)	mil. m3	(m3/s)	(m3/s)	(m3/s)	(m3/s)
25.08.2015	30.18	73.19	188.87	83.6	224.6	68	189.26	32.83
26.08.2015	31.38	74.92	189.10	101.0	201.1	60.38	155.15	93.31
27.08.2015	40.38	73.92	189.47	124.0	266.8	58.86	211.37	140.83
28.08.2015	32.98	75.39	189.86	135.8	136.6	93.38	121.65	145.88
29.08.2015	19.66	75.78	190.19	139.4	41.6	124.13	70.31	122.99
30.08.2015	17.79	75.77	190.34	141.0	17.8	124.42	48.70	95.27
31.08.2015	13.80	75.75	190.39	141.0	0.0	124.14	34.59	74.05
01.09.2015	14.74	75.74	190.40	140.5	-5.9	141.25	44.82	56.35
02.09.2015	44.15	99.27	190.39	170.8	351.3	151.74	359.63	122.8
03.09.2015	47.62	122.94	190.71	212.6	483.6	132.27	445.31	210.36
04.09.2015	33.06	101.01	191.42	218.8	71.8	257.42	195.11	201.68
05.09.2015	28.20	93.44	191.82	215.2	-41.9	285.77	122.26	158.57
06.09.2015	18.32	92.83	191.82	206.9	-95.6	274.07	67.27	145.32
07.09.2015	21.72	88.49	191.74	204.3	-29.9	183.04	42.95	140.16
08.09.2015	21.48	82.15	191.65	203.8	-6.0	151.33	41.73	113.49
09.09.2015	19.94	81.07	191.62	201.8	-23.9	152.25	27.34	86.33
10.09.2015	19.27	79.08	191.60	199.2	-29.9	151.1	22.88	65.63
11.09.2015	21.26	74.16	191.55	195.6	-41.8	150	12.77	49.83
12.09.2015	24.19	75.36	191.49	193.5	-23.9	149.26	25.82	38.77
13.09.2015	30.12	75.22	191.44	197.1	41.8	158.76	95.23	62.55
14.09.2015	33.82	77.99	191.45	205.4	95.6	245.4	229.18	96.91
15.09.2015	39.80	101.71	191.57	236.4	358.9	343.95	561.33	108.22
16.09.2015	44.63	78.14	191.97	244.7	95.8	327.8	300.84	142.61
17.09.2015	42.55	36.72	192.34	245.2	6.0	330.92	257.64	154.93
18.09.2015	36.41	106.59	192.41	243.6	-18.0	324.31	163.35	134.23
19.09.2015	34.86	140.19	192.40	239.5	-47.9	316.05	93.09	113.01
20.09.2015	32.73	133.69	192.34	232.8	-77.8	309.1	64.85	86.15
21.09.2015	31.35	125.41	192.24	224.0	-101.7	302.01	43.51	65.63
22.09.2015	31.12	118.69	192.09	215.7	-95.7	300.37	54.87	50.31
23.09.2015	31.49	113.34	191.92	208.5	-83.7	270.2	41.68	50.94
24.09.2015	30.97	107.54	191.77	207.4	-12.0	217.3	66.84	50.42
25.09.2015	33.49	106.01	191.69	206.4	-12.0	217.52	66.06	66.37

Local Inflow is calculated by using Water Balance Equation:

Local Inflow= Tinnsjø outlet – Mår Outlet – Skarsfoss Outlet + Storage

Storage (m3/s) = $\frac{Change\ in\ volume *\ 1000000}{86400}$

Appendix G(Table)- 2: Manual local flow calculaiton for Norsjø

Date	Sauarelva Runoff	Skotfoss Runoff	Hagadrag	Vestfelta	Norsjø		Local inflow by cal.	Local inflow from FMTV
					Volume	Storage		
	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)
26.08.2015	168.00	452.53	68.79	153.59	146.64	98.61	160.76	17.93
27.08.2015	264.00	533.02	97.87	189.45	150.90	49.31	31.00	24.47
28.08.2015	338.00	522.66	120.85	192.54	151.74	9.72	-119.01	29.04
29.08.2015	306.00	488.96	101.23	167.42	151.89	1.74	-83.96	27.22
30.08.2015	182.40	483.70	78.85	195.66	147.58	-49.88	-23.10	19.88
31.08.2015	222.00	422.81	61.32	213.59	141.76	-67.36	-141.46	14.50
01.09.2015	216.00	377.54	49.31	212.60	135.83	-68.63	-169.01	11.49
02.09.2015	360.00	415.79	100.10	188.99	138.39	29.63	-203.67	34.55
03.09.2015	609.00	725.86	240.23	216.55	166.38	323.96	-15.96	77.28
04.09.2015	602.00	980.84	222.21	308.31	186.56	233.56	81.89	38.45
05.09.2015	400.00	960.25	158.48	307.53	185.73	-9.61	84.63	25.92
06.09.2015	363.80	897.64	117.27	300.07	178.02	-89.24	27.27	18.53
07.09.2015	369.60	736.54	85.51	261.08	168.24	-113.19	-92.85	13.21
08.09.2015	256.00	538.91	63.23	196.34	152.71	-179.75	-156.41	9.33
09.09.2015	219.30	407.60	48.65	140.84	143.42	-107.52	-108.71	6.54
10.09.2015	226.00	338.52	38.99	114.30	138.75	-54.05	-94.82	4.55
11.09.2015	222.00	333.68	32.47	116.36	139.52	8.91	-28.24	3.10
12.09.2015	220.00	353.80	28.17	109.77	135.72	-43.98	-48.12	2.32
13.09.2015	217.20	344.06	29.08	117.39	132.81	-33.68	-53.29	5.38
14.09.2015	294.00	426.70	45.46	186.99	133.75	10.88	-88.87	10.91
15.09.2015	510.00	687.29	115.09	321.83	155.70	254.05	-5.58	23.10
16.09.2015	663.10	1115.44	199.11	531.95	203.51	553.36	274.64	50.10
17.09.2015	568.80	1194.65	169.27	421.11	223.92	236.23	271.70	44.03
18.09.2015	437.30	1200.81	150.43	344.91	234.34	120.60	388.78	35.85
19.09.2015	385.10	1201.14	113.08	333.75	220.72	-157.64	211.57	29.79
20.09.2015	326.00	1199.51	87.07	320.87	200.23	-237.15	228.42	21.27
21.09.2015	290.20	1114.58	70.42	291.11	181.26	-219.56	243.29	15.16
22.09.2015	305.40	771.05	61.57	255.63	170.29	-126.97	21.49	11.70
23.09.2015	361.70	749.55	58.05	256.57	168.55	-20.14	53.09	12.66
24.09.2015	326.00	744.03	54.81	247.58	164.29	-49.31	66.33	12.42
25.09.2015	268.00	714.51	55.69	203.75	157.79	-75.23	111.84	10.87

Local Inflow is calculated by using Water Balance Equation:

Local Inflow= Skotfoss – Hagadrag – Sauarelva - Vestfelta + Storage

Storage (m3/s) = $\frac{Change\ in\ volume *\ 1000000}{86400}$