Master's thesis

2023

Tulu Bedada Gemechu

Master's thesis

NTNU
Norwegian University of
Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

NTNU
Norwegian University of
Science and Technology

Tulu Bedada Gemechu

Flood Dampening by Reservoirs in Trondheim Kommune

July 2023

NTNU
Norwegian University of
Science and Technology

Norwegian University of
Science and Technology

Flood Dampening by Reservoirs in Trondheim Kommune

Tulu Bedada Gemechu

Hydropower Development
Submission date: July 2023
Supervisor: Knut Alfredsen

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

NTNU
Norwegian University of
Science and Technology

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

M.Sc. THESIS IN

HYDROPOWER DEVELOPMENT

Candidate: **Tulu Bedada Gemechu**

Title: Flood Dampening by Reservoirs in Trondheim Kommune.

BACKGROUND

Floods can be damaging to nature, humans and built infrastructure and is expected to increase in the future climate. Reservoirs with the possible controlled releases and therefore a potential buffer capacity during the flood can dampen the flood peak and thereby reduce the damage potential downstream. Trondheim Kommune is responsible for 19 dams with three in class 4, four in class 3, five in class 2 and the remainder in class 1. This provides some reservoir capacity that could provide flood dampening during high flood events.

The objective of this thesis is to investigate the flood dampening potential of the reservoirs in the Leirelva Watercourses based on design inflow to the reservoir the dampening effect of the reservoirs and the reduction in outflow to the rivers downstream should be computed. The potential for operational flood control should also be evaluated.

MAIN QUESTIONS FOR THE THESIS

The thesis shall cover, though not necessarily be limited to the main tasks listed below. The following main steps will be carried out during the thesis work:

1. Briefly review the current work on design flood computations and flood dampening work
2. Prepare data for the Leirelva watercourses. Evaluate data quality and any uncertainties that is necessary to propagate into the dampening computation.

3. Establish the flood scenarios for the analysis in this project.
4. Carry out a flood dampening study for the Leirelva watercourses. By developing a routing model for the reservoir, evaluate the dampening effect given different water levels in the reservoirs, evaluate the potential for pre-releases of water and do the dampening computation for the flood scenarios established in 3).
5. Evaluate the sensitivity of the model from 4) and how uncertainties in data influences the results from the computations.
6. Establish a hydrological model for the reservoirs that could be used to generate the inflow prognosis in a flood management setup.

SUPERVISION, DATA AND INFORMATION INPUT

Professor Knut Alfredsen will be the main supervisor of the thesis work. The work will be carried out in cooperation with Trondheim Kommune, represented by Odd Atle Tveit and Ganesh Hiriyanna Rao (now with Statkraft).

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

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

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, a list of literature formatted according to a common standard and other relevant references. A signed statement where the candidate states that the presented work is his own and that significant outside input is identified should be included.

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

All data and model setups should be compiled, documented, and submitted with the thesis.

The thesis shall be submitted no later than 12th of June 2023.

Trondheim 11th of January 2023

Knut Alfredsen

Professor

SUMMARY

Floods can be harmful to nature, humans and built infrastructure, and their occurrence is anticipated to increase as the climate changes. Reservoirs with the capacity for controlled releases and, therefore, a potential buffering capacity during a flood can reduce the potential for downstream damage by mitigating the flood peak. This study, objective is to evaluate the flood-dampening effects of reservoirs along the Leirelva Watercourses in Trondheim Kommune. To conduct this research, various methodologies are employed. Building of a routing model for computations of dampening effects, hydraulic simulation with HEC RAS 2D, and hydrological modelling setup are the primary methods. Along the Leirelva watercourses, three dams are connected in series; one dam transfers discharge to downstream dams, while the Leirsjøen dam receives floodwaters from the Kvistingen and Skjellbreia dams. Based on the flood routing results, the Kvistingen dam dampens the Q500 from 4.1m3/s to 3.97 m3/s by 3.76% dampening effects. The pre-release capacity is determined by lowering the water level by 2.5 meters, and the dampening effect is 13.85%. The dam is evaluated with a low flood M50 design flood of 2.47 m3/s and a dampening effect of 12.43 %. Following pre-release capacity, the dam mitigates 59.47% of incoming flooding. Dam Skjellbreia is designed for a Q1000 return period with 18.12 m3/s reduced to 14.49 m3/s by 20.02% dampening effects. This dam has a pre-release capacity of 2.55 meters water level and a dampening effect of 20.6%. Additionally, the Skjellbreia dam is tested with a low flood M50 design flood of 14.21 m3/s. With dampening effects of 24.44%, a dam reduces low flood to 10.78 m3/s. The dam dampening effects are 24.44% after pre-release capacity. The design flood for the Leirsjøen dam is Q1000, and the total incoming flood is 28.55 m3/s. Dam reduces flooding to 28.32 m3/s through dampening effects of 0.82 percent. Reduced by 3.13m water level for pre-release capacity and 0.86 percent for dampening effects. Total low flood M50 entering this dam is 21.87 m3/s, which reduces to 20.95 m3/s by dampening effects of 4.23 percent. After pre-release capacity, the dampening effects rise to 4.24 percent. Total outflow floods from the Leirsjøen dam are 28.32 m3/s, which is used by HEC-RAS 2D for hydraulic simulation along the Leirelva watercourses in order to evaluate potential downstream river damage. According to the simulation, Granåsen parking lot, Selsbakk factory or forskslia, and the Proven area are severely flooded by the Leirsjøen dam outcoming floods. This watercourse is hydrologically modelled for the purposes of flood management and to prepare potential buffering prior to a flood by lowering the water level to capture the incoming flood.

SAMMENDRAG

Flom kan være skadelig for naturen, mennesker og bygd infrastruktur, og forekomsten av flommer forventes å øke som en konsekvens av endringene i. Magasiner med kapasitet for kontrollert tapping og derfor en potensiell bufferkapasitet under en flom kan redusere potensialet for nedstrøms skade ved å dempe og forskyve flomtoppen. I denne studien er målet å evaluere de flomdempende effektene av magasin i Leirelva-vassdraget i Trondheim kommune. For å utføre denne analysen brukes forskjellige metoder. En ruting modell for beregninger av dempende effekter er programmert, hydraulisk simulering med HEC RAS 2D for flomutbredelse og oppsett av en hydrologisk modell for tilsigsprognoser er de viktigste metodene. Langs Leirelva-vassdragene er tre magasiner koblet i serie; et magasin (Kvistingen) overfører vann til nedstrøms magasin, mens Leirsjøen mottar flomvann fra Kvistingen og Skjellbreia. Basert på flomrutingsresultatene demper Kvistingen Q500 fra 4,1 m^3/s til 3,97 m^3/s med 3,76%. Om vannstanden før flomepisoden senkes med 2,5 meter, øker dempningseffekten til 13,85%. Magasinet ble også evaluert med en flom tilsvarende 50-års nedbør(M50) som gir en designflom på 2,47 m^3/s og en dempende effekt på 12,43 %. Ved nedtapping før flomepisoden er reduksjonen i Kvistingen 59,47% av innkommende flom. Dam Skjellbreia er som er designet for en returperiode på 1000 år tilsvarende en flom på 18,12 m^3/s blir får en utløpsflom på 14,49 m3/s tilsvarende en 20,02% dempende effekt. Ved forhåndsnetapping på 2,55 meter vannstand får en en dempende effekt på 20,6%. I tillegg testes Skjellbreia magasinet med en flom fra 50-årsnedbør(M50) som tilsvarer en designflom på 14,21 m^3/s. Med en flomdempende effekt på 24,44% reduserer magasinet vannføringen til 10,78 m^3/s. Designflommen for Leirsjøen magasinet er Q1000, og den totale innkommende flommen er 28,55 m^3/s. Magasinet reduserer flommen til 28,32 m^3/s tilsvarende en dempende effekt på 0,82 prosent. Reduserer en vannstand før flom med 3,13m øker flomdempingen bare maginalt til 0,86 prosent. Ved 50-årsnedbør, tilsvarer 21,87 m^3/s, får vi en reduksjon til 20,95 m^3/s som gir en dempeeffekt på 4,23 prosent. Også i dette tilfellet gir forhåndstapping en marginal økning i demping til 4,24 prosent. En flomvannføring fra Leirsjøen 28,32 m^3/s, er brukt som inngangsdata til HEC-RAS 2D for hydraulisk simulering langs Leirelva-vassdraget for å evaluere potensiell nedstrøms eskade. Ifølge simuleringen blir Granåsen parkeringsplass, Selsbakk fabrikk-Forsøkslia, oversvømmet av flommen fra Leirsjøen. Vassdraget er videre hydrologisk modellert med tanke på flomhåndtering og for å forberede potensiell lagring

før en flom ved å senke vannstanden før flommen oppstår. Den hydrologiske modellen kan brukes i en driftssituasjon for å planlegge flomhåndtering og et eksempel på dette er vist.

ACKNOWLEDGMENTS

I would like to express my deep appreciation and gratitude to all those who have supported and guided me throughout the course writing of this Master Thesis.

First and foremost, I would like to extend my heartfelt gratitude to my thesis advisor Knut Alfredsen. Their expertise, dedication, and invaluable guidance have been instrumental in shaping the direction and quality of thesis. I am truly grateful for their patience, insightful feedback, and unwavering support throughout the entire process.

I would also like to thank the faculty members of the Civil and Environmental Engineering for their contributions to my academic journey. Their passion for teaching, their commitment to excellence, and their willingness to share their knowledge have greatly enriched my understanding of the subject matter and have played a significant role in the completion of this thesis.

I would like to acknowledge the contribution of the researchers and scholars whose works have laid the foundation for my research. Their dedication to advancing knowledge and their significant contributions to the field have served as a source of inspiration and have informed my own work.

Finally, I would like to express my gratitude to the NORAD for providing financial Support that have facilitated the completion of this HPD Program. I am thankful for the academic environment, the access to libraries, databases, and research materials, and the support from other NTNU staff that have been instrumental in my academic growth.

To all those who have played a part, whether big or small, in shaping this thesis, I offer my heartfelt thanks. Your contributions and support have been invaluable, and I am truly grateful for your presence in my academic journey.

DECLAIMER

I hereby to verify that '***Flood Dampening by Reservoirs in Trondheim Kommune***' is my own works which is submitted to Norwegian University of Science and Technology University (NTNU) as a requirement of M.Sc. Degree in Hydropower Development. I fully referenced the ideas and works of other scholars which is published and not published.

…………………………………………………………………………………….

NOMENCLATURES

DEM	Digital Elevation Model
HRWL	Higher Regulated Water Level
VM	Critical Magazines Duration
AM	Area of Magazines
C	Overflow Coefficient
L	Length of Floodway
Qi	Inflow Flood
Qo	Outflow Flood
2D	Two Dimensional
HEC-RAS	Hydrologic Engineering Center River Analysis System
NVE	Norwegian Water and Energy Directorate
M5	Five-year Precipitation
M-50	50-year Return Period Design Flood
Q-1000	1000-year Return period Flood
Q-500	500-year Return Period Flood
Fly Discharge	Discharge on scanning laser data date
TCT	Terrain Correction Techniques
PET	Potential Evapotranspiration
NWS	National Weather Service

Table of Contents

SUMMARY I

SAMMENDRAG II

ACKNOWLEDGMENTS IV

DECLAIMER V

NOMENCLATURES VI

List of Tables X

List of Figures XI

1. INTRODUCTION 1

1.1. Floods 1

1.2. Flood Protection 2

1.3. Geographical location of the water courses 3

1.4. Objectives of the Study 3

1.4.1. Specific Objectives of the Study 3

1.5. Scope of the Study 4

1.6. Limitation of the Study 4

2. THEORY 5

2.1. Flood Dampening Process 5

2.2. Flood Duration 5

2.3. Extreme Precipitation 6

2.4. Rainfall-Runoff Model 6

2.4.1. Model Parameter 7

2.5. Reservoir Routing 8

2.6. Hydraulic Model with HEC-RAS 2D 8

2.7. Hydrological Modeling for Flood Management 8

3. LITERATURE REVIEW 10

4. DATA ACQUISTION AND ANALYSIS TOOL 12
4.1. Catchment characteristics 12
4.2. Precipitation, Temperature and Runoff data 13
4.3. Other Data 13
4.4. Software Tool 14
5. METHODOLOGY OF THE STUDY 15
5.1. Developing Routing Model 15
5.1.1. Storage-Water level curve (S-H Curve) 15
5.1.2. Outflow-water level curves (Q-H Curve) 15
5.2. Test Dampening effects of the reservoirs for T-Year flood 15
5.2.1. Test the effect of dampening for Low flood (M-50) 16
5.3. Setup of Pre-release capacity 16
5.4. Hydraulic Modelling with HEC-RAS 2D 16
5.5. Setup Hydrological Modelling 17
6. RESULTS 18
6.1. Storage-Water level (S-H) curve 18
6.2. Outflow-Water level (Q-H) Curve 19
6.3. Flood Duration 20
6.4. Computed QT-Flood and PMF 20
6.5. M-50 (PMF)-Design Flood Computation 21
6.5.1. Model Parameters 22
6.6. M50-Design Flood Routing Results 24
6.6.1. M50-Kvistingen Dam Routing Results 25
6.6.2. M50-Skjellbria Dam 26
6.6.3. M50-Leirjøen Dam 27
6.7. Q-T-Return Period Routing Results 28

6.7.1. Q500- Kvistingen Dam 29

6.7.2. Q1000-Skjellbreia Dam 30

6.7.3. Q1000-Leirsjøen Dam 32

7. DISCUSSIONS 34

7.1. Reservoirs Dampening Effects 34

7.1.1. Kvistingen Dam 34

7.1.2. Skjellbreia Dam 36

7.1.3. Leirsjøen Dam 39

7.2. Hydraulic Modelling by HEC-RAS 2D 41

7.2.1. Terrain Modification 41

7.2.2. HEC-RAS 2D Simulation along Leirelva Watercourses and Results. 44

7.2.3. HEC-RAS 2D Simulation with Culverts on Leirelva River 47

7.3. Building Hydrological Model for Forecasting 48

7.3.1. Data preparation for Calibration and its Quality 48

7.3.2. Potential Evapotranspiration (EPOT) Computations 49

7.3.3. Calibration Nearest Station on 1hour Resolution 50

7.3.4. Calibration on Daily basis for Svarrtjørnbekken Gauging Station. 52

7.3.5. Simulated Runoff Series for Leirelva Watercourse by Parameter Transfer 53

7.3.6. Flood Forecasting with Hydrological Model for Leirelva Watercourses 54

7.3.7. Flood Routing with Forecasted Simulated Runoff for Pre-Release Capacity ... 58

7.4. Sensitivity Analysis and Uncertainty 58

8. CONCLUSION 60

8.1. Flood dampening along Leirelva Watercourses 60

8.2. Hydraulic Simulation with Outflow from Leirsjøen Dam 61

8.3. Flood management Setup 61

9. FUTURE WORK 62

References..63

Appendix...XV

List of Tables

Table 4-1: Leirelva Catchment characteristics..12

Table 4-2: Gauging Stations characteristics..13

Table 6-1: Kvistingen S-H data..18

Table 6-2: Skjellbreia S-H data..18

Table 6-3: Leirsjøen S-H data..19

Table 6-4: Skjellbreia and Leirsjøen Dam Q-H Curves..20

Table 6-5: Flood Duration in Hours from Reports..20

Table 6-6: PMF, Q500 and Q1000 From the Reports...21

Table 6-7: Model Parameters for all dams...22

Table 6-8: Computed Model Parameters from Reports (NVKGRUPPEN, 2000)..................22

Table 6-9: Summary of M-50 Design Flood for Leirelva Watercourses 24

Table 6-10: Summary of M50-Kvinistingen Dam Results before reduction of water level....25

Table 6-11: Summary of M50-Kvinistingen Dam Results after reduction of water level.......26

Table 6-12: Summary of M50-Skjellbreia Dam before water level reduction 26

Table 6-13: Summary of M50-Skjellbreia dam after reduction of water level........................27

Table 6-14: Summary of M50-Leirsjøen Dam result...28

Table 6-15: Summary of M50-Leirsjøen dam after water level reduction 28

Table 6-16: Q-T and Their consequences for all dams 29

Table 6-17: Summary of Q500-Kvinistingen dam routing...29

Table 6-18: Summary of Q500-Kvistingen Dam after reduction of water level 30

Table 6-19: Summary of Q1000-Skjellbreia dam...31

Table 6-20: Summary of Q1000-Skjellbreia dam after water level reduction........................31

Table 6-21: Summary of Q1000-Leirsjøen Dam routing result 32
Table 6-22: Summary of Q1000-Leirsjøen dam after water level reduction 33
Table 7-1: Scaling fly discharge from Hokkfossen Gauging station 43
Table 7-2: Computed Hydraulic calculation with fly discharge. 43
Table 7-3: Calculated Potential Evapotranspiration (PET) 50
Table 7-4: 1-hour calibration result from nearest catchments.. 50
Table 7-5:Weather forecast for 10-day for Leirsjøen dam. 55

List of Figures

Figure 2-1: Inflow Qi and Outflow Qo of the Reservoirs 5
Figure 2-2: M5(24-hr) values for Norway for 1957-1990 6
Figure 2-3: Sketch of Rainfall-Runoff model (NVE, 2011) 7
Figure 5-1: Terrain Correction Techniques for Leirelva (Choné, et al. (2018))....................... 17
Figure 6-1: Capacity Curve for Kvistingen Dam (SWECO, 2005) 19
Figure 6-2: M-50 and rainfall -Kvistingen dam 23
Figure 6-3: M-50 Skjellbreia Dam 23
Figure 6-4: M-50 Leirsjøen Dam 24
Figure 6-5: M50-Routing Result -Kvistingen dam 25
Figure 6-6: M50- Kvistingen dam after 2.5m water level reductions...................................... 25
Figure 6-7: M50-Skjellbria dam routing result 26
Figure 6-8: M50-Sjellbria dam routing after reduction 27
Figure 6-9: M50-Leirsjøen dam routing result before reduction of water level 27
Figure 6-10: M50-Leirsjøen Dam after water level reduction 28
Figure 6-11: Q500-Routing Result Kvistingen 29
Figure 6-12: Q500-Routing Result Kvistingen after reduction of water level 30
Figure 6-13: Q1000-Skjellbreia dam routing result before water level reduction 30

Figure 6-14: Q1000-Skjellbreia after water level reduction 31

Figure 6-15: Q1000-Leirsjøen result 32

Figure 6-16: Q1000-Leirsjøen after reduction of WL 32

Figure 7-1: Kvistingen dam routing with Q500= 4.1m3/s...34

Figure 7-2: Kvistingen Dam routing with Q500 after 2.5m water level reduction..................35

Figure 7-3:Routing result for Q1000-Skjellbreia at Initial water level....................................37

Figure 7-4: Q1000 routing result for Skjellbreia dam at new initial water level for Pre-release capacity 37

Figure 7-5: Q1000 for Leirsjøen dam at initial water level. 39

Figure 7-6:Q1000 for Leirsjøen dam after reduction of water level with new initial water level..40

Figure 7-7: River Cross section from Upper Part of the Leirelva watercourses.......................42

Figure 7-8: Cross Section before Terrain Modification or LiDAR Data 43

Figure 7-9: Cross section after Terrain Modification with Full Bathymetry 44

Figure 7-10: Granåsen Parking area flood Inundation area 45

Figure 7-11:Selsbakk Factory or Forsøkslia Flooding Areas...46

Figure 7-12: Proven Flooded Area...46

Figure 7-13: Effects of Culvers on Simulation 47

Figure 7-14: Svarrtjørnbekken Precipitation for calibration..48

Figure 7-15: Svarrtjørnbekken Temperature grC...49

Figure 7-16: Svarrtjørnbekken Runoff in m3/s..49

Figure 7-17: Svarrtjørnbekken Simulated and Observed Runoff for 1hour basis. 51

Figure 7-18: Hokkfossen Simulated and Observed Runoff for 1-hour basis...........................51

Figure 7-19: Accumulated and Simulated runoff of daily basis in mm 52

Figure 7-20: Observed and Simulated runoff for daily basis in m3/s......................................53

Figure 7-21: Snowpack in mm for daily basis 53

Figure 7-22: Leirelva Simulated Runoff in m3/s from 1970-2023..54

Figure 7-23: Model Updating for the Future Forecast without Observed Runoff 55

Figure 7-24:10-day forecast with different Climate data along Leirelva Watercourses until 25 of June 2023. 56

Figure 7-25: Weather forecast with different Climate data along Leirelva Watercourses until start of Winter 2023 57

Figure 7-26: Forecasted simulated Runoff with Normal Climate Data 57

Figure 7-27: Forecasted Simulated Runoff with 2grC, +2grC of temperature and 200% of Precipitation. 58

1. INTRODUCTION

1.1. Floods

Worldwide, floods are the most prevalent sort of natural disaster, and they pose significant threats to human lives, private property, agricultural production, and the environment's capacity to remain healthy (Mishra, A. et al. (2022)). This has been the case for thousands of years, and it is unlikely to change soon, given that climate change forecasts predict a global increase in short intensive rainfall events and an increase in the intensity and frequency of extreme precipitation in mid-latitude regions (Collins, M. 2013). Urbanization converts permeable landscapes to impermeable concrete in densely populated cities. Surface runoff from heavy rainfall flows into surface waterbodies or urban sewage systems due to a lack of soil. Urbanization reduces infiltration, increases runoff, and floods (Abass, K. (2022)). Land-use change and floods are tightly associated, therefore a watershed facing fast urbanization would experience a succession of floods, causing more human and economic loss (Fernando, N et al. (2022)). However, intense or prolonged rainfall is not the only cause of flooding. Other causes include snowmelt, storm surges from cyclones, and even man-made factors such as dam or levee failure, which frequently occur in conjunction with heavy precipitation. Floods are the most common natural disaster1 and the primary cause of death, having killed 6.8 million people in the 20th century. The highest mortality rate (death per flood event) is associated with flash floods, which are characterized by intense precipitation, high flood velocities, and shorter warning periods (Doocy, S. et al. (2013)).

Flash floods cause most weather-related deaths in the US. The National Weather Service (NWS) establishes a survey team to investigate and report on weather-related disasters with 30 or more deaths or $100 million in property damage. All NWS survey reports on flash floods from 1969-81 were analysed to establish mortality, warning effects, and causes of death. 32 flash floods caused 1,185 deaths-37 each flood. The four flash floods caused by dam breaks following heavy rainfall had the greatest average mortality toll. 18 flash floods in 1977-81 compared to 14 in 1969-76 resulted in 2 1/2 times more deaths. The survey team found that flash floods with inadequate warnings caused more than twice as many deaths (French, J., et al. (1983)).

In the final decade of the 20th century, floods killed 100,000 people and impacted more than 1.4 billion people worldwide. Flooding is estimated to cost the global economy between 50 and 60 billion US dollars annually. According to a United Nations (UN) study, floods claim an average of 22,800 deaths annually and cost the Asian economy an estimated US$ 136 billion. The losses incurred by developing countries per unit of gross domestic product are five times greater than those of developed nations (Shrestha, M. S., & Takara, K. (2008)).

Floods dominate European natural disasters. Flooding kills, injures, and mentally ill. Floods' health effects are often overlooked because worry and despair can last months or years. European floods rarely affect communicable diseases. If they can forecast, cope, resist, and recover from natural disasters, a person or group is vulnerable. Vulnerability evaluation is hard. Flooding harms the elderly, disabled, children, women, ethnic minorities, and poor. Improve epidemiology data before creating vulnerability indices. Pre-disaster preparation could replace post-disaster improvisation with better information. Although public health efforts have failed, a risk-based disaster management system of readiness, response, and recovery can reduce flood-related health effects (Hajat, S. et al. (2005)).

Norway is vulnerable to flooding, but its small population prevents mortality rates from reaching the levels mentioned. Only 100 people have died in Norwegian floods. Over 300 years, disasters2 have struck the nation. The "Storofsen" flood of 1789, the greatest on Glomma, Norway's longest river, caused most of these deaths. heavy snowmelt and persistent heavy precipitation caused 68 deaths and serious damage to farmland, buildings, and cattle along the river reach. The 1995 "Vesleofsen" flood in the Glomma basin killed one person and caused NOK 1.8 billion (USD 0.22 billion) in economic damages (Hansen, B. K. T. (2018)).

1.2. Flood Protection

Flood protection measures may include efforts to reduce a flood by diverting or intercepting portions of it with channels/tunnels or reservoirs, or by constructing flood-resistant levees and dams in vulnerable areas. Examples include dams in the Mississippi river valley in the United States, Egypt's Aswan High Dam on the Nile River, China's Linhuaigang project on the Huaihe River, and Canada's Red River Floodway. A typical reservoir is designed to store water during the wet (flood) season and distribute it during the dry season for purposes such as water supply, irrigation, and hydropower generation. This is because a reservoir's primary purpose is to store water from the wet (flood) season and disperse it during the dry season. However, there may be a conflict of interest between flood protection and other uses if reservoirs are already full when a flood is predicted; there is a chance that the flood won't be as severe as predicted, and if the reservoir is drained to make room for it, there may be insufficient water for other uses in the future(Hansen, B. K. T. (2018)).

This thesis seeks to investigate the effectiveness of reservoirs as a flood dampening strategy and the trade-offs associated with their construction and operation. It will review relevant literature on the topic, examine case studies of reservoirs used for flood control, and assess the impact of reservoirs on social, economic, and environmental factors. The findings of this study will contribute to the understanding of the benefits and drawbacks of reservoirs as a flood dampening strategy and inform policy decisions on their implementation.

1.3. Geographical location of the water courses

Trondheim Kommune is a central Norwegian municipality. It is located in Trøndelag, and its approximate geographical coordinates are 63.43050 North and 10.39510 East. Trondheim Kommune is the Norwegian municipal government agency responsible for providing services such as education, health care, public transportation, and wastewater management to its residents.

Along the river Leirelva are numerous hiking and biking pathways, making this a popular recreational area. The river is renowned for its salmon and trout fishing, and local authorities sell fishing licenses.

1.4. Objectives of the Study

The main goal of this study is to determine how reservoirs in Trondheim kommune along the Leirelva watercourses can dampening the flood.

1.4.1. Specific Objectives of the Study

- ✓ Briefly review the current work on design flood computations and flood dampening work
- ✓ Prepare data for the Leirelva and Evaluate data quality and any uncertainties that is necessary to propagate into the dampening computation.
- ✓ Establish the flood scenarios for the analysis in this project.
- ✓ Carry out a flood dampening study for the Leirelva watercourses by developing a

routing model for the reservoir, evaluate the dampening effect given different water levels in the reservoirs, evaluate the potential for pre-releases of water and do the dampening computation for the flood scenarios established in 3).

- ✓ Evaluate the sensitivity of the model from 4) and how uncertainties in data influences the results from the computations.
- ✓ Establish a hydrological model for the reservoirs that could be used to generate the inflow prognosis in a flood management setup.

1.5. Scope of the Study

The primary goal of this study is to calculate the dampening effects of the dam along the Leirelva watercourses with their design flooding. In addition to the flood dampening effects, it is essential to calculate the hydraulics of the watercourses in order to determine the downstream effects of entering floods. likewise, the development of a hydrological modelling for flood management is a component of this study.

1.6. Limitation of the Study

- ✓ All dams are old, and the data for constructing the routing model are insufficient. For this analysis on Storage-Water Level Curves, assumptions are made that may contribute to the uncertainty of the data.
- ✓ Along the river, there are no culvert data for simulation of hydraulic calculation on the HEC RAS model. Along Leirelva watercourses, there are numerous culverts for which no data are available. Due to a lack of data, all culverts have been removed from the Terrain for this analysis, which influences the simulation. For the continuation of this research, it is necessary to collect and compile data.
- ✓ Leirelva watercourses, there is no gauging station to record observed discharge data and meteorological data. Due to a lack of observed runoff data, the model is not updated for the forecast of future flooding in the context of flood management or hydrological modelling.

2. THEORY

2.1. Flood Dampening Process

The shape of the incoming flood hydrograph entering the reservoir shifts as a result of water releasing out of reservoirs due to the temporary volume of water that has been held there. The peak of the hydrograph will be lowered, the time it reaches its peak will be put off, and the base of the hydrograph will rise. This has a beneficial impact on retention during floods by attenuating the flood waves that are approaching and dampening the peak hydrographs they produce. After then, the damping rate is referred to as the ratio between the peaks of the inflow (Qi) and the outflow (Qo) hydrographs (Souza et al. 2017).

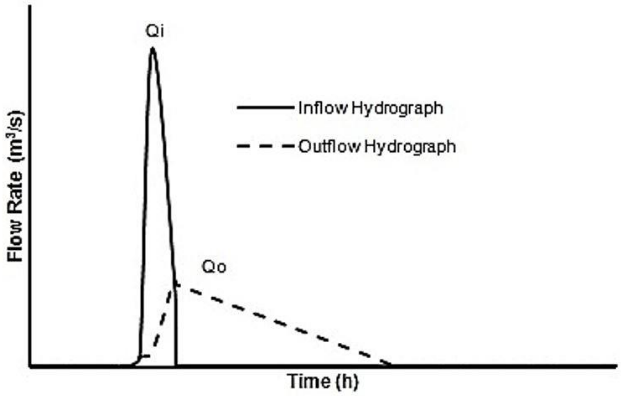


Figure 2-1: Inflow Qi and Outflow Qo of the Reservoirs

Percentage of flood dampening is computed based on the formula:

$$\% - dampening = 100 * \frac{Peak_{inflow} - Peak_{outflow}}{Peak_{Inflow}} \qquad 2.1$$

2.2. Flood Duration

The critical flood duration is the amount of time required to acquire the maximum flood discharge. The duration of the flood is determined by the concentration of time, Vf, and the reservoir critical duration of flood, Vm. The duration of a magazine inundation is computed using the following formula for all reservoirs based on their characteristics.

$$VM = 480 * AM * Qi^{-\frac{1}{3}} * (C * L)^{-\frac{2}{3}} \quad in\ Hours. \qquad 2.2$$

Where, VM is critical magazines duration, AM is area of the magazine at HWRL in Km^2, L is fixed floodway in m, C is overflowing coefficients, Qi is inflow floods in m^3/s.

The above formula is derived by assuming the reservoir's initial water level is at HRWL, a constant overflow coefficient, and a constant inflow flood intensity (NVE, 2011).

2.3. Extreme Precipitation

The Norwegian meteorological institute calculates precipitation values, taking into account a variety of return periods and the highest possible rainfall. The following map provides a map of M5 with varied durations of rainfall values and their associated values.

Figure 2-2: M5(24-hr) values for Norway for 1957-1990

Extreme precipitation is computed for various rainfall durations, seasons, and entire years. It is presumed that the probable maximum precipitation (PMP) values for the year, which are almost always higher than PMP values for the season, occur during the season with the highest PMP values. Precipitation estimates are representative of the fields. Regardless of the precipitation situation, greater precipitation will fall than the point values. Based on their areal reduction values, the point values must be converted to their areal equivalents. The areal reduction factor can be derived from the growth factor presented for MT for various return periods and PMP as a function of M5 for a 24-hour duration. For fields larger than 1000 km2 and those with excellent station coverage, meteorological institutes can calculate areal precipitation without the need for an areal reduction factor (NVE, 2011).

2.4. Rainfall-Runoff Model

Rainfall-Runoff is an alternative method for calculating the magnitude of inflow floods, and model parameters should be calibrated against significant flood events. This model's objective is to calculate the size of inflow flood and potentially snowmelt courses that must be converted to water flow. This model simulation will produce an unregulated inflow flood to the reservoir, residual flow floods upstream of the reservoir, or an unregulated inflow flood from all areas. When utilizing this model to compute inflow flood with a given return period interval, the result should be compared to flood size computed using flood frequency analysis, observed flood data, or flood size computed using other methods (NVE, 2011)

2.4.1. Model Parameter

Essentially, the Rainfall-Runoff model is a linear vessel. The model has the following three parameters, which are determined using a calibration procedure or a formula based on historical data. These parameters consist of K1, K2, and T. The model has a snow routine that is comparable to the HBV model. However, the model is practically distinct from the HBV model, and parameter estimation has been simplified.

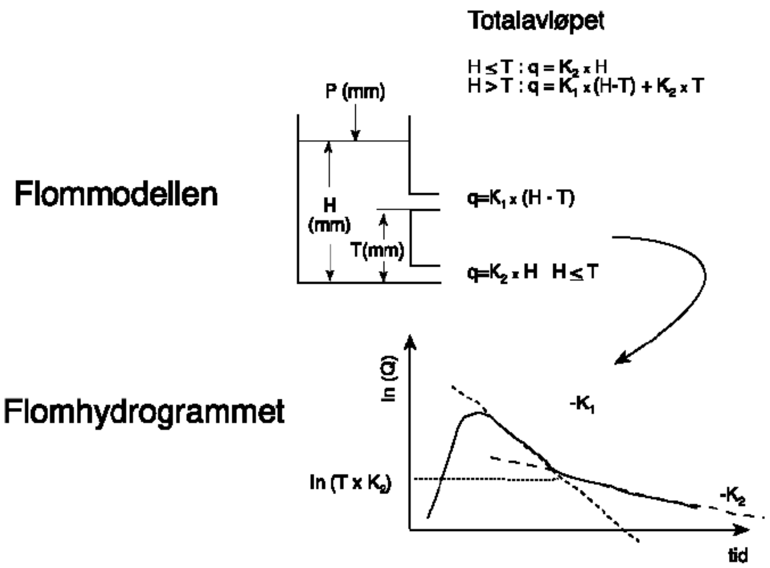


Figure 2-3: Sketch of Rainfall-Runoff model *(NVE, 2011)*

If data are available, model parameters should be calibrated against observed discharge time series; if data are unavailable, field parameters can be used instead. Calibration requires representative observed discharge and precipitation (precipitation and temperature) data with high temporal resolution. If we lack discharge and precipitation data, we can use the following equation.

$$K1 = 0.0135 + 0.00268 * HL - 0.01665 Ln(ASEE) \qquad 2.3$$

$$K2 = 0.009 + 0.21 * K1 - 0.00021 * HL \qquad 2.4$$

$$T = -9.0 + 4.4 * K1^{-0.6} + 0.28 * qN \qquad 2.5$$

Where: K1 Upper discharge constant (per hour), K2 Lower discharge constant (per hour) and T is threshold values (mm). When the effective lake percentage (A_{SEE}) is zero, the value is equal to 0.001 (NVE, 2011).

2.5. Reservoir Routing

Input I(t), Output Q(t), and Storage S(t) are related to continuity equations for hydrologic systems.

$$\frac{dS}{dt} = I(t) - Q(t) \qquad 2.6$$

If the inflow hydrograph into the reservoir is known, the above equation cannot be explicitly solved to obtain the outflow hydrograph Q(t) because both Q and S are unknown. Therefore, a storage function is required to relate S, I, and Q (CHOW, et. al 1988).

2.6. Hydraulic Model with HEC-RAS 2D

HEC-RAS is USACE-developed, open-source software that can simulate 1D, 2D, and combined 1D-2D unsteady flow. This model is also valuable for modeling river channel water quality and sediment transport. In terms of result visualization, HEC-RAS is one of the most widely used hydrodynamic models that can provide results as gridded data, including velocity, depth, water surface elevation, and hydraulic hazard. However, HEC-RAS 2D is used to simulate the system in this investigation. This model solves either the complete Saint-Venant equation or the 2D diffusion wave equation (El Bilali et al., 2021).

2.7. Hydrological Modeling for Flood Management

A model is a simplified representation of a system in the physical world. The most accurate model is the one with the fewest parameters and the least amount of model complexity. Models are primarily employed for predicting system behavior and understand different hydrological processes. A model is comprised of numerous parameters that define its characteristics. A runoff model is a set of equations used to estimate runoff as a function of various parameters used to describe watershed characteristics. The two key inputs required by all models are precipitation data and drainage area. In addition, water discharge characteristics such as soil properties, vegetation cover, watershed topography, soil moisture content, and aquifer characteristics are taken into account. Hydrological models are currently regarded as an essential and necessary tool for the management of water and environmental resources. There are three types of models for hydrological models: Empirical model, conceptual model and Physical based model are the main types of models (Devia, et al. (2015)).

3. LITERATURE REVIEW

Comparing the inflow and discharge during multiple flood events is the primary method for determining the flood dampening percentage. Begueria et al. (2002) analyzed the effect of the Yesa reservoir (Spain) on flooding by comparing observed inflow and outflow hydrographs 41 years after the reservoir's construction. Based on the reservoir's peak inflow and outflow, flood peaks are obviously diminished. When reservoir capacity is below 50 percent, the inundation is controlled. When the reservoir capacity is between 50 and 70 percent, only the greatest flood is managed. According to the report, the diminution largely depends on the water storage level and the season. Only autumn and spring floods are mitigated by reservoirs, while the majority of winter floodwaters are released downstream for dam safety (Begueria et al. (2002)).

Pokhrel, Y., et al. (2018) found that rapid dam development is causing unforeseen changes in the Mekong River basin. This report has three components. The first section assesses the model, while the rest present their research findings. HiGW-MAT and CaMa-Flood global Mekong River basin calibration. Floods and surface water levels calibrate the model. The model then replicates peak floods in the Mekong River basin, key lakes, and flood plains. The main conclusion shows that 26% of total storage dynamics explain Mekong River floodplains. 49% of the lower Mekong River basin has substantial flow change potential, which can modify natural regimes. If the flood peak at the same location is dampened by 50 percent and delayed by one month, a reduction of more than 20 percent in the flood pulse peak near the Stung Treng gauging station could change the water balance of the TSL, possibly halting the flow reversal in the TSR and disrupting lake inundation dynamics. During average and wet years, flood occurrence may increase at the outer edge of the permanent water in the TSL and post-flooding agricultural regions in the middle reach of the Mekong Delta. However, during dry years, flood occurrence may decrease by up to 5 months or more around the outer edge of the flooded areas in the TSL region, in the flood-recession agricultural region upstream of Phnom Penh, and in the downstream portion of the Meko. Flow regulations may influence places flooded for five to six months the least. These findings illuminate how proposed dams may affect downstream flood dynamics to ensure food security and ecological integrity in the Mekong area. These findings affect regional hydropower sustainability. These results show potential downstream implications owing to varied degrees of upstream flow restriction, not the actual impacts of any dam (Pokhrel, Y., et al. (2018)).

Khaddor, I et al. (2021). Study on the impact of the construction of a dam on flood management, the storage reservoir reduces flood water volume and peak inflow discharge. As the return period increases from 2 or 10 to 100 years, the peak input discharge decreases from 80.4 to 40 m3 /s for 2 years and from 333.5 to 174 for 200 years, a 49.8 and 52.2% drop. For 2 and 200 years return periods, 39.45 and 40.38% flood volume attenuation. The model's calibration demonstrated that reducing water levels would prevent it from recreating the 2008 storm's flood size (Khaddor, I et al. (2021)).

Mateo,C et al. (2014) examined how two big reservoirs affected the 2011 Chao Phraya flood in Thailand. The two reservoirs, with a combined storage volume of 23 billion m3, provide flood protection during the wet season and water supply during the dry season. The authors simulated flood dampening from the reservoirs using alternative operational strategies. Historical operation was simulated by setting a fixed discharge rate in the wet and dry seasons (based on bias corrected mean annual inflow) and water storage levels to reach by certain dates (with contingencies for releases during abnormal inflows). The authors simulated flood dampening by changing the storage limit goal level and date. The reservoir lowered the flood peak by 22% and their alternate reservoir operation may dampen it by 6.25% of the unregulated peak, however the authors argued that this did not indicate flood mitigation capability. A model with an integrated floodplain inundation computation (H08 combined with CaMa-flood) reduced the inundated area by 20% in the best scenario. The average 2011 flood plain inundation reduction was 40% (depending on flood depth) (Mateo,C et al. (2014)).

4. DATA ACQUISTION AND ANALYSIS TOOL

4.1. Catchment characteristics

Catchment area, specific discharge, hypsographic curves, lake percentage, and other catchment characteristics are extracted from NVE's NEVINA tool via the website https://nevina.nve.no/ for this study. This tool automatically outlines catchment characteristics based on our points of interest, such as gauging stations and dam locations. The results are exported as both shape and pdf files.

Table 4-1: Leirelva Catchment characteristics

	Area of Study (Local Catchment)		
Characteristics	Kvinistingen	Sjellbirea	Leirsjøen
Area (Km^2)	1.2	7.6	7.6
Local Area (Km^2)	1.2		
ASE (%)	14.84	9.77	4.56
Eff Length(Km)	1.3	4.3	7.6
Spec Discharge(l/s*Km2)	27.7	21.3	19.5
Høyde-Min	428	222	193
Høyde-10	436	226	217
Høyde-20	439	259	225
Høyde-30	448	291	240
Høyde-40	458	328	258
Høyde-50	465	362	282
Høyde-60	475	386	319
Høyde-70	487	411	357
Høyde-80	504	439	392
Høyde-90	516	468	439
Høyde-Max	564	564	564

The above-mentioned catchment characteristics represent both local catchments and total catchment area derived from NEVINA. For this study's analysis, however, local catchments are used for all lakes. Local catchment refers to the net catchment achieved by reducing the contribution of other catchments to other lakes. The lake Leirsjøen receives water from the upland catchments of Kvistingen and Skjellbreia. Local catchment for the Leirsjøen is calculated by subtracting Skjellbreia catchments from the total catchment and using the same method to calculate for Skjellbreia.

Table 4-2: Gauging Stations characteristics

	Guaging Stations	
Characteristics	Hokkfossen	Svarrtjørnbekken
Area (Km^2)	8.1	3.5
ASE (%)	1.24	0.82
Eff Length(Km)	5	3.7
Spec Discharge(l/s*Km2)	27.6	27.9
Høyde-Min	234	280
Høyde-10	288	306
Høyde-20	301	318
Høyde-30	316	329
Høyde-40	329	334
Høyde-50	338	341
Høyde-60	349	352
Høyde-70	359	366
Høyde-80	376	384
Høyde-90	403	414
Høyde-Max	512	511

In addition, a 1m-resolution terrain model is extracted from the NVE tool Høydedata via the website https://hoydedata.no/LaserInnsyn2/. This terrain model is utilized for the hydraulic calculation by the HEC-RAS 2D tool to determine the inundation area in the area downstream of the Leirsjøen dams.

4.2. Precipitation, Temperature and Runoff data

Grid-interpolated precipitation and temperature data for the entire country of Norway with a resolution of 1 square kilometer can be downloaded from the Norwegian Meteorological Institute's seNorge2 database at https://www.senorge.no/. This source contains information from 1957 to the present with daily time resolutions. This extracted data is used to calibrate the discharge data transfer and to configure the hydrological model by PINE HBV. Through this website, runoff data series are extracted from NVE Tool called Sildre NVE.

4.3. Other Data

Trondheim Kommune compiles reports for all dams. Other reports and relevant data are gathered from Professor Knut Alfredsen. The NVE Atlas tool is accessed via the website https://atlas.nve.no/ to obtain basic information about a dam.

4.4. Software Tool

R-Package: R-studio is utilized for hydrological calculation. To calculate the Potential Evapotranspiration (EPOT) for the Hokkfossen, Voll, and Svarrtjørnbekken gauging stations. Using the Thornthwaite method, potential evapotranspiration is calculated. This package also extracts climate data from SeNorge2 for the calibration of discharge.

Excel: Excel is used for flood routing model and graphs.

MS-Word: MS- word is used for the reporting this master thesis.

HEC-RAS 2D: Analysis of the hydraulic calculation and flood inundation for Leirelva water courses.

ArcMap: is used to compute the area beneath the water level for Kvistingen, Skjellbreia, and Leirsjøen to construct the reservoir routing model using the area-elevation curve.

NVE-Tool: NEVINA, Sildre-NVE, SeNORGE, SEKLIMA, and NVE Atlas are utilized to obtain the data as well. Høydedata was also used to obtain Digital Elevation Model (DEM) data with 1m resolution.

Pine HBV: Also used to build the hydrological model for the Leirelva watercourses and to calibrate the model to transfer the catchment properties for ungauged and predict the future flood.

5. METHODOLOGY OF THE STUDY

5.1. Developing Routing Model

The first step in evaluating the effect of reservoir dampening is to construct an Excel routing model. For each reservoir, we must develop an Excel routing model based on their respective data. However, there are insufficient data to construct the model. On the report, only Outlet-capacity curves for all reservoirs are provided. Therefore, we must construct the Storage-water level curves. All dams were constructed in the 1990s, and there is insufficient information on the design document.

There is no measuring station at the reservoirs' location. Therefore, we must transfer the runoff series to construct the model using the scaling procedure. Runoff data are obtained from 2005 to 2023 from Hokkfossen and Svarrtjørnbekken gauging stations.

5.1.1. Storage-Water level curve (S-H Curve)

The reports from Trondheim kommune lack information regarding the reservoir capacity and water level required to construct the S-H Curves. Therefore, it is necessary to measure the storage at various elevations below the water level for the Leirelva water courses (Kvistingen, Skjellbreia, and Leirsjøen). We used a report on the biological diversity of ten water courses in Trondheim kommune to calculate the submerged area at each elevation (Terje Nøst, 2001). On the report is a digital image containing contour lines of varying elevations. The area at each water level is computed by georeferencing the image's contour lines using ArcMap. The relationship between storage and water level is then developed for routing calculation.

5.1.2. Outflow-water level curves (Q-H Curve)

On the reports, the discharge-water level (Q-H) curve is computed for some dams. For the Kvistingen dam, the discharge capacity is calculated. For the Skjellbreia and Leirsjøen dams, however, no calculated outlet capacity exists. However, the formula is listed on the report. Therefore, the outflow capacities of both dams are computed using the formulas and data provided in the reports.

5.2. Test Dampening effects of the reservoirs for T-Year flood

Once the routing model has been developed and is available for calculation, the calculated flood values based on their return periods must be inputted. On the report, floods are computed based on various return periods and consequence classes for each dam. The flood dampening of all reservoirs is defined by the percentage reduction in peak hydrograph. This is determined by comparing the peak flood values calculated before and after routing. Then, the equation below can be used to calculate the percentage of dampening.

$$\% - dampening = 100 * \frac{Peak_{inflow} - Peak_{outflow}}{Peak_{Inflow}}$$

Peak inflow is the peak flood hydrograph before routing, whereas Peak outflow is the peak flood hydrograph after routing.

5.2.1. Test the effect of dampening for Low flood (M-50)

Due to the small size and age of all dams, it is essential to evaluate the dam capacity at minimum flood. In the reports, annual precipitation is provided for Kvistingen dam, and the 50-year design flood is computed for each dam. Then, incorporate M-50 into the routing model and evaluate its low flood dampening effects.

Extreme precipitation (PMP) is determined using a growth factor curve. The annual precipitation (PN) for the Kvistingen dam is provided by the meteorological institute in a 2005 report. Meteorological institutes are contacted if the values of PN need to be updated, but the values remain the same, so we proceed with the values indicated on the reports (met.no. personal communication). And same PN values are assumed for Skjellbreia and Leirsjøen. Areal reduction factor is taken into account during calculation. Finally, the linear tank model is employed to change PMP to PMF (design flood).

5.3. Setup of Pre-release capacity

The routing model is performed at a higher level of regulated water (HWRL). However, we must establish the pre-release capacity prior to the onset of the flood in order to reduce the water level needed for storage and the peak flood. The pre-release capacity is determined by the impact of a flood on the river downstream. This is evaluated by reducing water level reduction by considering environmental protection. Then, we adjust the pre-release water level for each dam to decrease the water level prior to a flood. In reservoirs, 15% of water is designated for environmental purposes for aquatic life.

5.4. Hydraulic Modelling with HEC-RAS 2D

The HEC-RAS 2D model will be used to evaluate the incoming flood from the Leirsjøen dam. This is to assess the impact of the incoming floods after the downstream flooding has been dampened. For HEC-RAS 2D Terrain model (DEM), is downloaded from høydedata.no. The problem with Høydedata is that the terrain model (DEM) lacks complete riverbed bathymetry. In order to obtain the complete bathymetry of the river, we perform the survey twice by using terrain correction techniques (TCT). The TCT evaluates flow depth during the LiDAR survey and adjusts the DEM accordingly. A 2D flow simulation is used to evaluate the flow depth at consistently spaced cross-sections. Each cross section is designed as a rectangular shape, with a wetted width derived from the DEM and the assessed water elevation at the date of LiDAR acquisition serving as the bottom bed elevation. As a result, the 2D flow simulation employs the water surface slope as a proxy for the bed slope. Using linear interpolation between cross-sections, the computed flow depth is then subtracted from the original water surface elevation to estimate the true bed elevation, which is burned into the DEM used for flood modeling (Choné, et al. (2018)).

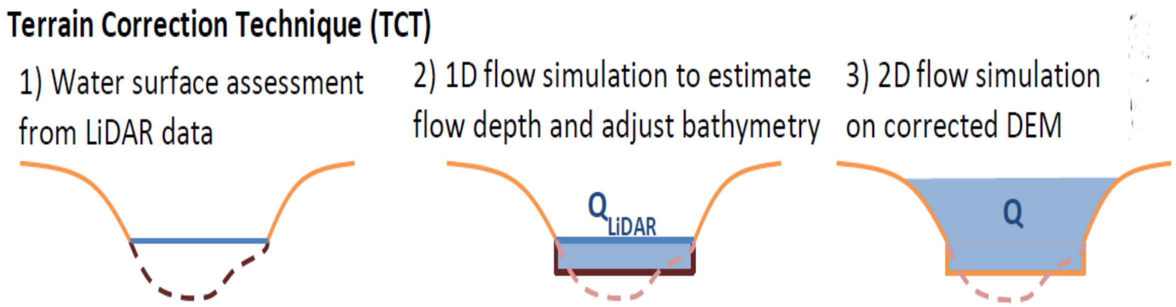


Figure 5-1: Terrain Correction Techniques for Leirelva (Choné, et al. (2018)).

5.5. Setup Hydrological Modelling

A hydrological model is to be developed using catchment properties, climate data, and observed runoff time series to predict future runoff from a catchment area. In this thesis, PINEHBV is used to construct hydrological models. This section will construct a hydrological model for the Leirsjøen dam and predict future flooding along Leirelva waterways. On the Leirsjøen impoundment, there is no gauging station. Therefore, we must calibrate the nearest catchment and transmit its properties. The primary objective of this section, once the model has been developed, is to prepare buffering for approaching flooding. The model should be developed using input data with an hourly resolution.

6. RESULTS

6.1. Storage-Water level (S-H) curve

Since all dams are aging and there are no flood routing data, flooding cannot be predicted. Using the ArcMap application, the storage capacity of every dam along the Leirelva watercourses is computed. The report Environmental investigation of 10 water courses in Trondheim Bymarka (Terje Nøst, 2001) provides all the data required by ArcMap to calculate the storage area. Based on this report, a digital image is captured and uploaded to ArcMap. Then, the area at various elevations is computed. The results for all dams along watercourses are presented in the table below for each pond, based on the information given earlier.

Table 6-1: Kvistingen S-H data

Water Level(m)	Storage(m^3)
411	0
415.0	27724
419.0	102520
423.0	217954
427.0	338592
431.0	482502
435.0	643296
436.0	662389.5
436.5	703593.75

Table 6-2: Skjellbreia S-H data

Water Level(m)	Storage m^3
186.00	0
190.00	153432
194.00	355380
198.00	564616
202.00	795886
206.00	1049882
210.00	1313488
214.00	1569488
218.00	1843140
222.00	2230016
225.68	2422746.4
226.00	2439505.57
226.30	2455217.28
226.50	2465691.76
226.85	2544748.26

Table 6-3: Leirsjøen S-H data

Water Level(m)	Storage(m3)
175	0
179	104238
183	176728
187	280658
191	459750
195	703740
198.13	793005.845

6.2. Outflow-Water level (Q-H) Curve

There is no gauging station to measure discharge data to establish the relationship between outflow and water level (Q-H Curve) for routing calculations. For the Kvistingen dam, the discharge over the spillway is calculated and included in the Kommune report (SWECO, 2005).

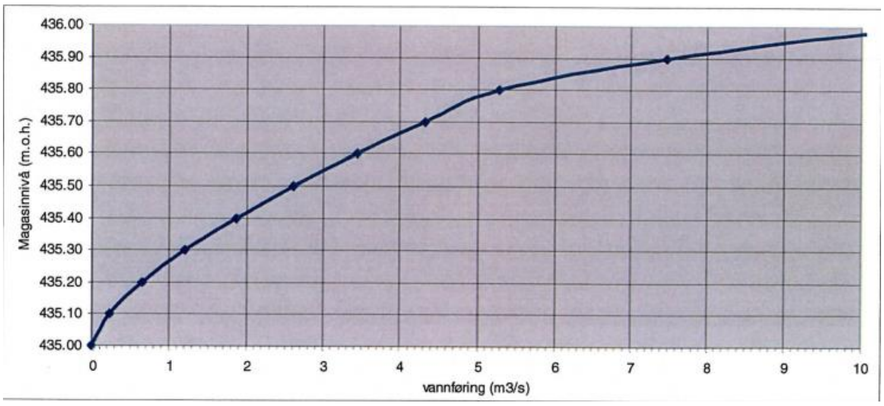


Figure 6-1: Capacity Curve for Kvistingen Dam *(SWECO, 2005)*

For the Skjellbreia and Leirsjøen dams, an output capacity formula is provided in the report. However, the formula for calculating the outflow capacity is different for each dam, as stated in the reports (NVKGRUPPEN, 2000), and the computed Q-H Curve is presented in the table below. Computed values of outflow and water level do not fit, and the curve fitting indicates a negative trendline, which is not used to establish the relationship and to determine the routing formula. Since Q-H Curves exist for every dam, it is difficult to determine the relationship between Q and H. Therefore, Excel's linear interpolation method is utilized for formula-based routing calculation between Q-H Curves.

Table 6-4: Skjellbreia and Leirsjøen Dam Q-H Curves

Skjellbreia Dam		Leirsjøen Dam	
Water Level(m)	Q-total (m3/s)	Water Level(m)	Q-total (m3/s)
225.55	0.00	198.13	0.00
226.00	2.04	198.50	1.23
226.50	5.18	199.00	5.67
227.00	15.62	199.50	6.96
227.50	22.94	200.00	11.47
228.00	47.89	200.50	19.59
228.50	106.97	201.00	32.95
229.00	217.75	201.50	40.29
229.50	401.53	202.00	58.79
230.00	682.31	202.50	93.75

6.3. Flood Duration

Based on equation 2:2, the critical inflow floods for all reservoirs in Trondheim Kommune is computed and presented in the table below. The flood duration is then used to calculate the flood routing and the low flow or M50 design flooding.

Table 6-5: Flood Duration in Hours from Reports

S.No	Dam	Flood Duration (VM) in Hr.
1	Kvistingen	96
2	Skjellbreia	72
3	Leirsjøen	72

All flood duration is taken from the reports calculated by Trondheim Kommune. (NVKGRUPPEN, 2000) (SWECO, 2005).

6.4. Computed QT-Flood and PMF

PMF, Q500, and Q1000 return period flood are computed for Leirelva based on their consequence class. Kvistingen dam is classified as class 1, while Skjellbreia and Leirsjøen are classified as classes 2 and 3. SWECO Company calculates the PMF, Q-500, and Q-1000 return periods for watercourses and the Kvistingen dam in 2005 (SWECO, 2005). NVK Gruppen computes Skjellbreia and Leirsjøen dam in 2000 (NVKGRUPPEN, 2000). The calculated values are tabulated below.

Table 6-6: PMF, Q500 and Q1000 From the Reports

S.no	Dam	Q500/Q1000 (m^3/s)	PMF (m^3/s)
1	Kvistingen	4.1	
2	Skjellbreia	18.12	37.26
3	Leirsjøen	14.87	44.71

The above-computed Q500 Return period for the Kvistingen dam and Q1000 Return period for the Skjellbreia and Leirsjøen dams are then utilized for routing calculation to evaluate the dampening effects. In addition to these values, the M-50 design flood is calculated and evaluated for dampening effects. The Q-1000 and PMF for Skjellbreia dam catchment (18.12 and 37.26 m3/s) includes the catchment area for Kvistingen catchments. Therefore, there is no outflow from Kvistingen dam to Skjellbreia dam, as it is already accounted for in the Q1000 and PMF calculations. All Q-500, Q-1000, and PMF for all dams were calculated almost 20 years ago, and other tools were used instead of NEVINA. The catchment properties and field parameters differ from the NEVINA-calculated values.

6.5. M-50 (PMF)-Design Flood Computation

Using a precipitation-runoff model applied to a linear tank model with two outlets, the design floods are computed. Q-50 is calculated from the 50-year precipitation (M50) for each dam. The precipitation values and scaling factor (n-hours) were computed by the meteorological institute based on the Kvistingen dam report (SWECO, 2005). Annual precipitation in Kvistingen is 1200 millimeters. For these studies, there are no updated precipitation values and constant precipitation is presumed for Leirelva watercourses including (Skjellbreia and Leirsjøen dams). Multiplying precipitation values by an areal reduction factor derived from their catchment areas. The runoff is distributed asymmetrically based on their n-hour duration. On this model, snowmelt has not been accounted for. The model run with an hourly time step for all dams.

6.5.1. Model Parameters

Model parameters are calculated on field characteristics computed by NEVINA.NO.

Table 6-7: Model Parameters for all dams

	Kvistingen	Skjellbreia	Leirsjøen
HL	50	41.86	21.97
K2	0.179265602	0.16441151	0.123802
K1	0.036145776	0.03473572	0.030384
T	11.09711782	9.96250316	11.87047

The previously mentioned Table 6-7 is computed using the field characteristics from NEVINA. However, the value calculated on the company report differs from the above table. The report conclusion is presented in the table below.

Table 6-8: Computed Model Parameters from Reports *(NVKGRUPPEN, 2000)*

	Skjellbreia	Leirsjøen
HL	42.9	14.6
K2	0.141	0.057
K1	0.03	0.018
T	13.7	24

The values derived from the NEVINA report and those derived from the report are different. They calculated the field parameter using a method other than NEVINA.

Based on above new field parameters computed from NEVINA and utilizing linear tank with two outlet M-50 design flood and water flow into all dams along Leirelva watercourses are computed and given in figure below to assess dampening effects with low flow in addition to Q500 and Q1000 floods. Results shown below.

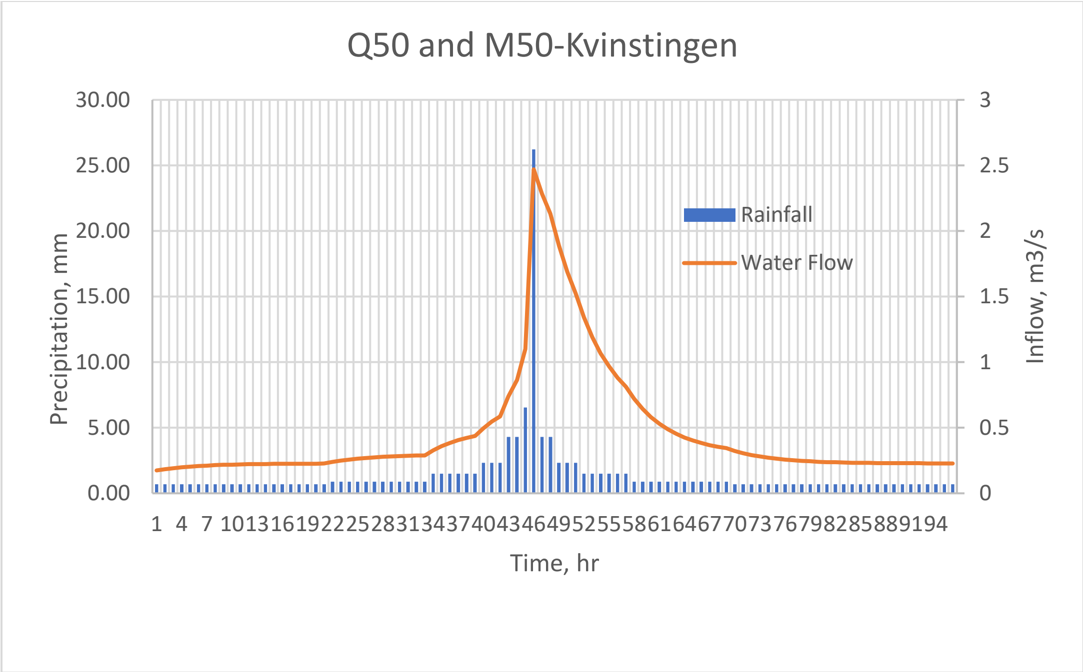


Figure 6-2: M-50 and rainfall -Kvistingen dam

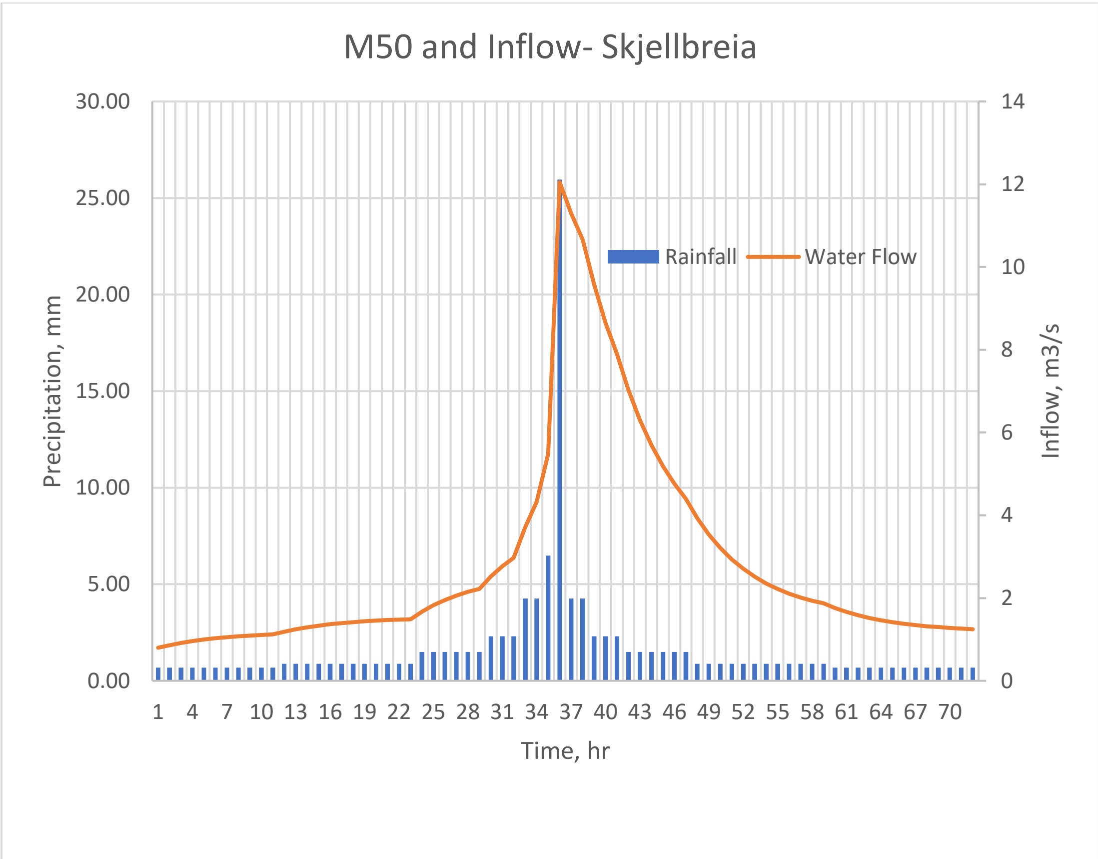


Figure 6-3: M-50 Skjellbreia Dam

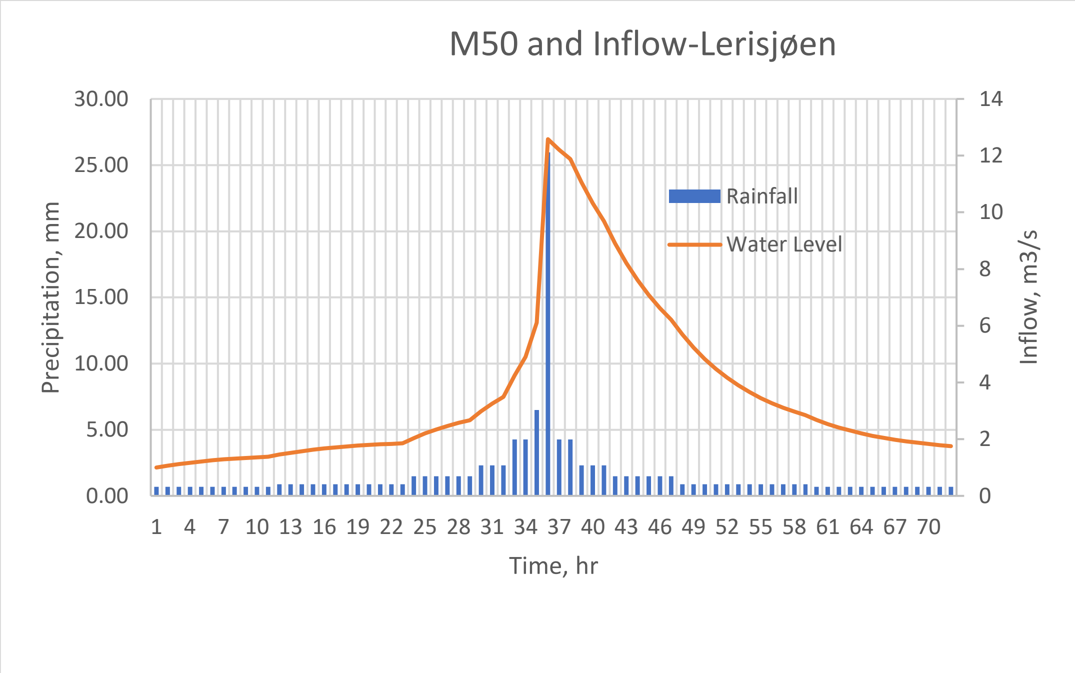


Figure 6-4: M-50 Leirsjøen Dam

The average and Maximum M-50 design floods for all dams are presented in table below. The next step is to compute the flood routing and check the dampening effects for all dams with low flood M-50. Maximum M-50 design flood are used for the routing calculation for all dams.

Table 6-9: Summary of M-50 Design Flood for Leirelva Watercourses

M-50	Kvistingen	Skjellbreia	Leirsjøen
Mean (m^3/s)	0.47	2.84	3.62
Maximum(m3/s)	2.47	12.05	12.58

6.6. M50-Design Flood Routing Results

Then, the flood routing for all dams is computed using the M-50 design flood and the maximum design flood derived from Table 6-9. Based on the result, the damping effects of the dam are also computed using the formula in equation 2.2, which is discussed in the theory section. Initial water level is presumed to be higher regulated water level for all dams, and the routing calculation is performed using this assumption. After that, the pre-release capacity is fixed by considering 15% of the total storage volume capacity for environmental purposes. Since aquatic life exists in all waters, 15% of the total capacity must be accounted for when reduce water level for reducing of water level. The water level is decreased, and flood routing and dampening effects are also determined. Below are the results for every dam before and after the reduction in water level.

6.6.1. M50-Kvistingen Dam Routing Results

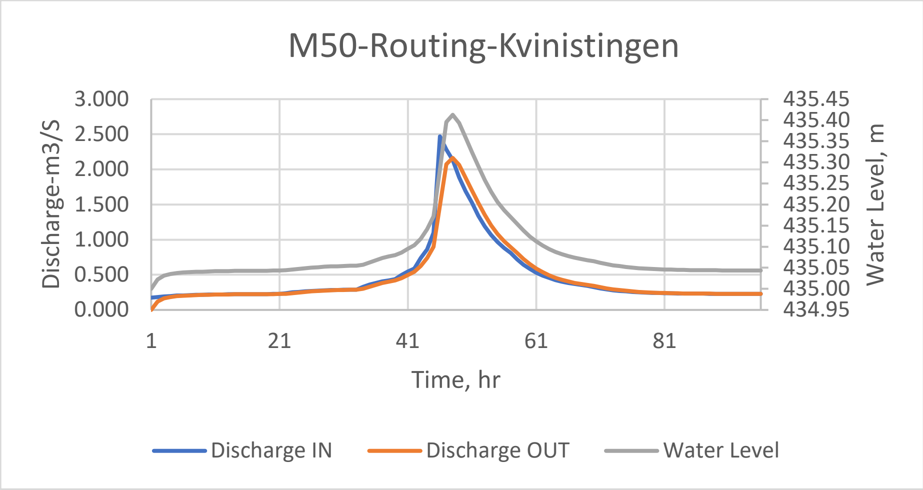


Figure 6-5: M50-Routing Result -Kvistingen dam

Table 6-10: Summary of M50-Kvinistingen Dam Results before reduction of water level

Kvistingen Dam	M50
Maximum Inflow (m3/s)	2.47
Maximum Outflow (m3/s)	2.16
Dampening Effect (%)	12.43
HRWL in Reservoir (masl)	435.41
Maximum water Level(m)	0.41

Since 15% of the storage volume is reserved for environmental purposes, the reservoir should be emptied by lowering the water level by 2.5 meters below the HRWL (435.00 meters) to 435.5 meters before a flood occurs. If 85% of water is reduced, the volume decrease is 0.1Mm3.

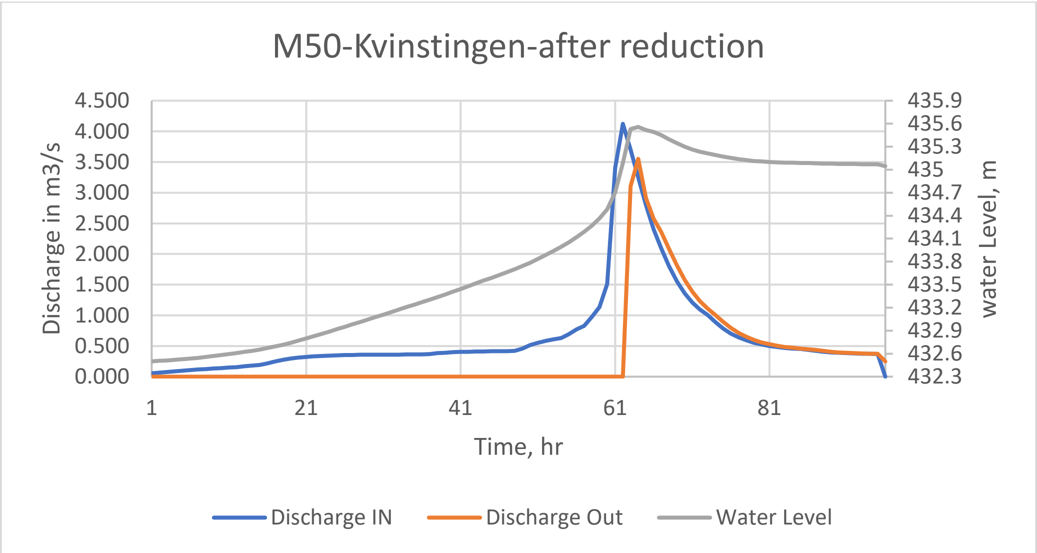


Figure 6-6: M50- Kvistingen dam after 2.5m water level reductions

Table 6-11: Summary of M50-Kvinistingen Dam Results after reduction of water level

Kvistingen Dam	M50
Maximum Inflow (m3/s)	2.47
Maximum Outflow (m3/s)	1.00
Dampening Effect (%)	59.47
HRWL in Reservoir (masl)	435.19
Maximum Water level (m)	0.19

6.6.2. M50-Skjellbria Dam

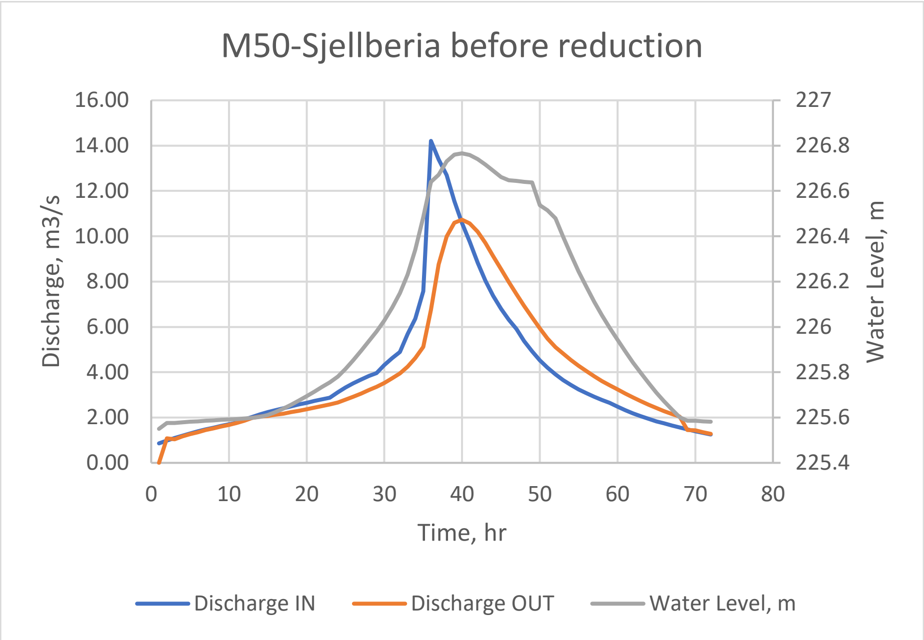


Figure 6-7: M50-Skjellbria dam routing result

Table 6-12: Summary of M50-Skjellbreia Dam before water level reduction

Skjellbreia Dam	M50
Maximum Inflow (m3/s)	14.21
Maximum Outflow (m3/s)	10.73
Dampening Effect (%)	24.48
HRWL in Reservoir (masl)	226.77
Maximum water level (m)	1.22
Max inflow water level(m)	226.69
Max outflow water level(m)	226.38
Water Level Reduction(m)	0.31

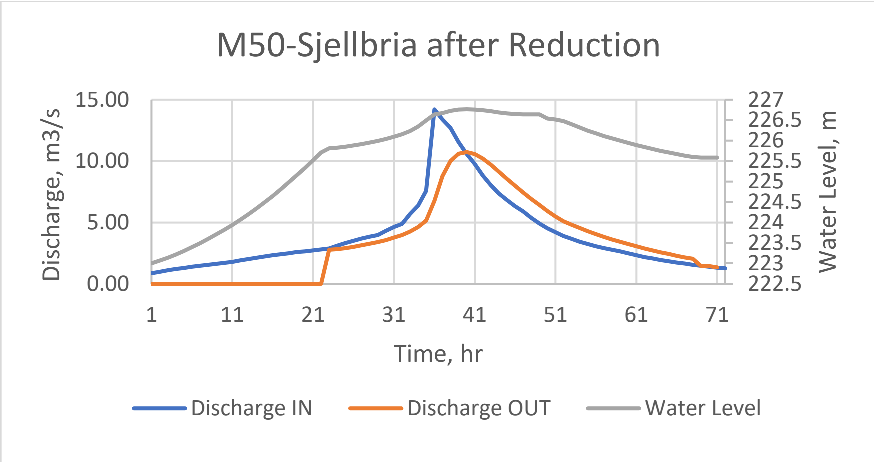


Figure 6-8: M50-Sjellbria dam routing after reduction

Table 6-13: Summary of M50-Skjellbreia dam after reduction of water level

Skjellbria Dam	M50
Maximum inflow (m3/s)	14.21
Maximum outflow (m3/s)	10.73
Dampening Effect(%)	24.46
HRWL in Reservoir (masl)	226.77
Maximum water level(m)	1.22
Max inflow water level(m)	226.69
Max outflow water level(m)	226.38
Water Level Reduction(m)	0.31

6.6.3. M50-Leirjøen Dam

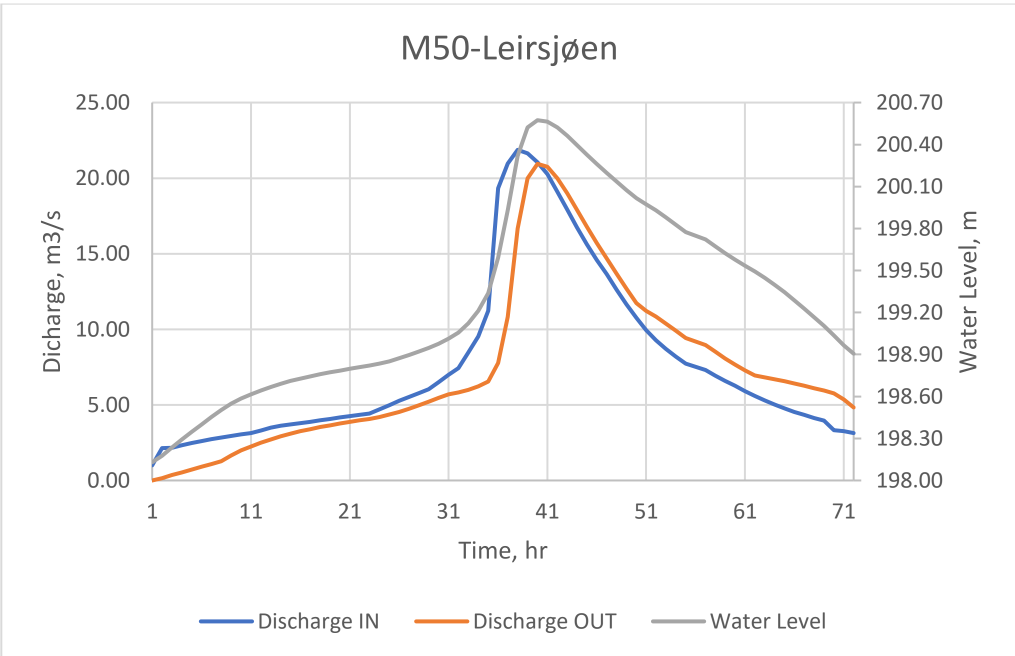


Figure 6-9: M50-Leirsjøen dam routing result before reduction of water level

Table 6-14: Summary of M50-Leirsjøen Dam result

Leirsjoen Dam	M50
Maximum inflow (m3/s)	21.87
Maximum outflow (m3/s)	20.95
Dampening Effect(%)	4.23
HRWL in Reservoir (masl)	200.57
Maximum water level(m)	2.44
Max inflow water level(m)	200.52
Max outflow water level(m)	200.39
Water Level Reduction(m)	0.13

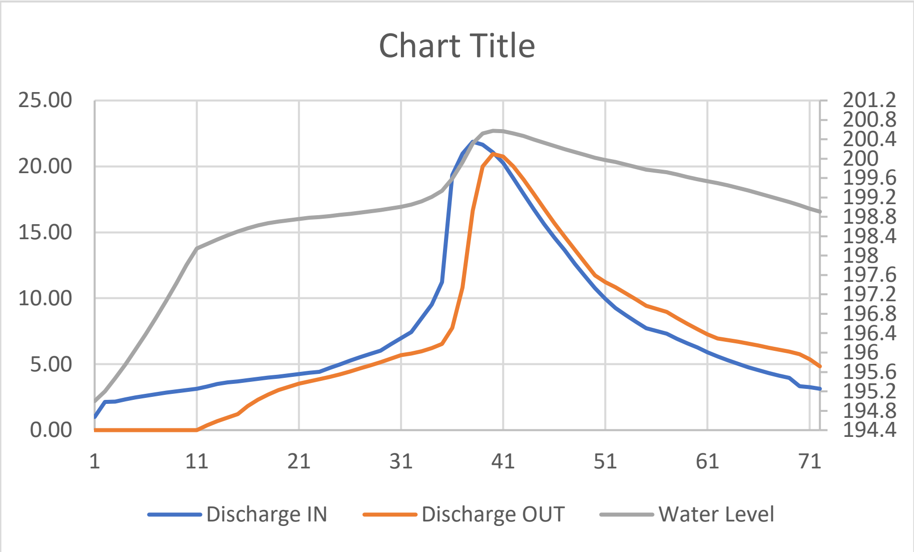


Figure 6-10: M50-Leirsjøen Dam after water level reduction

Table 6-15: Summary of M50-Leirsjøen dam after water level reduction

Leirsjøen Dam	M50
Maximum inflow (m3/s)	21.87
Maximum outflow (m3/s)	20.94
Dampening Effect(%)	4.24
HRWL in Reservoir (masl)	200.57
Maximum Water Level(m)	2.44
Max inflow Water level(m)	200.32
Max outflow Water level(m)	199.85
Water Level Reduction(m)	0.47

6.7. Q-T-Return Period Routing Results

For each dam, the design flood and flood for various return periods (Q-T) are computed based on their consequence classes. The following table provides a summary of all computed values from the report (SWECO, 2005) (NVKGRUPPEN, 2000).

Table 6-16: Q-T and Their consequences for all dams

Dam	Consequence Class	Dimensioning Flood Size	Inflow in (m3/s)
Kvistingen	1	Q500	4.1
Skjellbreia	2	Q1000	18.12
Leirsjøen	2	Q1000	14.87

In addition to the M50-Design flood analyzed in the preceding section, the computed values are used in the dampening effects routing computation for all dams. The results of the routing model for all dams before and after water level reduction are presented in the section below.

6.7.1. Q500- Kvistingen Dam

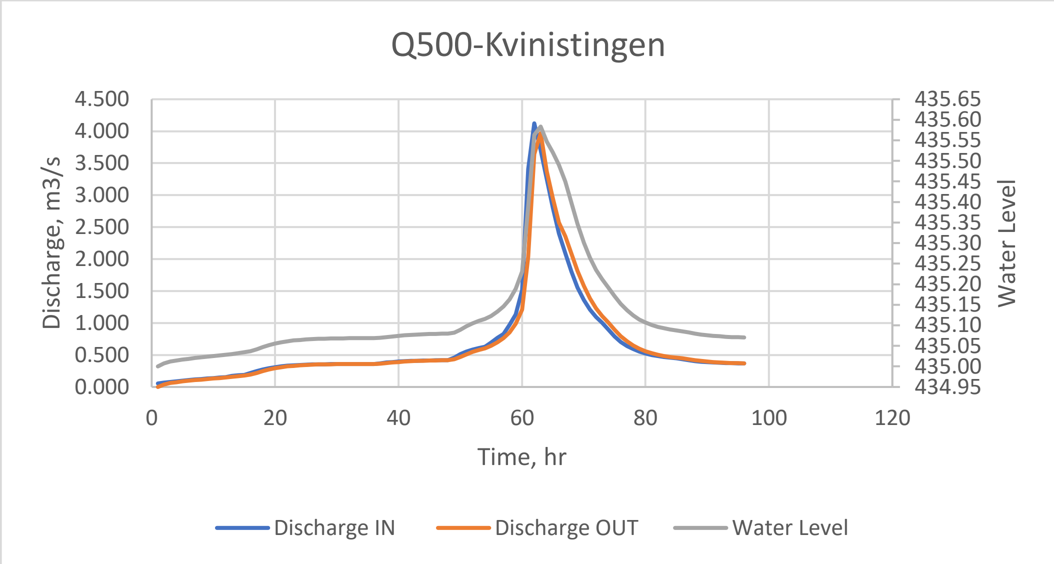


Figure 6-11: Q500-Routing Result Kvistingen

Table 6-17: Summary of Q500-Kvinistingen dam routing

Kvistingen Dam	Q500
Maximum Inflow (m3/s)	4.1
Maximum Outflow (m3/s)	3.97
Dampening Effect(%)	3.76
HRWL in Reservoir (masl)	435.41
Maximum Water Level(m)	0.41

After reduction of water level by 2.5m below HRWL For Q500 flood.

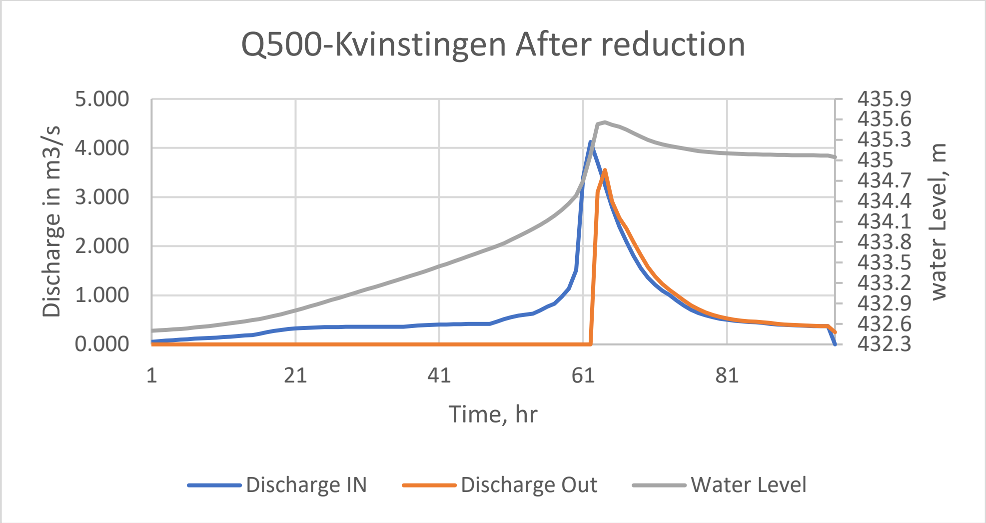


Figure 6-12: Q500-Routing Result Kvistingen after reduction of water level

Table 6-18: Summary of Q500-Kvistingen Dam after reduction of water level

Kvistingen Dam	Q500
Maximum Inflow (m3/s)	4.1
Maximum Outflow (m3/s)	3.55
Dampening Effect (%)	13.85
HRWL in Reservoir (masl)	435.56
Maximum water Level(m)	0.56

6.7.2. Q1000-Skjellbreia Dam

Skjellbreia is the bigger dam if compared with Kvistingen and Leirsjøen dams. The storage capacity is 2.4Mm^3.

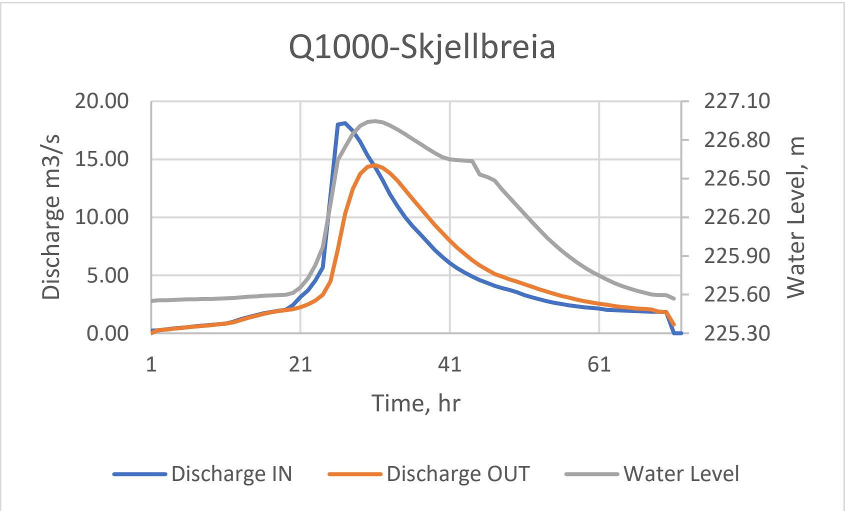


Figure 6-13: Q1000-Skjellbreia dam routing result before water level reduction

Table 6-19: Summary of Q1000-Skjellbreia dam

Skjellbreia Dam	Q1000
Maximum inflow (m3/s)	18.12
Maximum outflow (m3/s)	14.49
Dampening Effect (%)	20.02
HRWL in Reservoir (masl)	226.95
Maximum water level(m)	1.4
Max inflow water level(m)	226.94
Max outflow water level(m)	226.65
Water Level Reduction(m)	0.29

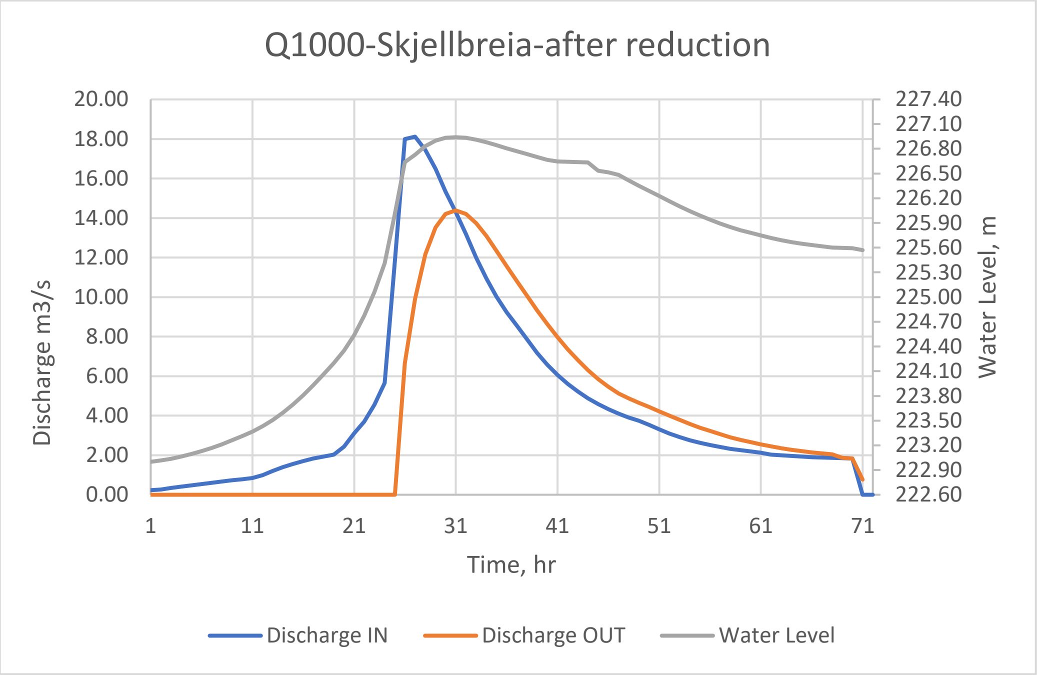


Figure 6-14: Q1000-Skjellbreia after water level reduction

Table 6-20: Summary of Q1000-Skjellbreia dam after water level reduction

Skjellbreia Dam	Q1000
Maximum inflow (m3/s)	18.12
Maximum outflow (m3/s)	14.38
Dampening Effect(%)	20.60
HRWL in Reservoir (masl)	226.94
Maximum water level(m)	1.39
Max inflow water level(m)	226.79
Max outflow water level(m)	226
Water Level Reduction (m)	0.79

6.7.3. Q1000-Leirsjøen Dam

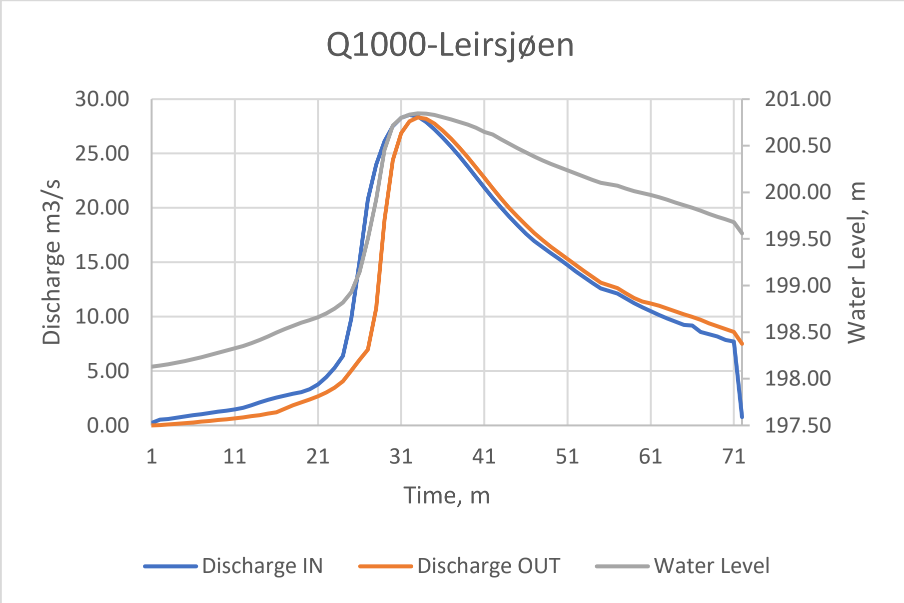


Figure 6-15: Q1000-Leirsjøen result

Table 6-21: Summary of Q1000-Leirsjøen Dam routing result

Leirsjøen Dam	Q1000
Maximum inflow (m3/s)	28.55
Maximum outflow (m3/s)	28.32
Dampening Effect(%)	0.82
HRWL in Reservoir (masl)	200.85
Maximum water level(m)	2.72

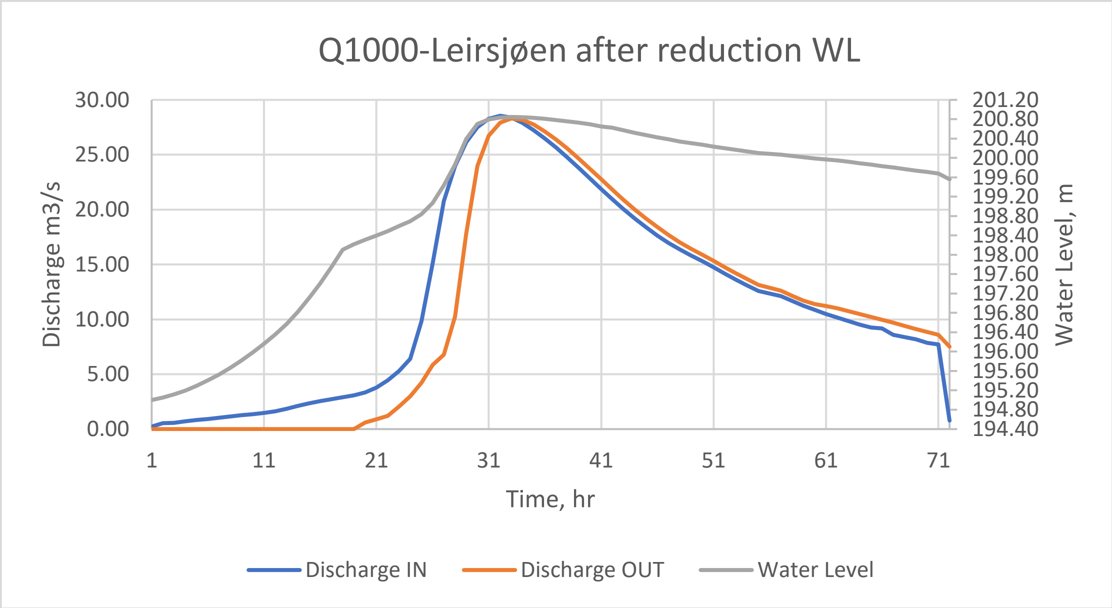


Figure 6-16: Q1000-Leirsjøen after reduction of WL

Table 6-22: Summary of Q1000-Leirsjøen dam after water level reduction

Leirsjøen Dam	Q1000
Maximum inflow (m3/s)	28.55
Maximum outflow (m3/s)	28.31
Dampening Effect (%)	0.86
HRWL in Reservoir (masl)	200.85
Maximum water level(m)	2.72

7. DISCUSSIONS

7.1. Reservoirs Dampening Effects

Lack of data to create a routing model for all dams is the primary limitation of this study. There is no compiled data for creating a model for routing calculations as all dams are old. Based on the report on the Environmental inquiry of 10 water courses in Trondheim Bymarka (Terje Nøst, 2001), a scanned image is captured and digitalized using the ArcMap software to calculate the elevation-area for all dams. The capacity of storage is then computed based on the elevation-area from ArcMap. This technique is inadequate for obtaining accurate data for calculation, as there are no other options for locating data for further analysis.

7.1.1. Kvistingen Dam

The reservoir capacity of Kvistingen dam is 0.6 million m3. The Kvistingen dam is in the upper portion of the Skjellbreia dam, and its discharge serves as the Skjellbreia dam inflow. Higher regulated water level is 435 meters above sea level, and the initial water level for the calculation of flood routing is presumed to be HRWL. The Kvistingen dam is classified as consequence class 1 with a flood capacity of Q500. This dam has a calculated Q500 of 4.1 m3/s (SWECO, 2005). In addition to Q500, a low-flow M-50 design flood is also used to test the dam. According to the routing calculation, the Kvistingen dam reduces the incoming Q500 inundation from 4.1 m3/s to 3.97 m3/s. By means of reservoirs, 0.13 m3/s of water is reduced or subdued. The Kvistingen dam has only a 3.76 percent dampening effect due to this. The reservoir higher regulated water level (HRWL) is 435.41m. The dam's initial water level is 435.00 meters. The highest water level is 0.41m.

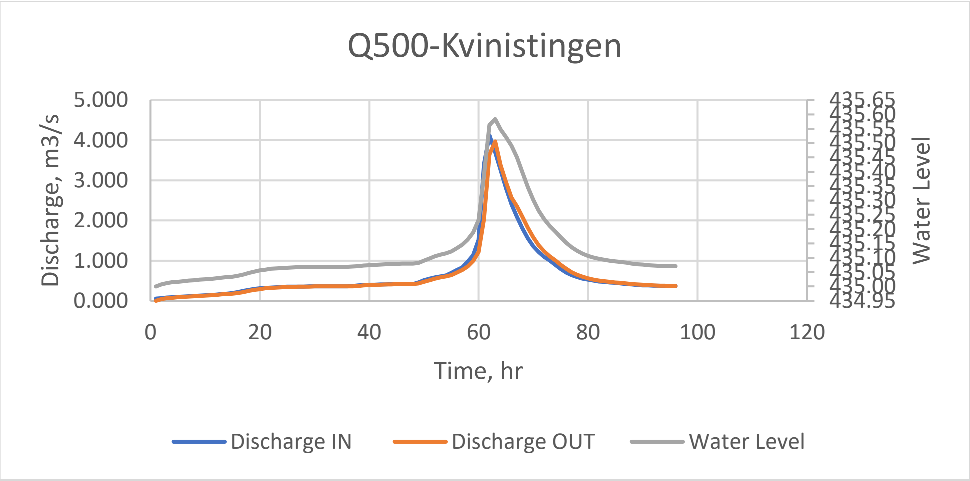


Figure 7-1: Kvistingen dam routing with Q500= 4.1m3/s

On this report, pre-release capacity is also performed. For pre-release capacity, 85% of water level reduction by 2.5 meters below HRWL 435.00 meters. Because the pond is with aquatic life, 15 percent of the water is deemed for environmental protection. To save their lives, 15% of the total volume of the dam is considered, and 85% of the water is discharged before the start of the floods. After water level reduction, the maximum outflow measured is 3.55 m3/s. After a water reduction of 2.5m, 0.55 m3/s is reduced. The dam dampening effects are become 13.85%. This shows that the incoming flow is significantly greater than reservoir capacity.

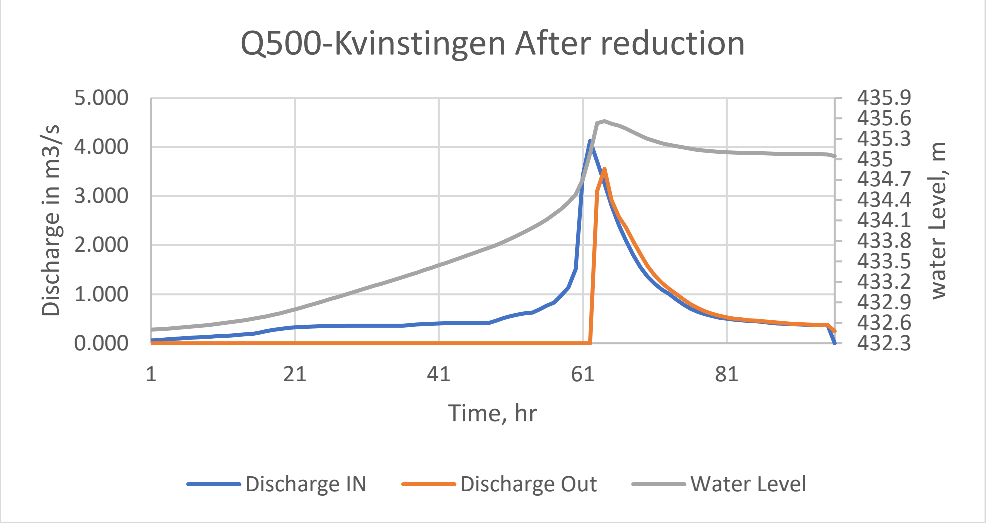


Figure 7-2: Kvistingen Dam routing with Q500 after 2.5m water level reduction

The capacity of the reservoir is 0.6Mm3 and the incoming floodwaters are 1.42Mm3 (4.1m3/s*60sec*60min*96hr, where 96hr is the duration of the flood). Therefore, the dam capacity is less than the capacity of the incoming floods. Even if we drain the reservoir, the incoming floods exceed the capacity of the dam. The reservoir has a higher regulated water level of 435.56 meters and a maximum water level of 0.56 meters.

The Kvistingen dam is also examined with a low flood M-50 design flood discharge. The computed low flood design flood for the M-50 is 2.47m3/s. After routing calculation, the maximum discharge for M-50 is 2.16 m3/s. Reservoirs only reduce incoming floodwaters by 0.31 m3/s. The reservoir dampening effects are 12.43 percent for low flood. The reservoir has a higher regulated water level of 435.41m and a maximum water level of 0.41m.

The maximum outflow from the dam is 1m3/s following a 2.5-meter reduction in water level below the initial water level for a low-flow M-50 design flood and dampening effect is 59.47%. As shown in Table 6.11, the higher regulated water level in the reservoir is 435.19 meters and the maximum water level for low flood design flood is 0.19 meters.

However, the total incoming design flood to the Kvistingen dam for the low flood design flood M-50 is 0.85Millm3 (2.47m3/s*60sec*60min*96hour, where 96hr is the flood duration for the Kvistingen dam), which is greater than the dam total capacity. Even if 15% is neglected for environmental purposes and the dam is emptied, 0.25 Millm3 (0.85 Millm3-0.6 Millm3) will be flooded downstream.

7.1.2. Skjellbreia Dam

Skjellbreia dam is located downstream of the Kvistingen dam, and in addition to local flow, the discharge from the Kvistingen dam serves as the dam inflow. Since they are connected, water from the upstream portion is transmitted to the downstream portion. The dam's total capacity is 2.4 Mm3, making it the greatest capacity along Leirelva watercourses. Higher regulated water level in the reservoir is 225.55 meters above sea level, and HRWL is assumed as the initial water level for calculation purposes. The Skjellbreia dam is classified as consequence class 2, and the flood capacity is sized for a 1000-year return period. The Skjellbreia dam's computed Q1000 design floods are 18.12 m3/s (NVKGRUPPEN, 2000). However, the computed Q1000 for Skjellbreia dam includes the Kvistingen dam catchment area because the catchment area for Skjellbreia includes the Kvistingen catchment area. During the calculation of the routing model, the outflow from Kvistingen is ignored for flood routing because the Q1000 incorporates both catchment areas. For the Low flow design flood, however, the Kvistingen dam's outflow is included into routing calculations.

From the routing model, the maximum outflow for a Q1000 design flood of 18.12m3/s at Skjellbreia dam is calculated to be 14.49m3/s. At an initial water level of 225.55 meters, the reservoir damping effect is 20.02%. The reservoir can only dampen 3.63 m3/s of incoming floods. Chapter 6 Table 6:19 provides a summary of the routing results for Q1000. The reservoir higher regulated water level is 226.95 meters above sea level, and its maximum water level is 1.4 meters. In addition to Figure 6:15 in the preceding chapter, the initial water level result graph is shown below.

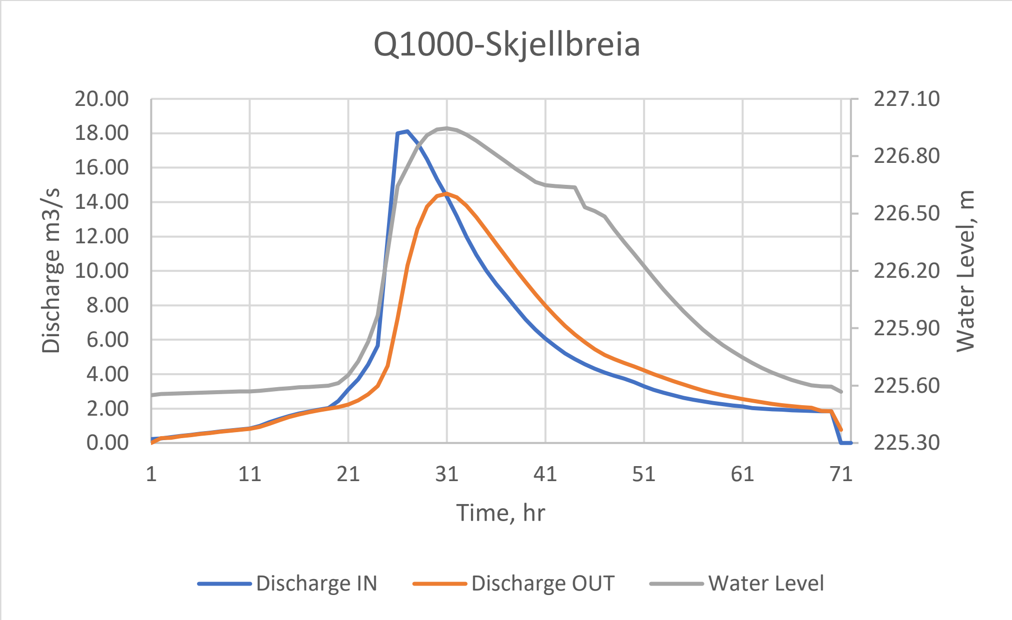


Figure 7-3:Routing result for Q1000-Skjellbreia at Initial water level

For the Skjellbreia dam, pre-release capacity is also implemented to lower the water level prior to the onset of a flood. 85% of the water is lowered to mitigate the incoming floods, while 15% is retained in the dam for environmental reasons. Since there is aquatic life in the pond and 15 percent of its total capacity is regarded to be environmental protection, the pond is protected. The water level is decreased by 2.55 meters below the initial water level, and the new pre-release capacity water level is 223 meters above sea level. New routing result for Q1000 at initial water level of 223m for Skjellbreia dam is shown below in addition to Figure 6:16 in Chapter 6.

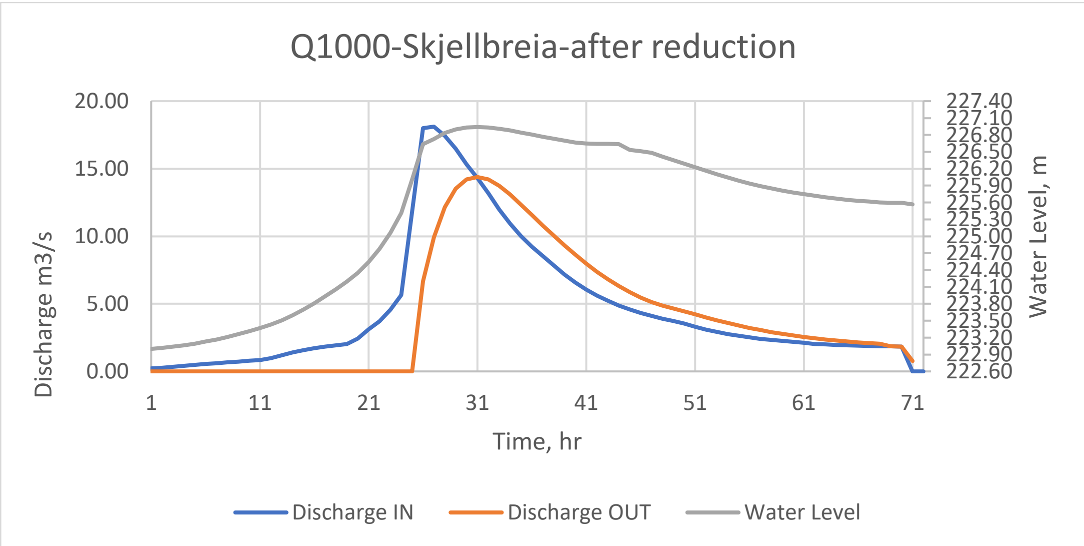


Figure 7-4: Q1000 routing result for Skjellbreia dam at new initial water level for Pre-release capacity

The maximum outflow from the reservoir is 14.38 m3/s, and the dampening effect is 20.60% based on the graphs or new routing result presented previously. Only 3.74 m3/s of incoming floods get reduced by reservoirs. Skjellbreia dam has greater dampening effects than other dams. However, there are no significant dampening effects after lowering the reservoir water level. The results indicate that the dam dampening effects, and maximum outflow are nearly identical before and after lowering the water level. Table 6:20, which is displayed in the result chapter, provides a summary of the routing results for Q1000.

The reservoir capacity of the Skjellbreia dam is 2.4 Millm^3. The duration of a flood is 72 hours. The total Q1000 flood entering the Skjellbreia dam is 4.7Millm^3 (18.12 m3/s x 3600 seconds x 72 hours). It nearly doubles the reservoir capacity. The incoming flood exceeds the dam capacity. Even if the total amount of water in the reservoir is reduced, 2.3Millm3(4.7 Millm3-2.2 Millm3) of water will flow downstream from the dam.

The Skjellbreia dam is also examined using the Low flood M-50 design flood. The calculated M-50 design flood is 12.05 m3/s. Skjellbreia dam is connected to Kvistingen dam, and the maximum outflow from Kvistingen dam is considered as additional inflow to Skjellbreia dam. Total M-50 low flood to the Skjellbreia dam is 14.21m3/s (12.05 m3/s plus 2.16 m3/s). Table 6:9 in the results section provides the maximum and mean values for the low flood M-50 design values. Based on the computed M-50 design floods, the routing model calculates the reservoir dampening effects. The result indicates that the reservoir maximum outflow is 10.73 m3/s. The reservoir has a dampening effect of 24.48% at an initial water level of 225.55 meters above sea level. The reservoir has a maximum water level of 1.22 meters and a maximum water level of 226,77 meters. Reservoirs reduce the total incoming M-50 design floods by 3.48 m3/s at the initial water level. Table 6:12 in Chapter 5 provides a summary of the routing of M-50 for the Skjellbreia dam.

Low flood pre-release capacity for the reservoir M-50 is also evaluated by considering the dam 85% reduction in water level. The greatest discharge from the reservoir has increased to 10.73 m3/s. With the minimum flood, the dam dampening effect is equal to 24.46%. The dam is absorbing 3.48 m3/s of incoming minimum flood. Before and after lowering the water level, Skjellbreia dam has the same dampening effects. Because the incoming floods exceeds the capacity of the reservoir. The total amount of low flood M-50 entering the dam is 3.68Millm3, which is greater than the dam capacity of 2.4Millm3. Therefore, there are no dampening effects prior to or after lowering the water level to prevent incoming flooding.

7.1.3. Leirsjøen Dam

The Leirsjøen dam is downstream from the Skjellbreia dam. The inflow to the Leirsjøen dam is the discharge from the Kvistingen and Skjellbreia dams. The reservoir has a total capacity of 0.66 million m3 and a maximum regulated water level of 198.13 meters. The initial water level is assumed as higher regulated water level for the purposes of this analysis. The Kvistingen and Skjellbreia dams are connected in series to the Leirsjøen dam, and the maximum outflow from the upstream of both dams is transferred to this dam. The maximum outflow from Kvistingen and Skjellbreia dams are added to the local flood for the catchments in this dam analysis for flood dampening analysis.

The Leirsjøen dam is classified as having consequence class 2 and the flooding is sized for a Q1000 return period. The Leirsjøen dam Q1000 is calculated to be 14.87m3/s (NVKGRUPPEN, 2000).

Routing calculations are performed based on the data computed and routing model developed for both Q1000 and Low flow M-50. To calculate the dampening effects of the Leirsjøen dam with Q1000, the outflow from the Skjellbreia dam is added to the Q1000 value of 14.87m3/s. Total Q1000 utilized for analysis is 28.55 m3/s (14.87 m3/s local flood for the Leirsjøen dam and maximum outflow from the Skjellbreia dam). Maximum discharge from the Leirsjøen dam is 28.32 m3/s. The reservoir dampens only 0.23 m3/s of total incoming floodwaters. The reservoir dampening effect is 0.82 percent, indicating that the dam does not substantially mitigate incoming floods. The reservoir higher regulated water level is 200.85 meters above sea level, and its maximum water level is 2.72 meters. The Q1000 summary for the dam is provided in Table 6:21 of Chapter 6.

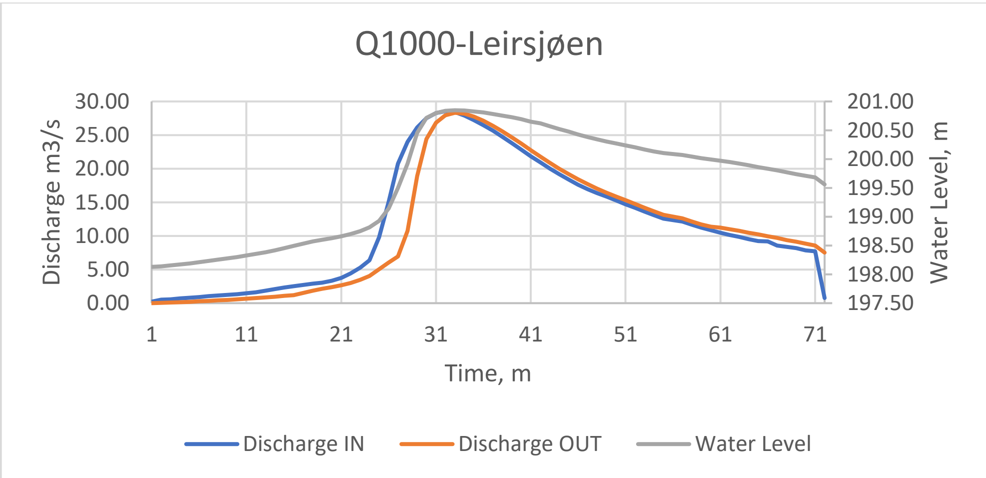


Figure 7-5: Q1000 for Leirsjøen dam at initial water level.

The pre-release capacity of the Leirsjøen dam is also considered. Since the Leirsjøen dam is situated at a lower elevation than the Leirelva watercourses. This dam is receiving a heavy burden from the upper part. 85% of water level reduction is planned, and 15% of total water volume is retained in the dam for environmental protection. If the water level is lowered by 3.13 meters below the initial water level and the new initial water level is 195 meters above sea level. Due to the small capacity of the Leirsjøen dam and the ineffectiveness of lowering the water level, the routing model predicts that the maximum outflow of water from the Leirsjøen dam is 28.31 m3/s. The dam is only preventing 0.24 m3/s of total flooding. The incoming floodwaters are significantly greater than the dam total capacity.

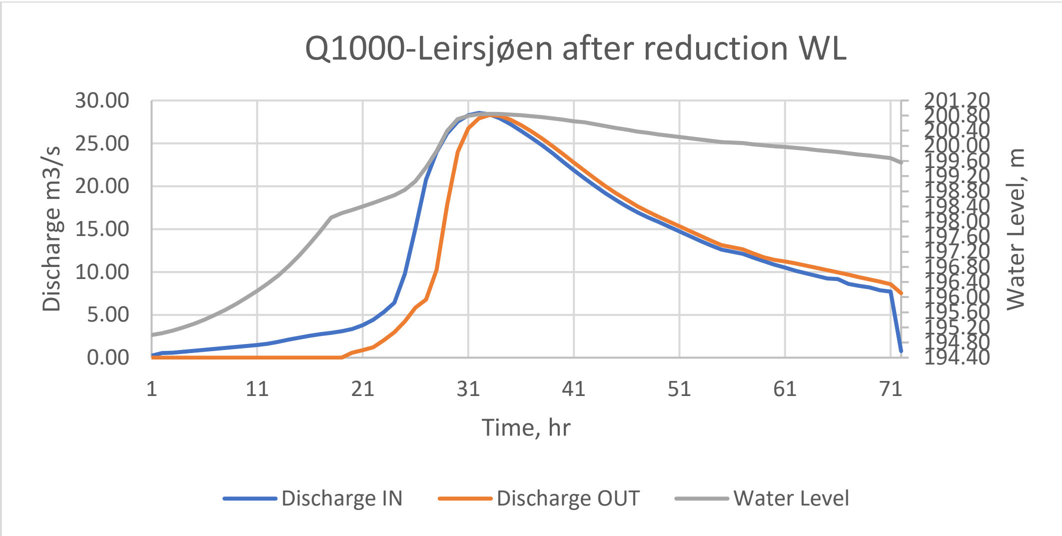


Figure 7-6:Q1000 for Leirsjøen dam after reduction of water level with new initial water level

The dam dampening effects after water level reduction are 0.86 percent, which is less dampening than before water level reduction. The reservoir higher regulated water level is 200.85 meters above sea level, and its maximum water level is 2.72 meters, which corresponds to the routing results. Chapter 6, Table 6:22 provides a summary of the routing results following a reduction in water level.

The Leirsjøen dam is examined using low-flood M-50. The calculated M-50 design flood is 12.58 m3/s. The Leirsjøen dam is linked to the Kvistingen dam and the Skjellbreia dam. For the routing calculation, the maximum outflow from Skjellbreia dam for low flood design flood is added to M-50 for Leirsjøen dam. Maximum M-50 discharge from Skjellbreia dam is 10.73 m3/s. Total inflow for M-50 low flood for the Leirsjøen dam is 21.87 m3/s for routing calculations. The routing results for low flood indicate that the maximum outflow from the dam is 20.95 m3/s, given the preceding information. The total amount of water reduced from the peak inflow is 0.92 m3/s. The dampening effects of the Leirsjøen dam are 4.23 percent. The maximum water level in the reservoir is 2.44 meters at higher regulated water level 200.39 meters above sea level.

For Leirsjøen dam pre-release capacity for low flood design flood with 3.13-meter water level reduction, the maximum discharge of water is 20.94 m3/s with dampening effects of 4.24 percent. The dampening effects and maximum outflow of water from the dam are nearly the same as before the water level was lowered. The reservoir higher regulated water level is 200.57 meters above sea level, and its maximum water level is 2.44 meters, which corresponds to the initial water level routing result.

The reservoir capacity of Leirsjøen dam is 0.66Millm^3. Total incoming flood Q1000 of 28.55 m3/s is 7.4 Millm^3, which is significantly greater than dam capacity. The dam incoming low flood is 5.67 Millm^3. The Leirsjøen dam has no dampening effect on the Q1000, and M-50 flood. The dam capacity is extremely low, and the incoming flow is significantly greater than the reservoir capacity. Tables 6:14 and 6:15 in Chapter 6 provide a summary of the routing results.

7.2. Hydraulic Modelling by HEC-RAS 2D

7.2.1. Terrain Modification

The first step in creating the HEC-RAS model is correcting the river flow and geometry. The terrain model (DEM) is retrieved from the Hoydedata.no website. The downloaded DEM does not contain the complete bathymetry of the river; therefore, we must execute the HEC-RAS 2D model on top of the downloaded terrain model by employing discharge on scanning dates (Fly discharge). On 13.07.2020, a terrain model (DEM) was scanned (TERRATEC, 2020). There is no gauge station on the Leirelva river to determine the fly discharge on the day of the survey or scanning dates. Therefore, the nearest gauging station is Hokkfossen, and the average daily discharge for Hokkfossen Station on the date of scanned date is 0.140679 m3/s. Scaling from the Hokkfossen Station is the optimal method for calculating the fly discharge or discharge on scanning dates for the Leirelva river due to their similar catchment properties. The geometry of the DEM before terrain correction is shown below in figure.

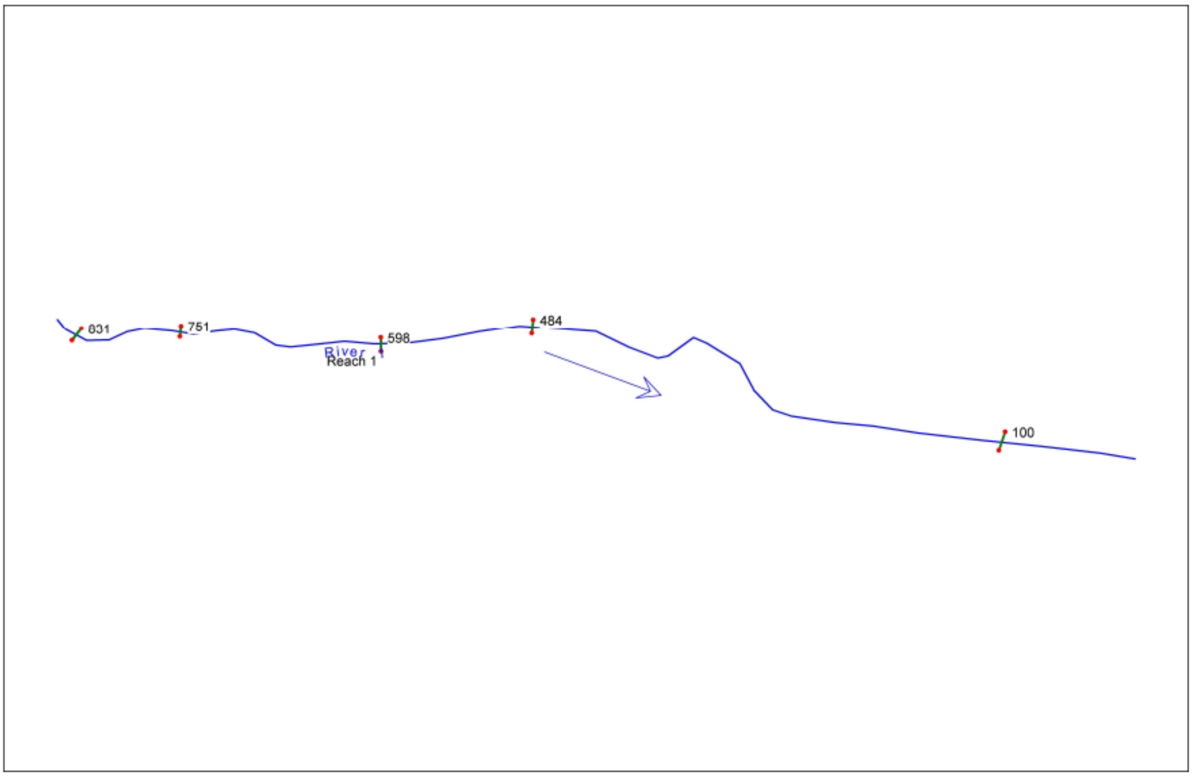
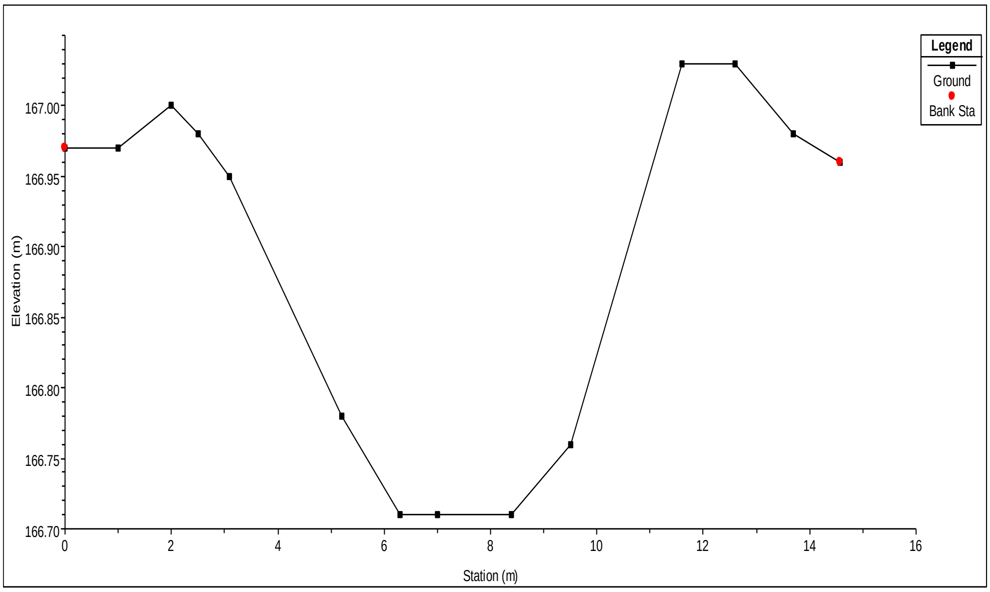


Figure 7-7: River Cross section from Upper Part of the Leirelva watercourses



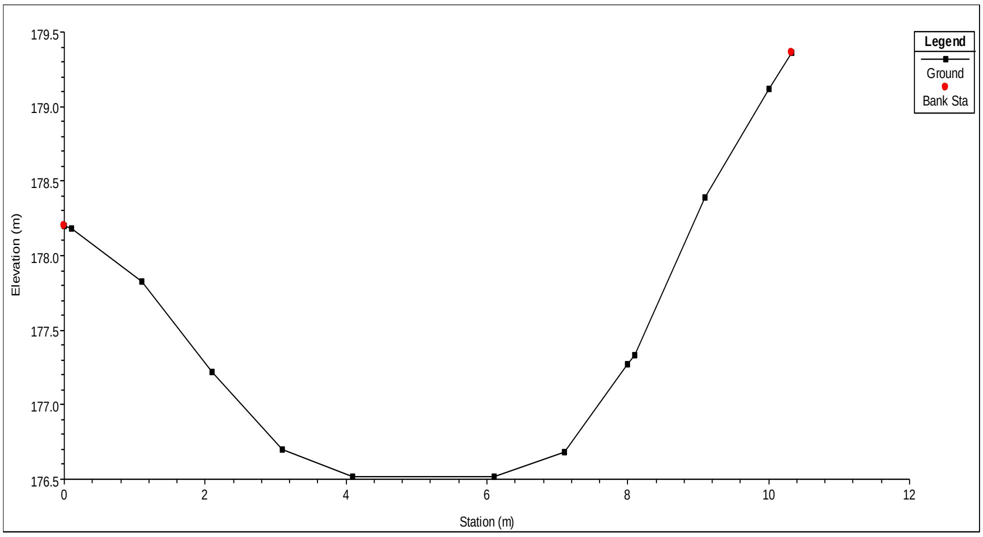


Figure 7-8: Cross Section before Terrain Modification or LiDAR Data

As shown in the cross-section figure above, the terrain lacks bathymetry and the bottom of the cross sections are flat.

Table 7-1: Scaling fly discharge from Hokkfossen Gauging station

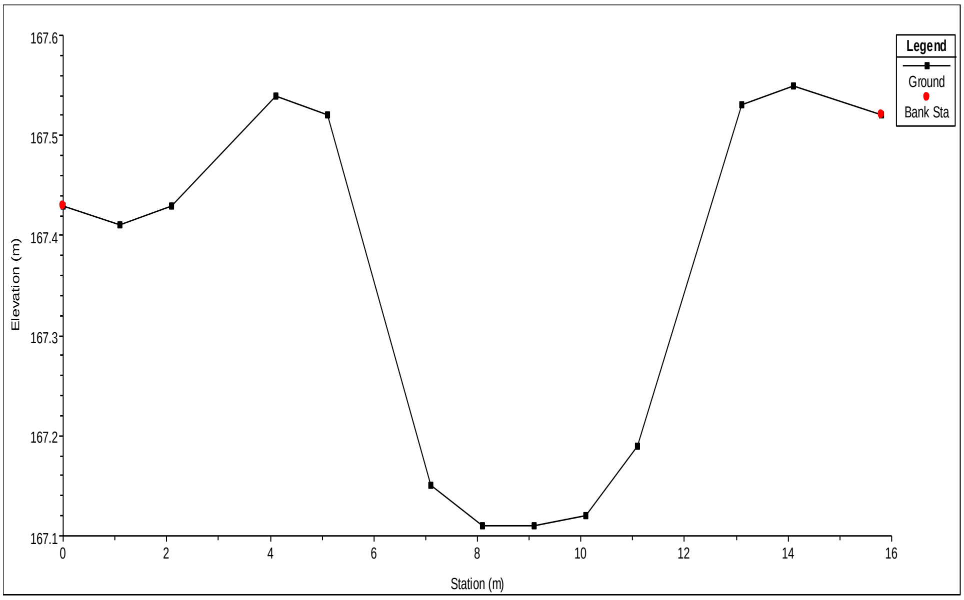
S. No	Hokkfossen Station Discharge in m3/s	Scaling Factor Leirelva River	Fly Discharge for Leirelva River in m3/s
1	0.14	3.10	0.44

Then, by using scaled fly discharge the HEC-RAS model is then compute the velocity and depth of the water by running on the top of the Lidar data or Terrain model. Computed values are summarized in table below.

Table 7-2: Computed Hydraulic calculation with fly discharge.

S. No	Average Velocity in m/s	Average Depth in m
1	1.5	0.12

Based on above-average velocity, average depth, and scaled fly discharge, the continuity equation is used to calculate the total volume in m^3 below the river surface to excavate the total volume computed below the surface and obtain the river complete bathymetry. Once we have complete bathymetry of the river and the total outflow discharge from Leirsjøen dam is calculated from the routing model for 72 hours, HEC-RAS 2D will calculate the hydraulic calculation and inundation areas along the Leirelva river. The corrected terrain is shown below with corrected geometry.



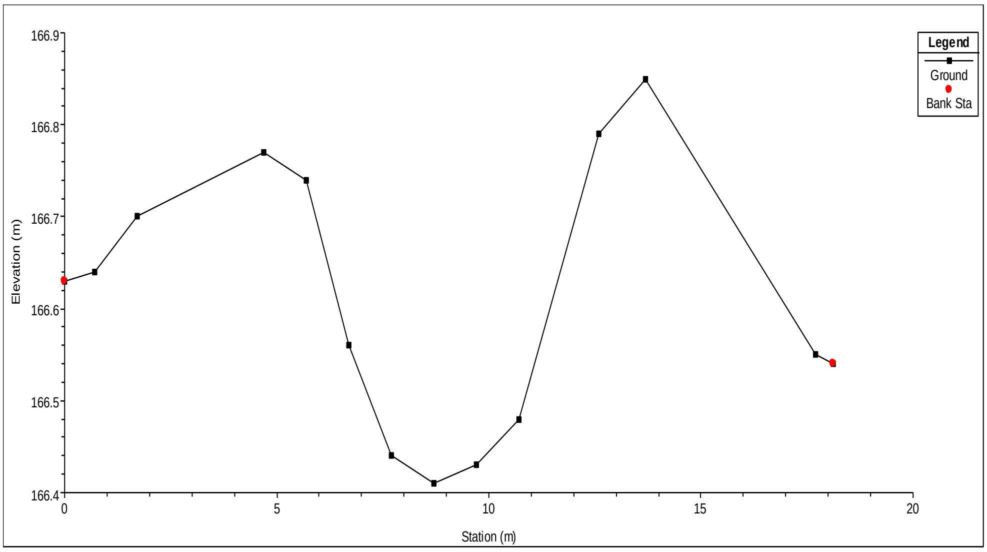


Figure 7-9: Cross section after Terrain Modification with Full Bathymetry

7.2.2. HEC-RAS 2D Simulation along Leirelva Watercourses and Results.

Once the terrain has been modified and calibrated for simulation as described in the preceding section, the model will be able to simulate the total Q1000 return period from the Leirsjøen dam. Total Q1000 from Leirsjøen dam is 28.32m3/s. Since the dam is connected to Kvistingen dam and Skjellbreia dam in series. In addition to the local flow for the catchment, the outflow from Kvistingen dam is the inflow for the Skjellbreia dam. In addition to local flow from Leirsjøen catchment, the total outflow discharge from Skjellbreia dam serves as the inflow to the Leirsjøen dam. On HEC-RAS 2D, the effects of maximum outflow from Leirsjøen dam are simulated using the modified terrain described in section 7.1.1.

For HEC-RAS simulation, a 2D flow area with a cell size of 2m by 2m and a refinement region with 0.5m by 0.5m cells are generated. The total number of cells in this simulation is 741k. The simulation period is same to the Leirsjøen dam flood duration, which is 72 hours.

The results of the area flooded by the dam incoming flood are shown below.

The parking lot in Granåsen is flooded. Around the Granåsen parking area there are steep sections, and the area is wet. The depth of the inundated area around the parking lot is 0.3 meters, which is close to the parking lot. The typical depth of ponds in the wet region is 1 m. No residence is impacted by inundation near the Granåsen parking areas. This area is anticipated to flood because it is a low and wet area. And there is a precipitous section with high incoming flow velocity. The inundation has surpassed the roadway that crosses the river. The flooded region is depicted in Figure 6:34 below.

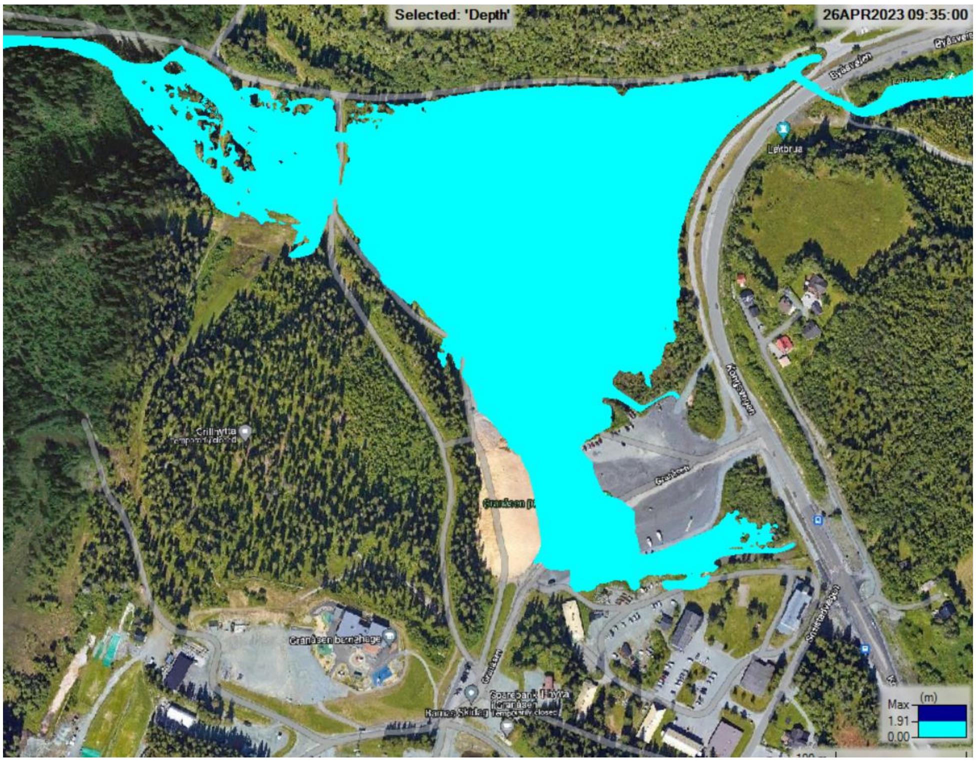


Figure 7-10: Granåsen Parking area flood Inundation area

The next flooded area at peak flow from the dam is Selsbakk factory or forsøkslia. This area is flooded with the depth water with average depth of 0.2m. There is also car repair industry around this flooded area and the industry is affected by floods. There is also forsøkslia asphalt road near to the flooded area, but the road is not flooded with this event. The flooded area is shown below in Figure 6:35 below.

Figure 7-11:Selsbakk Factory or Forsøkslia Flooding Areas

The third flooded area along Leirelva river with peak flood is called Proven area. The water is flow under the culvert and the culvert cross the industry where the flooding is created. But this simulation is considered as a river in terms of culverts. Within this simulation, industry is flooded at this peak flow from the dam. The simulation with culvert at this area analyzed in next section.

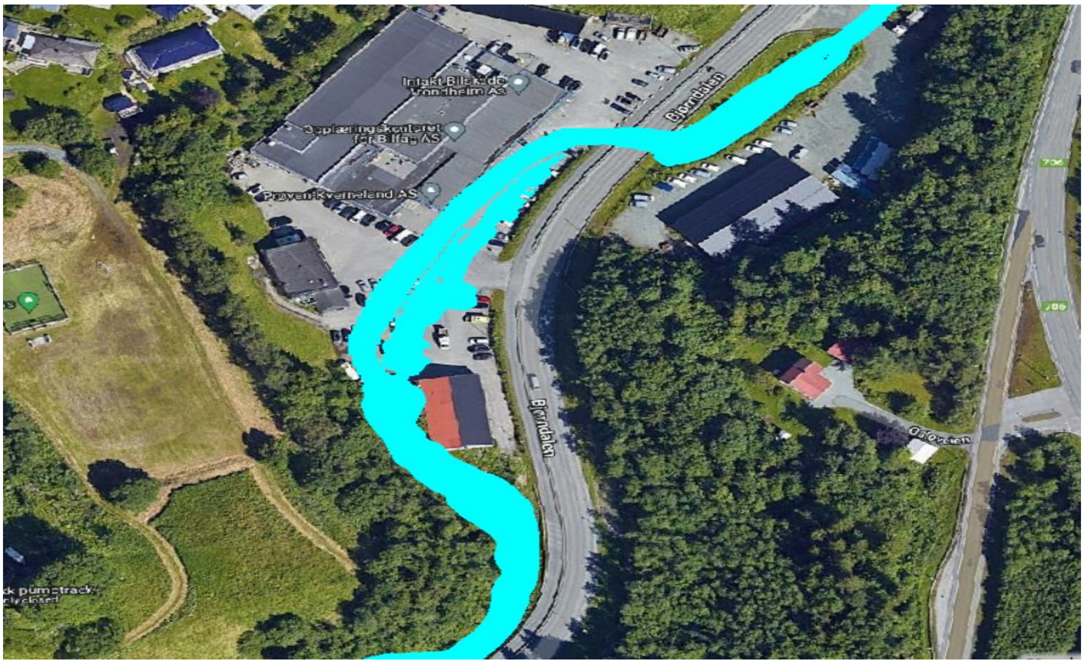


Figure 7-12: Proven Flooded Area

7.2.3. HEC-RAS 2D Simulation with Culverts on Leirelva River

Leirelva travels through numerous conduits. Trondheim Kommune provides no culvert data for Analysis Using Culverts. Fieldwork is performed to acquire data on culverts for this purpose. However, data collection focuses on flooding effects that pose a high risk. Since depth and width of the culverts are measured on the field work, the Field Work measurement data is a collection of random data, not real data. However, it is necessary to collect slope, thickness, length of culvert, and other dimensions. Proven is the first territory from which data is collected. This simulation analyzes only 200 meters of incoming Q1000 flood due to the simulation's time-consuming analysis of the entire geometry. The region is inundated with Q1000 coming from the Leirsjøen dam. As seen in the image below, the industry and road are severely impacted by the coming flooding. There is a highly serious flooding along this industry, So Trondheim kommune will take the mitigation measure to reduce the risk of flooding and damaging of the infrastructure in this area and other flooded area along the Leirelva watercourses.

Figure 7-13: Effects of Culvers on Simulation

7.3. Building Hydrological Model for Forecasting

This section objective is to construct the hydrological model for Leirelva liver. There is no measuring station for observed runoff series and climate data. The first stage is to transfer data from the nearest gauging station and prepare data for Leirelva river. The nearest catchment stations are Svarrtjørnbekken and Hokkfossen. Since the catchment area of the dam along the Leirelva watercourses is quite small, the model time resolution for flood forecasting should be one hour or less.

7.3.1. Data preparation for Calibration and its Quality

Along the Leirelva watercourses, there is no gauge station for hydrological modeling and other computations. The closest gauging station are Svarrtjørnbekken gauging station. The runoff and climate data come from the NVE database. Runoff is collected by Sildre NVE, and meteorological data is collected by the climate gauging station. The first stage is the calibration of the nearest catchment, referred to as the Svarrtjørnbekken gauging station, followed by the transfer of the calibrated catchment properties to the Leirelva watercourses. The Svarrtjørnbekken climate and runoff data is shown in the table below.

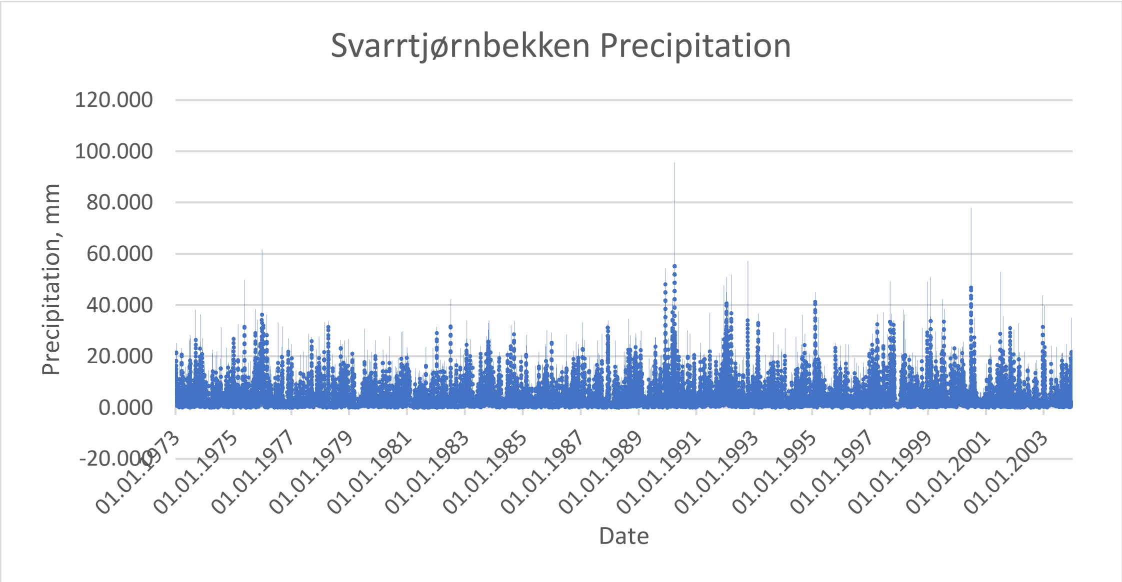


Figure 7-14: Svarrtjørnbekken Precipitation for calibration

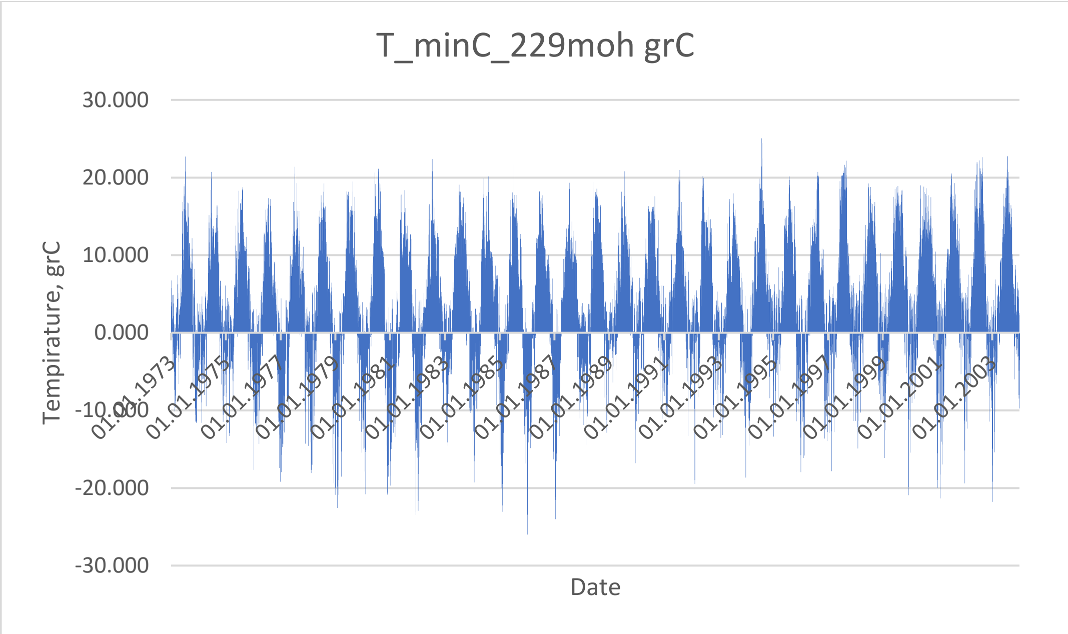


Figure 7-15: Svarrtjørnbekken Temperature grC

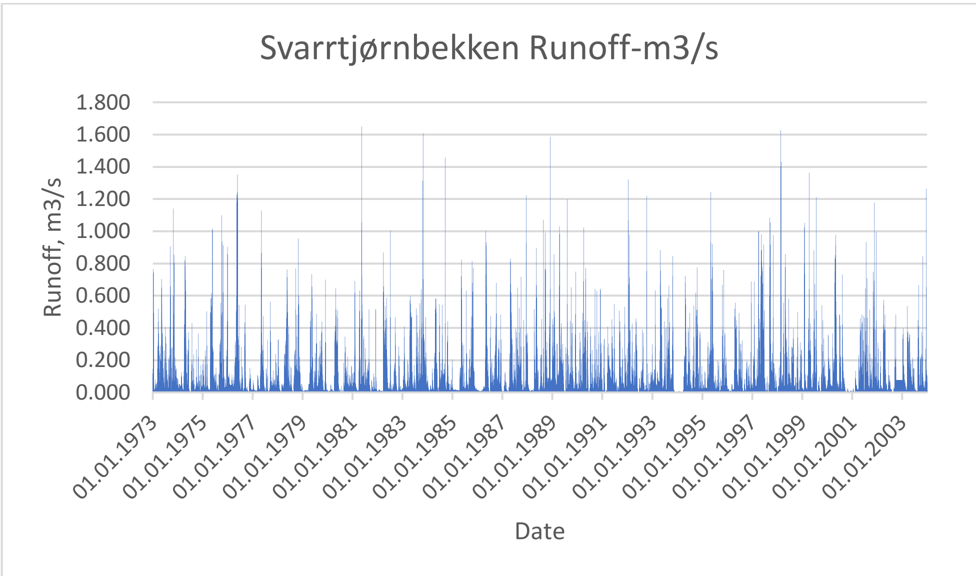


Figure 7-16: Svarrtjørnbekken Runoff in m3/s

7.3.2. Potential Evapotranspiration (EPOT) Computations

Potential evapotranspiration (PET) is computed from temperature data from gauging station by using Thornthwaite method and formula is provided below.

$$PET = \left(\frac{L}{12}\right) * \left(\frac{N}{12}\right) * \left(\frac{10Ta}{I}\right)^{\partial} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.1$$

Where, Ta is average monthly temperature, L is daylight of computed month, N is number of days in months and ∂ is f(I).

$$I = \sum_{1}^{12} \left(\frac{Tai}{5}\right)^{\wedge}1.514$$

Table 7-3: Calculated Potential Evapotranspiration (PET)

Month	Voll- EPOT (mm/Month)	Svarrtjørnbekken EPOT (mm/Month)	Leirelva EPOT (mm/Month)
January	0.10	0.04	0.04
February	0.23	0.03	0.03
March	0.60	0.09	0.14
April	1.16	0.47	0.73
May	1.43	0.84	1.79
June	1.53	0.71	2.50
July	1.76	1.06	2.83
August	1.91	1.66	2.65
September	1.73	1.76	1.92
October	1.06	1.24	1.10
November	0.44	0.43	0.29
December	0.16	0.05	0.06

7.3.3. Calibration Nearest Station on 1hour Resolution

For the Leirelva watercourses, an hourly basis is more representative or valuable for constructing a hydrological model to predict future floods than a daily basis. PINEHBV are used for the hydrological modeling for calibration and validation for this study. Based on the 1-hour resolution of the two closest stations, the autocalibration results are poor. For calibrating the Svarrtjørnbekken and Hokkfossen gauging stations, data are obtained from the NVE database from 2016 to 2022, containing hourly time series for runoff and climate data. The outcome of the calibration of both stations is displayed in Table 6:26.

Table 7-4: 1-hour calibration result from nearest catchments.

S.No	Station	Calibration-R2
1	Svarrtjørnbekken	-0.144
2	Hokkfossen	0.043

Both closest catchment areas are not calibrated properly on an hourly basis in order to transfer the catchment parameter for Leirelva watercourses. Below are the observed and simulated discharge results for the two nearest catchments, Hokkfossen and Svarrtjørnbekken.

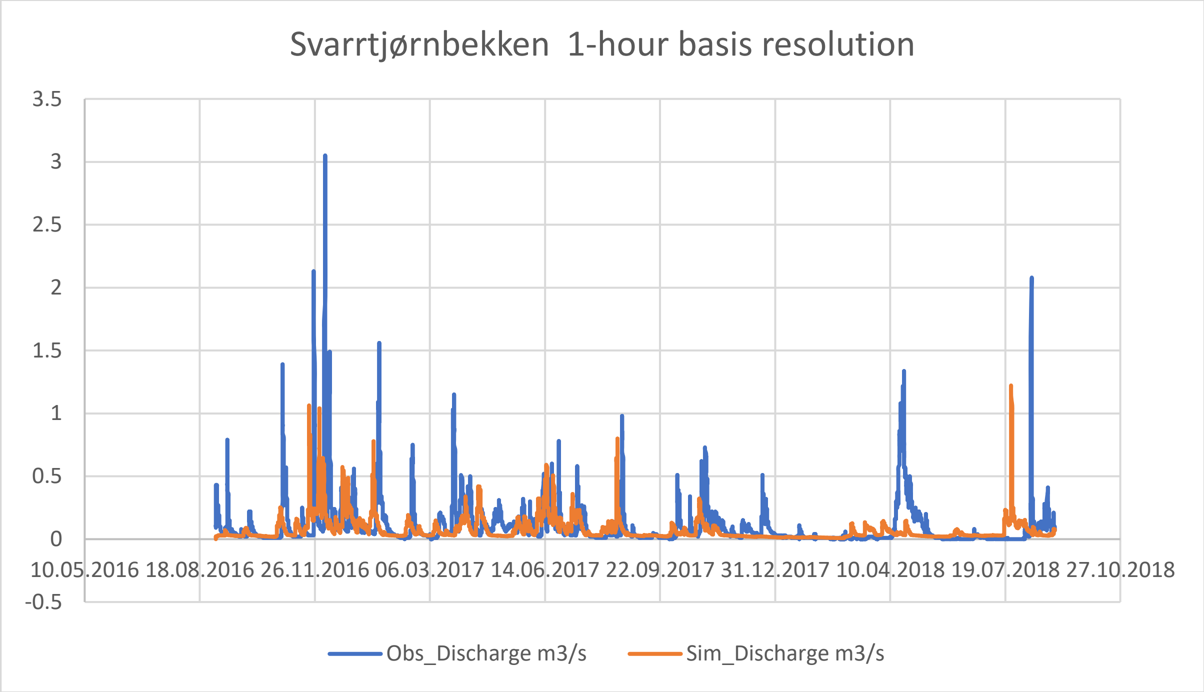


Figure 7-17: Svarrtjørnbekken Simulated and Observed Runoff for 1hour basis.

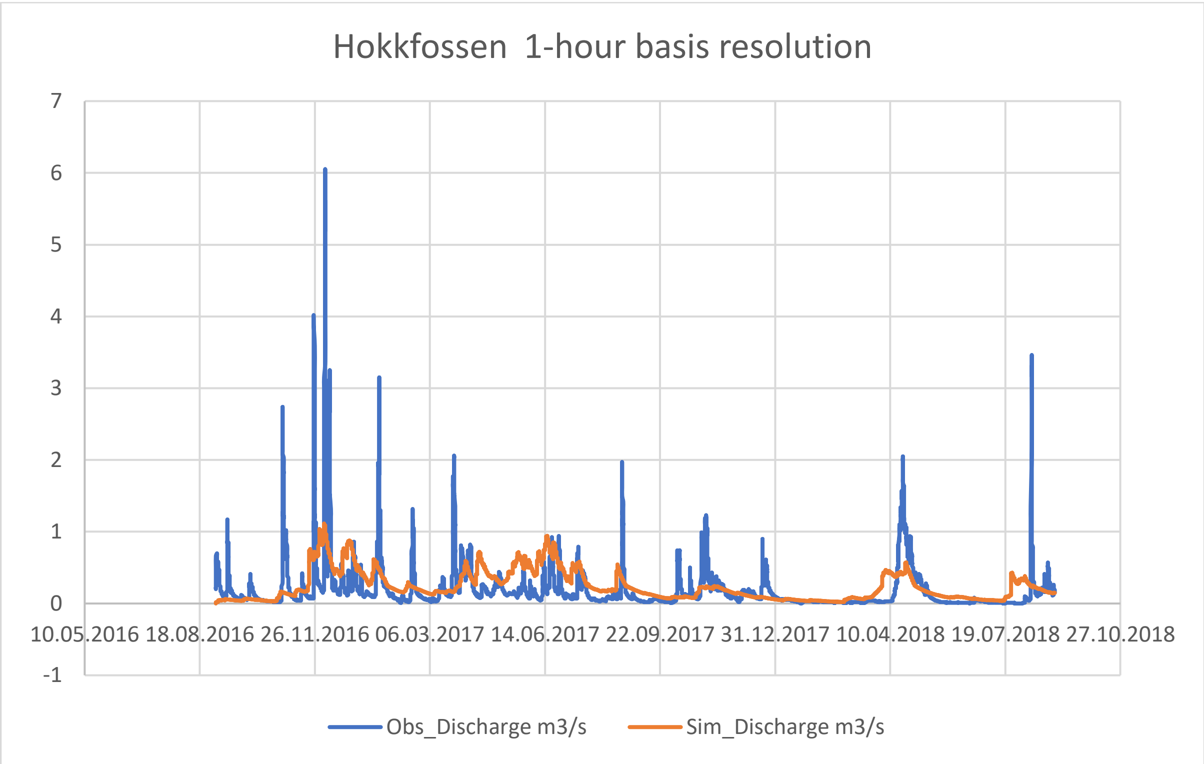


Figure 7-18: Hokkfossen Simulated and Observed Runoff for 1-hour basis.

Based on the calibration of the nearest catchment at a resolution of 1 hour, neither catchment is calibrated well. Therefore, the issue is data quality. To obtain high-quality data, more time is required to correct the error. The only option for this study is to construct the hydrological model for future flood forecasting on a daily basis. The forecast for Leirelva watercourses should be calibrated and simulated on an hourly basis with a resolution of one hour per day. Trondheim Kommune should therefore continue calibrating the hourly basis for developing hydrological models for this catchment.

7.3.4. Calibration on Daily basis for Svarrtjørnbekken Gauging Station.

The daily calibration for the Svarrtjørnbekken gauging station is extremely accurate. The calibration and validation time series range from 1973 to 2003. Autocalibration is computed for the years 1973 to 1978, yielding an R^2 of 0.825 and an accumulated difference of -54.3 mm. Based on the same-year R^2 calibration, the accumulated difference is -48.0 mm. the model simulates Observed discharge is 883.8 mm/year, Precipitation is 1070 mm/year and Evaporation is 181.1 mm/year. Validation is also performed for the subsequent ten years, from 1978 to 1988, with R^2 equaling 0.75 and the accumulated difference measuring -111.3 mm. It is anticipated that R2 for validation will decrease slightly. The daily calibration result is also displayed below for Svarrtjørnbekken catchments.

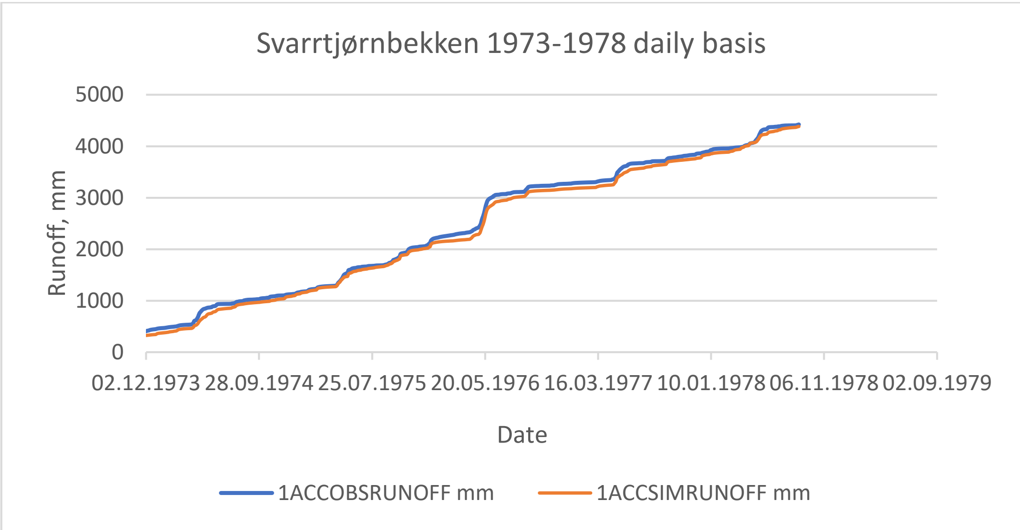


Figure 7-19: Accumulated and Simulated runoff of daily basis in mm

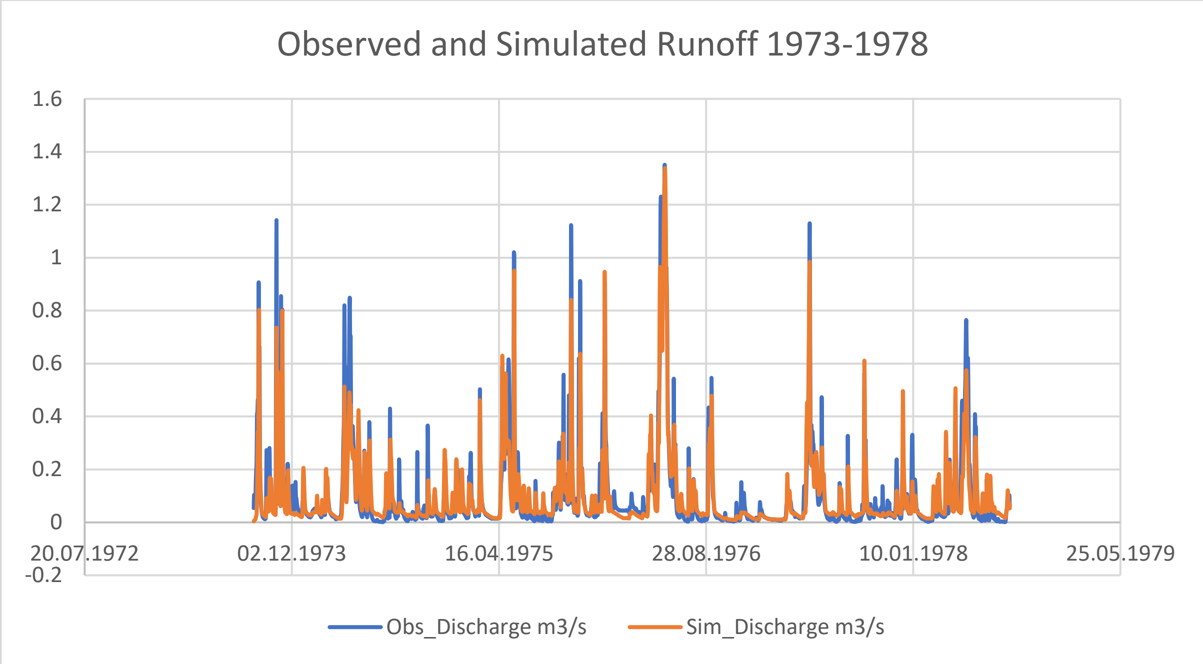


Figure 7-20: Observed and Simulated runoff for daily basis in m3/s

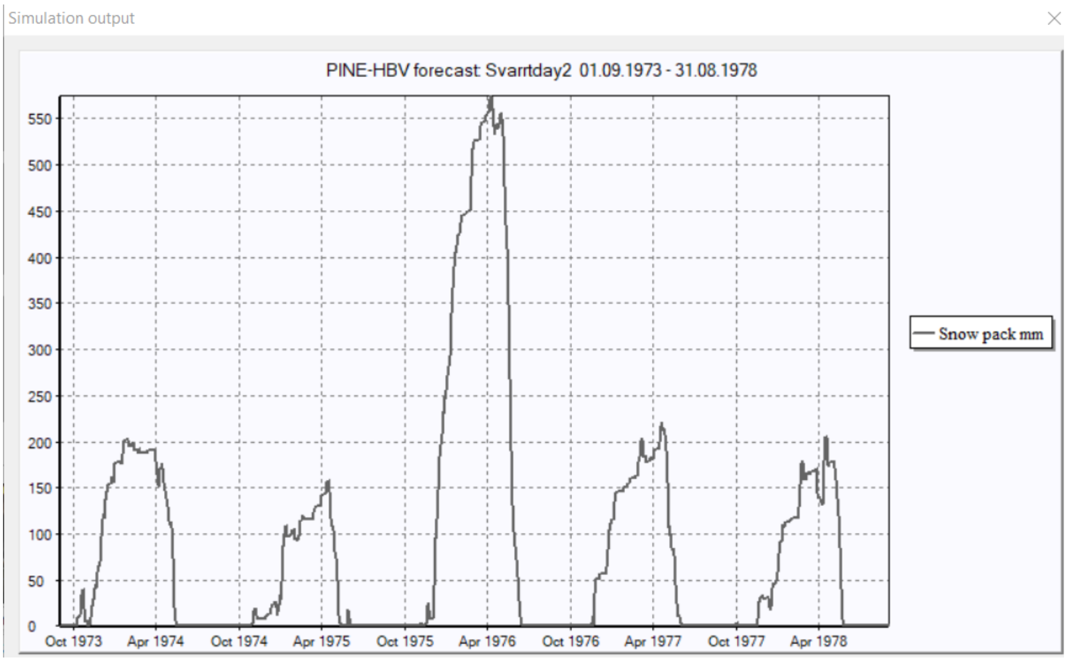


Figure 7-21: Snowpack in mm for daily basis

7.3.5. Simulated Runoff Series for Leirelva Watercourse by Parameter Transfer

Daily results are not more representative than hourly results for such small catchments as dams Leirelva watercourses. The Leirelva river should be calibrated every hour. Further stages in determining the runoff for Leirelva watercourses can only be determined using a daily basis and calibrated model from Svarrtjørnbekken catchment. Once the Svarrtjørnbekken catchment is calibrated and validated on a daily basis from 1973 to 2004, the data will be available for analysis. The parameter transfer from the calibrated model catchment is then transferred to the Leirelva watercourses to compute the runoff time series using the confined parameter from the Leirelva watercourses and the calibrated parameter from the Svarrtjørnbekken calibrated catchment. The graph below shows the computed discharge time series for Leirelva watercourses.

From 1970 to 2023, the simulated runoff series for Leirelva watercourses reaches a peak runoff rate of 3,2 m3/s in 1997. The model simulates an annual precipitation of 890 mm along Leirelva watercourses. The evaporation series is 194mm/year, and the simulates discharge series is 670mm/year. For watercourses, the simulated values are reasonable and appear favorable. The result is presented below.

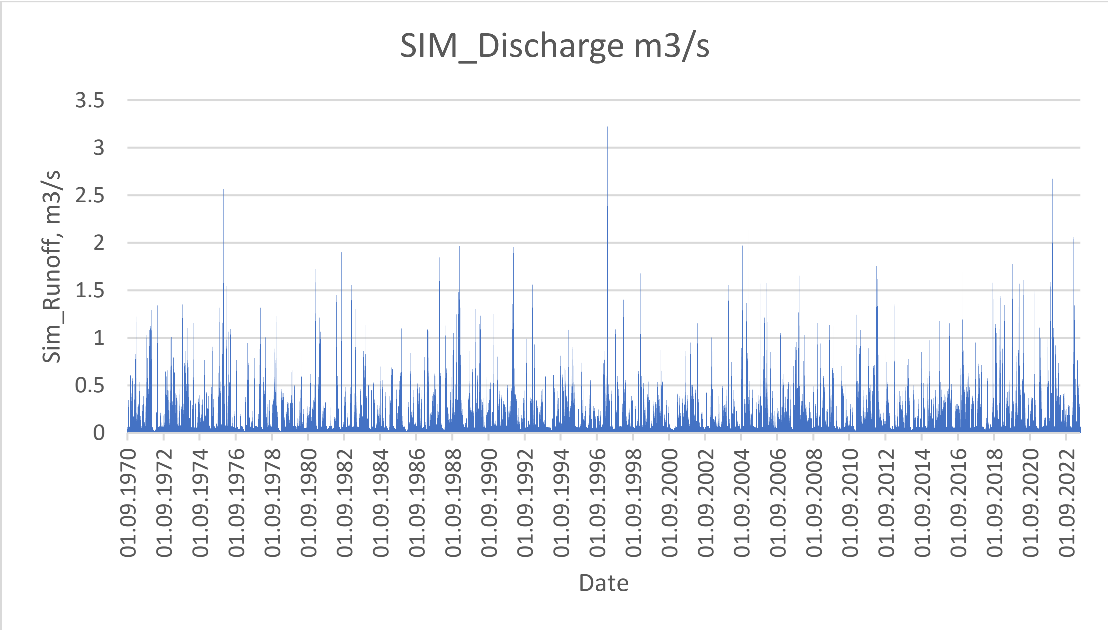


Figure 7-22: Leirelva Simulated Runoff in m3/s from 1970-2023

7.3.6. Flood Forecasting with Hydrological Model for Leirelva Watercourses

Having computed simulated runoff for Leirelva watercourses in the preceding section, the next step is establishing the hydrological model using a 10-day weather forecast. Simulated runoff is calculated from 01.09.1970 until June 15, 2023. Models are constructed beginning with the end of the simulated runoff on 15.06.2023 based on 10-day weather forecasts along Leirelva watercourses, and the model extends the simulation to the beginning of the next winter season on 15.11.2023. Therefore, the model predicted the flood from 15.06.2023 to 15.11.2023 at the beginning of winter. The 10-day weather forecast is collected from YR.no and shown in the table below and the result of 10-day weather forecast is shown below in Figure 7:21.

Table 7-5:Weather forecast for 10-day for Leirsjøen dam.

Date	Precipitation	Temperature
16.06	0	22
17.06	0	22.5
18.06	0	22
19.06	0	19.5
20.06	0	20
21.06	4.2	20
22.06	2.4	20.5
23.06	5.7	19
24.06	6.2	18
25.06	7	17

To predict the future flood, the next stage is to update the model by adjusting the parameter to match the observed and simulated runoff. For this study, however, there is no gauging station to document the observed runoff time series data from the catchment and update the model with simulated runoff data, the updating the model is missed as illustrated below.

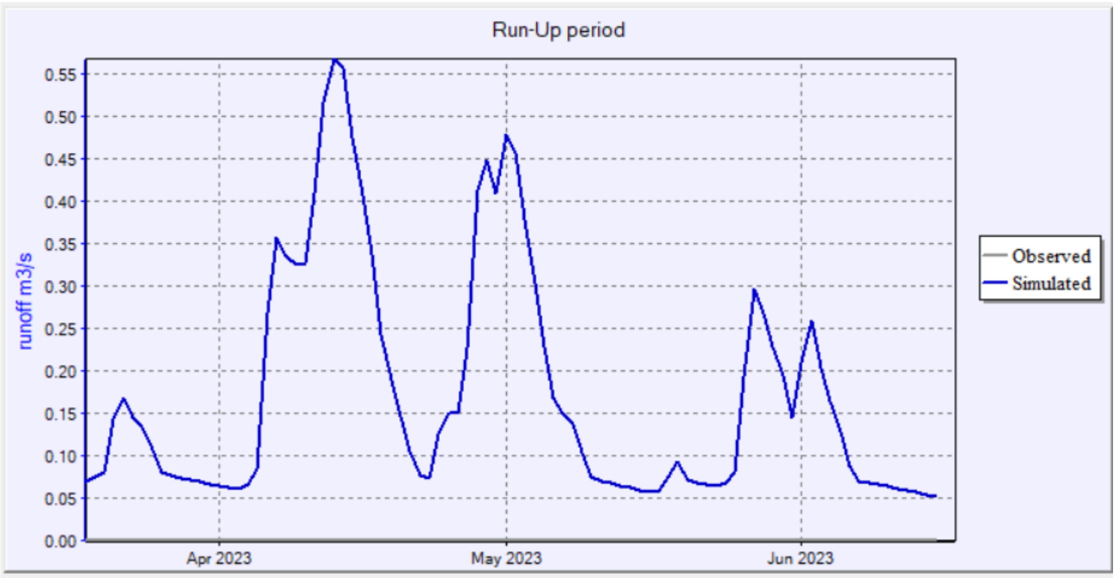


Figure 7-23: Model Updating for the Future Forecast without Observed Runoff

This analysis does not include a model update because there are no observed runoff time series along Leirelva watercourses. Based only on the simulated discharge time series, the model predicts future flooding along Leirelva watercourses for next 10 days until 25.06.2023. The 10 days forecast from the hydrological model is displayed below with different data Uncertainty.

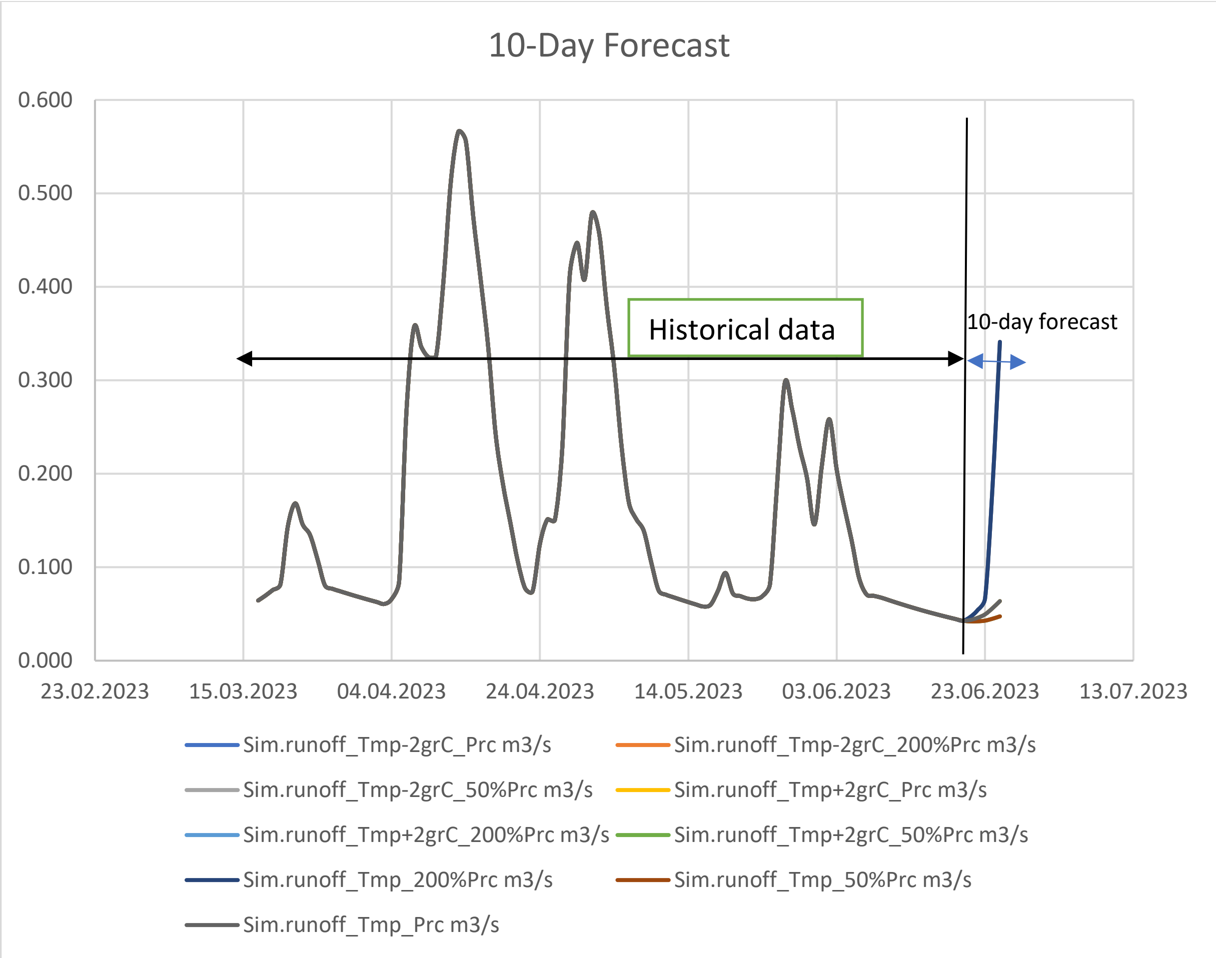


Figure 7-24:10-day forecast with different Climate data along Leirelva Watercourses until 25 of June 2023.

From the above figures, based on the normal climate and 10-day weather forecast along the Leirelva watercourses, there are no peak floods for next 10 days.

The model prognosis no peak flood was simulated along the Leirelva watercourse with normal climate data until the beginning of the 2023 winter season. On the other hand, based on the model predictions, a significant flow is anticipated at the middle of September 2023. However, this does not produce a flood based on the model. The outcome is shown below.

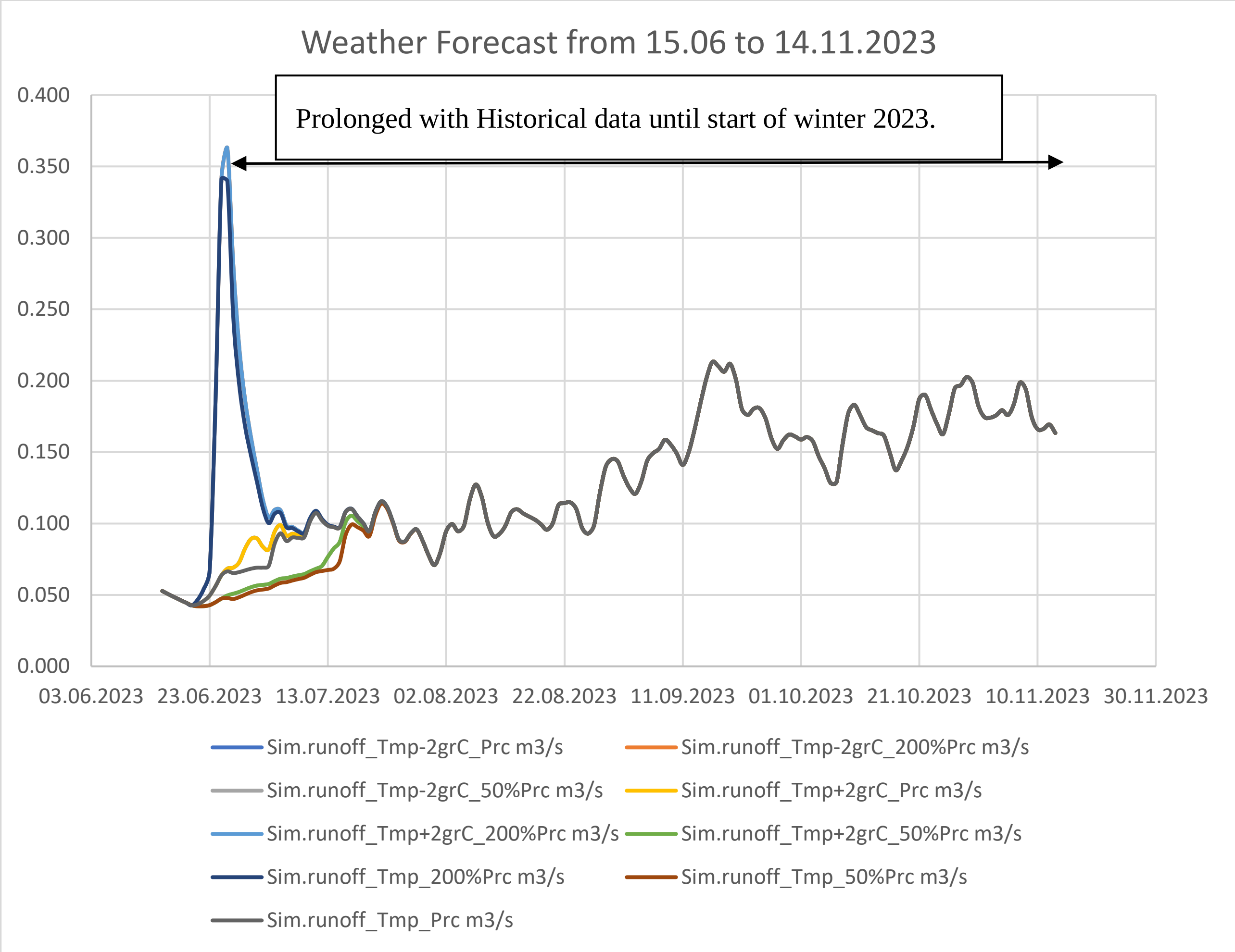


Figure 7-25: Weather forecast with different Climate data along Leirelva Watercourses until start of Winter 2023

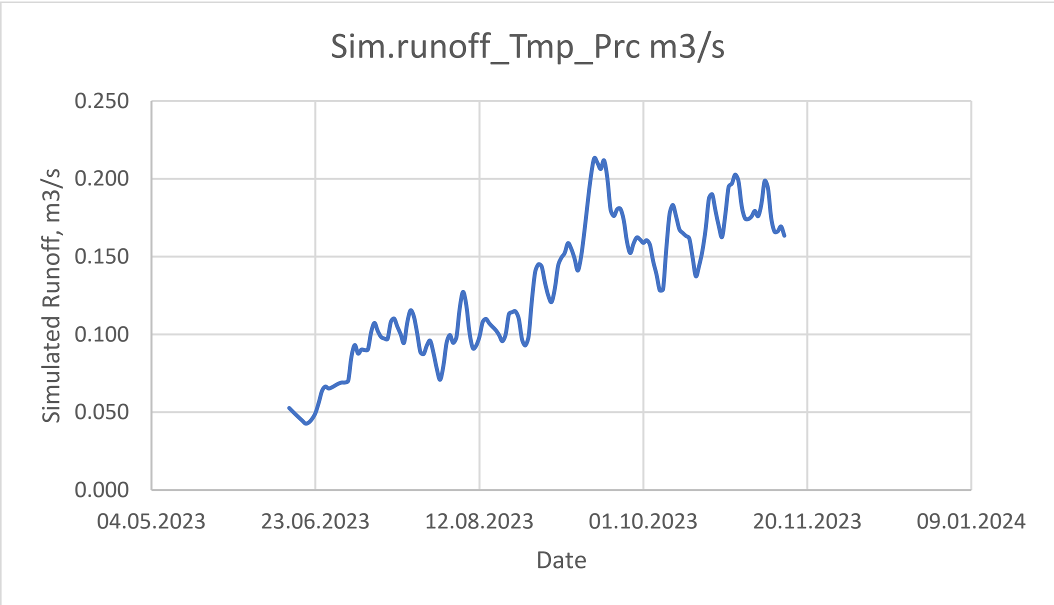


Figure 7-26: Forecasted simulated Runoff with Normal Climate Data

The model forecast higher runoff when the climate data with -2grC, +2grC of temperature and 200% of Precipitation changed. The result shown below.

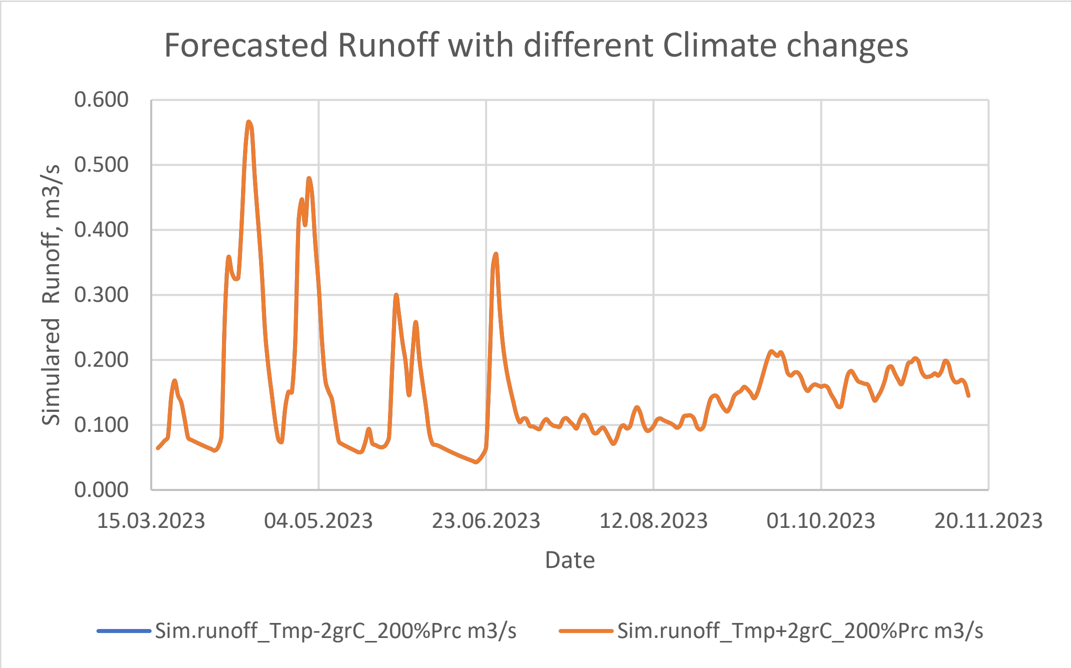


Figure 7-27: Forecasted Simulated Runoff with 2grC, +2grC of temperature and 200% of Precipitation.

7.3.7. Flood Routing with Forecasted Simulated Runoff for Pre-Release Capacity

This section demonstrates how real-world flood management is implemented and how pre-release capacity is determined. Since the PINEHBV Model predicts simulated runoff based on a 10-day weather forecast from Leirelva watercourses, the runoff is simulated. Forecasted peak discharge was then incorporated into the flood routing model. If the routing model calculates potential flooding along watercourses, we must prepare the reservoir by lowering the water level in reducing of the flooding. However, this model indicates that there will not be a peak flood at various scenarios for the catchment until the beginning of the winter season in 2023.

There is no peak flood along the watercourse, so flood forecasters can relax until the start of winter in 2023, and the population living downstream is secure until then.

7.4. Sensitivity Analysis and Uncertainty

The quality of data is checked for building of hydrological modeling for watercourses. There are data from Svarrtjørnbekken gauging station with very good quality with daily resolution. Parameter from Svarrtjørnbekken gauging station is used for hydrological modeling for Leirelva watercourses by transfer parameter techniques.

There is uncertainty of data on watercourses since there is no gauging station along Leirelva watercourses for hydrological modeling and flood management setup. This may affect the result and proper implementation on flood managements. There are assumptions on building the routing model that also affects the dampening affects for all dams. Sensitivity analysis should be tasted by actual data for dams. Culvert data are also not available for this study, so it should be tasted for the future study for the sensitivity analysis.

8. CONCLUSION

8.1. Flood dampening along Leirelva Watercourses

Kvistingen dam, with a reservoir capacity of 0.6Mm3, plays a crucial role in regulating the inflow to the Skjellbreia dam. The dam is a Q500 flood capacity of 4.1 m3/s. The dam reduces the incoming flood Q500 to 3.97 m3/s, representing 3.76% of dampening effects. The dam can't reduce a low-flow M-50 design flood either. Routing calculations for low flow reduces incoming flood water from 2.47 m3/s to 2.16 m3/s, dampening them by 12.43%. 15% of environmental protection is considered for both Q500 and M-50 design floods. The dampening effects for pre-release capacity after reducing water level with 2.5 meter are 13.85% and 59.47%. The reservoir inability to accept incoming floodwaters and the limited dampening effects highlight the need for further research and possible improvements to ensure effective flood management in the area.

Skjellbreia dam capacity is 2.4Millm^3 and dam has 18.12 m3/s -Q1000 flood. The routing calculations for the Q1000 design flood demonstrate that the Skjellbreia dam has a dampening effect of 20.02% at its initial water level of 225.55 meters. This corresponds to a reduction of 3.63 m3/s from the incoming floodwaters. However, despite this dampening effect, the total inflow exceeds the dam capacity. Even after implementing pre-release capacity measures, which involve lowering the water level by 2.55 meters and retaining 15% of the water for environmental purposes, the dam is unable to mitigate the incoming flood effectively. The reservoir dampening effect remains similar, with a maximum outflow of 14.38 m3/s and a reduction of 3.74 m3/s. The low-flow M-50 design flood analysis gives similar results. The M-50 flood discharge is 12.05 m3/s, while the total inflow to the Skjellbreia dam is 14.21 m3/s with the Kvistingen dam outflow. The dam reduces the M-50 flood 24.48% at the initial water level. Like the Q1000 flood scenario, the reservoir cannot fully mitigate the incoming floodwaters. The flood flow exceeds the dam capacity despite pre-release capacity measures that dampened 24.46%.

Leirsjøen dam capacity of reservoir is 0.66Millm^3 with higher regulated water level of 198.13 meter. According to the analysis of the Leirsjøen dam for the Q1000 return period, the dam has a computed design flood of 14.87 m3/s. When the Skjellbreia dam outflow is considered, the total Q1000 used for analysis becomes 28.55 m3/s. The maximum outflow from the Leirsjøen dam is 28.32 m3/s, indicating that the dam only reduces water flow by 0.23 m3/s. The calculated dampening effect is 0.82 percent, indicating that the dam does not significantly reduce incoming floodwaters. Despite the pre-release capacity, which reduces the water level by 3.13 meters, the dam dampening effect remains modest at 0.86 percent. The capacity of the Leirsjøen dam is inadequate in comparison to the incoming floodwaters, resulting in the reservoir flooding. For the low flow M-50 design flood, the dam has a dampening effect of 4.23 and 4.24 percent after water level reduction. The total capacity of the dam is 0.66 Millm^3, whereas the incoming Q1000 and M-50 design floods exceed 7.4 Millm^{3}and 5.67 Millm^3, respectively. In both instances, the dam limited capacity prevents it from preventing incoming flooding.

8.2. Hydraulic Simulation with Outflow from Leirsjøen Dam

The total Q1000 from Leirsjøen dam for simulation of HEC RAS is 28.32m^3/s. From the simulation with incoming floods most of the places are inundated and affected with the floods. Flood duration is 72 hour and flooded is occur at the 9:30. The most place flooded are Granåsen parking area which is wet area and steep section in the area. The area is flooded with the average depth of 0.3m near to parking areas. There average flooded depth along the river is 1meter in average.

The next flooded area around Selsbakk factory or forsøkslia. The third area highly flooded with peak floods are Proven area. Water is flow in culvert in this area and the area is industry. The result from this area is also simulated with the culvert and result shown there are flooding across this industry. So, the Trondheim Kommune they must take the mitigation measures place where the flooding is occurs.

8.3. Flood management Setup

For river flood forecasting along the Leirelva Watercourses, the hydrological model Leirsjøen dam is used to develop a flood management system. The model is built using a 10-day weather forecast for the Leirsjøen dam. The model extends the simulation until the beginning of winter 2023. The hydrological model is not updated due to the absence of observed dam discharge. From 16.06.2023 to 15.11.2023, there are no incoming peak floods, according to the results. However, this result is only based on simulated runoff series; to obtain improved results, we must update the model with observed runoff. Trondheim kommune should construct a runoff gauging station at the dam site to record observed runoff and generate more accurate flood forecasts.

9. FUTURE WORK

- ✓ Install runoff gauge at the Leirsjøen dam to record the observed runoff time series and outflow from the dam.
- ✓ Field measurement for all culvert along the Leirelva watercourses and simulate the effects of culverts on the peak flow along the river.
- ✓ Build the automatic hydrological modelling for flood forecasting and flood warning.
- ✓ Measure the capacity of all dam and redo dampening effects. Since for this study, there are assumptions and uncertainty of data for the analysis, it should be measured and analyzed.

References

Mishra, A., Mukherjee, S., Merz, B., Singh, V. P., Wright, D. B., Villarini, G., ... & Stedinger, J. R. (2022). An overview of flood concepts, challenges, and future directions. Journal of hydrologic engineering, 27(6), 03122001.

Collins, M., et al. Long-term Climate Change: Projections, Commitments and Irreversibility. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, US: 1032.

Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The human impact of floods: a historical review of events 1980-2009 and systematic literature review. PLoS currents, 5.

Abass, K. (2022). Rising incidence of urban floods: Understanding the causes for flood risk reduction in Kumasi, Ghana. GeoJournal, 87(2), 1367-1384.

Fernando, N. S., Shrestha, S., Saurav, K. C., & Mohanasundaram, S. (2022). Investigating major causes of extreme floods using global datasets: A case of Nepal, USA & Thailand. Progress in disaster science, 13, 100212.

French, J., Ing, R., Von Allmen, S., & Wood, R. (1983). Mortality from flash floods: a review of national weather service reports, 1969-81. Public Health Reports, 98(6), 584.

Shrestha, M. S., & Takara, K. (2008). Impacts of floods in South Asia. Journal of South Asia Disaster Study, 1(1), 85-106.

Hajat, S., Ebi, K. L., Kovats, R. S., Menne, B., Edwards, S., & Haines, A. (2005). The human health consequences of flooding in Europe: a review. Extreme weather events and public health responses, 185-196.

Hansen, B. K. T. (2018). Flood dampening in hydropower systems (Master thesis, NTNU).

Souza, D.N. de et al. (2017) 'Flood damping by reservoirs: proposition of a graphical parametric method', RBRH, 22, p. e39.

Te Chow, V., Maidment, D. R., & Mays, L. W. (1988). Applied hydrology.

El Bilali, A., Taleb, A., & Boutahri, I. (2021). Application of HEC-RAS and HEC-LifeSim models for flood risk assessment. Journal of Applied Water Engineering and Research, 9(4), 336-351.

Devia, G. K., Ganasri, B. P., & Dwarakish, G. S. (2015). A review on hydrological models. Aquatic procedia, 4, 1001-1007.

López-Moreno, J. I., Beguería, S., & García-Ruiz, J. M. (2002). Influence of the Yesa reservoir on floods of the Aragón River, central Spanish Pyrenees. Hydrology and Earth system sciences, 6(4), 753-762.

Pokhrel, Y., Shin, S., Lin, Z., Yamazaki, D., & Qi, J. (2018). Potential disruption of flood dynamics in the Lower Mekong River Basin due to upstream flow regulation. Scientific reports, 8(1), 17767.

Khaddor, I., Achab, M., Soumali, M. R., Benjbara, A., & Alaoui, A. H. (2021). The impact of the construction of a dam on flood management. Civil Engineering Journal, 7(2), 343-56.

Mateo, C. M., Hanasaki, N., Komori, D., Tanaka, K., Kiguchi, M., Champathong, A., ... & Oki, T. (2014). Assessing the impacts of reservoir operation to floodplain inundation by combining hydrological, reservoir management, and hydrodynamic models. Water Resources Research, 50(9), 7245-7266.

Choné, G., Biron, P. M., & Buffin-Bélanger, T. (2018). Flood hazard mapping techniques with LiDAR in the absence of river bathymetry data. In E3S Web of Conferences (Vol. 40, p. 06005). EDP Sciences.

NVE. (2011). Guidlines for Flood Calculation. Oslo: NVE.

NVKGRUPPEN. (2000). Flood calculation for Ilavassdraget, Leirsjøvassdraget and Damtjern. Trondheim, Norway: Trondheim Kommune.

SWECO. (2005). Flood calculation for Kvinistingen Dam. Trondheim, Norway: Trondheim Kommune.

Terje Nøst, H. S. (2001). Environmental Investigation in 10 selected water courses in Trondheim ByMarka. Trondheim, Norway.

TERRATEC. (2020). Laser Skanning. OSLO: TERRAREC COMPANY.

Appendix

Appendix 1: Kvistingen Dam Routing for Q500= 4.1m3/s

Time, hr	Dicharge in	Im	S	G	Discharge out	Water level
		(m3/s)	(m3)	(m3/s)	(m3/s)	(m)
Maximum	4.1		654437.98	183.77	3.97	435.58
1	0.055		643296.00	178.69	0.00	435
2	0.067	0.06	643442.99	178.75	0.04	435.01
3	0.078	0.07	643520.48	178.79	0.06	435.01
4	0.088	0.08	643572.03	178.81	0.08	435.01
5	0.098	0.09	643613.59	178.83	0.09	435.02
6	0.107	0.10	643650.56	178.84	0.10	435.02
7	0.116	0.11	643684.76	178.85	0.11	435.02
8	0.124	0.12	643716.83	178.87	0.12	435.02
9	0.132	0.13	643746.97	178.88	0.12	435.02
10	0.14	0.14	643776.46	178.89	0.13	435.03
11	0.147	0.14	643804.51	178.90	0.14	435.03
12	0.154	0.15	643830.89	178.92	0.15	435.03
13	0.172	0.16	643869.94	178.93	0.16	435.03
14	0.181	0.18	643915.69	178.95	0.17	435.03
15	0.19	0.19	643952.88	178.97	0.18	435.03
16	0.216	0.20	644007.64	178.99	0.20	435.04
17	0.249	0.23	644097.28	179.03	0.22	435.04
18	0.275	0.26	644198.72	179.07	0.25	435.05
19	0.295	0.29	644288.50	179.11	0.27	435.05
20	0.311	0.30	644362.28	179.14	0.29	435.06
21	0.323	0.32	644421.01	179.16	0.31	435.06
22	0.332	0.33	644466.20	179.18	0.32	435.06
23	0.339	0.34	644500.78	179.19	0.33	435.06
24	0.345	0.34	644528.16	179.20	0.34	435.06
25	0.349	0.35	644549.48	179.21	0.34	435.07
26	0.352	0.35	644565.13	179.22	0.35	435.07
27	0.354	0.35	644576.46	179.22	0.35	435.07
28	0.356	0.36	644585.12	179.23	0.35	435.07
29	0.357	0.36	644591.66	179.23	0.36	435.07
30	0.358	0.36	644596.29	179.23	0.36	435.07
31	0.359	0.36	644600.26	179.23	0.36	435.07
32	0.36	0.36	644604.02	179.24	0.36	435.07
33	0.36	0.36	644606.50	179.24	0.36	435.07
34	0.361	0.36	644608.54	179.24	0.36	435.07
35	0.361	0.36	644610.44	179.24	0.36	435.07
36	0.361	0.36	644611.08	179.24	0.36	435.07
37	0.371	0.37	644623.35	179.24	0.36	435.07

38	0.382	0.38	644652.80	179.26	0.37	435.07
39	0.391	0.39	644686.88	179.27	0.38	435.07
40	0.398	0.39	644717.69	179.28	0.39	435.07
41	0.403	0.40	644742.59	179.29	0.40	435.08
42	0.407	0.41	644761.87	179.30	0.40	435.08
43	0.411	0.41	644778.03	179.31	0.41	435.08
44	0.413	0.41	644790.74	179.31	0.41	435.08
45	0.415	0.41	644799.86	179.32	0.41	435.08
46	0.417	0.42	644807.77	179.32	0.41	435.08
47	0.418	0.42	644814.06	179.32	0.42	435.08
48	0.419	0.42	644818.60	179.33	0.42	435.08
49	0.46	0.44	644870.74	179.35	0.43	435.08
50	0.513	0.49	645001.66	179.40	0.47	435.09
51	0.553	0.53	645158.05	179.47	0.51	435.10
52	0.585	0.57	645297.76	179.52	0.55	435.10
53	0.609	0.60	645412.55	179.57	0.58	435.11
54	0.628	0.62	645503.24	179.61	0.61	435.12
55	0.693	0.66	645635.16	179.66	0.64	435.12
56	0.769	0.73	645849.72	179.75	0.70	435.13
57	0.827	0.80	646083.84	179.85	0.77	435.15
58	0.974	0.90	646410.13	179.99	0.85	435.16
59	1.136	1.06	646892.93	180.19	0.99	435.19
60	1.513	1.32	647705.86	180.52	1.21	435.23
61	3.407	2.46	650717.36	181.77	2.04	435.39
62	4.123	3.77	654051.21	183.50	3.64	435.56
63	3.701	3.91	654437.98	183.77	3.97	435.58
64	3.25	3.48	653734.73	183.28	3.37	435.55
65	2.8	3.03	653236.75	182.93	2.95	435.52
66	2.402	2.60	652659.57	182.58	2.57	435.49
67	2.093	2.25	651883.11	182.26	2.36	435.45
68	1.803	1.95	650898.43	181.85	2.09	435.40
69	1.553	1.68	649914.32	181.44	1.82	435.35
70	1.36	1.46	649047.27	181.08	1.58	435.30
71	1.21	1.29	648340.34	180.79	1.38	435.26
72	1.093	1.15	647779.22	180.55	1.23	435.23
73	1.003	1.05	647339.77	180.37	1.11	435.21
74	0.893	0.95	646949.97	180.21	1.00	435.19
75	0.787	0.84	646557.70	180.05	0.90	435.17
76	0.705	0.75	646198.33	179.90	0.80	435.15
77	0.641	0.67	645900.71	179.77	0.71	435.14
78	0.592	0.62	645663.76	179.68	0.65	435.12
79	0.553	0.57	645477.48	179.60	0.60	435.11
80	0.524	0.54	645332.46	179.54	0.56	435.11
81	0.501	0.51	645220.69	179.49	0.53	435.10
82	0.483	0.49	645133.44	179.46	0.50	435.10
83	0.469	0.48	645065.33	179.43	0.49	435.09

84	0.458	0.46	645012.14	179.41	0.47	435.09
85	0.45	0.45	644971.24	179.39	0.46	435.09
86	0.435	0.44	644929.67	179.37	0.45	435.09
87	0.419	0.43	644878.24	179.35	0.43	435.08
88	0.406	0.41	644825.88	179.33	0.42	435.08
89	0.396	0.40	644780.44	179.31	0.41	435.08
90	0.388	0.39	644743.36	179.29	0.40	435.08
91	0.383	0.39	644715.14	179.28	0.39	435.07
92	0.378	0.38	644693.53	179.27	0.38	435.07
93	0.374	0.38	644675.37	179.27	0.38	435.07
94	0.372	0.37	644661.99	179.26	0.37	435.07
95	0.37	0.37	644652.64	179.26	0.37	435.07
96	0.368	0.37	644644.65	179.25	0.37	435.07

Appendix 2: Kvistingen Dam after reduction of water level by 2.5m

Time, hr	Dicharge in	Im	S	G	Discharge out	Water level
	(m3/s)	(m3/s)	(m3)	(m3/s)	(m3/s)	(m)
Maximum	4.12		653945.62	183.43	3.55	435.56
1	0.06		542799.75	150.78	0.00	432.50
2	0.07	0.06	543019.35	150.84	0.00	432.51
3	0.08	0.07	543280.35	150.91	0.00	432.51
4	0.09	0.08	543579.15	150.99	0.00	432.52
5	0.10	0.09	543913.95	151.09	0.00	432.53
6	0.11	0.10	544282.95	151.19	0.00	432.54
7	0.12	0.11	544684.35	151.30	0.00	432.55
8	0.12	0.12	545116.35	151.42	0.00	432.56
9	0.13	0.13	545577.15	151.55	0.00	432.57
10	0.14	0.14	546066.75	151.69	0.00	432.58
11	0.15	0.14	546583.35	151.83	0.00	432.59
12	0.15	0.15	547125.15	151.98	0.00	432.61
13	0.17	0.16	547711.95	152.14	0.00	432.62
14	0.18	0.18	548347.35	152.32	0.00	432.64
15	0.19	0.19	549015.15	152.50	0.00	432.65
16	0.22	0.20	549745.95	152.71	0.00	432.67
17	0.25	0.23	550582.95	152.94	0.00	432.69
18	0.28	0.26	551526.15	153.20	0.00	432.72
19	0.30	0.29	552552.15	153.49	0.00	432.74
20	0.31	0.30	553642.95	153.79	0.00	432.77
21	0.32	0.32	554784.15	154.11	0.00	432.80
22	0.33	0.33	555963.15	154.43	0.00	432.83
23	0.34	0.34	557170.95	154.77	0.00	432.86
24	0.35	0.34	558402.15	155.11	0.00	432.89
25	0.35	0.35	559651.35	155.46	0.00	432.92

26	0.35	0.35	560913.15	155.81	0.00	432.95
27	0.35	0.35	562183.95	156.16	0.00	432.98
28	0.36	0.36	563461.95	156.52	0.00	433.01
29	0.36	0.36	564745.35	156.87	0.00	433.05
30	0.36	0.36	566032.35	157.23	0.00	433.08
31	0.36	0.36	567322.95	157.59	0.00	433.11
32	0.36	0.36	568617.15	157.95	0.00	433.14
33	0.36	0.36	569913.15	158.31	0.00	433.17
34	0.36	0.36	571210.95	158.67	0.00	433.21
35	0.36	0.36	572510.55	159.03	0.00	433.24
36	0.36	0.36	573810.15	159.39	0.00	433.27
37	0.37	0.37	575127.75	159.76	0.00	433.30
38	0.38	0.38	576483.15	160.13	0.00	433.34
39	0.39	0.39	577874.55	160.52	0.00	433.37
40	0.40	0.39	579294.75	160.92	0.00	433.41
41	0.40	0.40	580736.55	161.32	0.00	433.44
42	0.41	0.41	582194.55	161.72	0.00	433.48
43	0.41	0.41	583666.95	162.13	0.00	433.52
44	0.41	0.41	585150.15	162.54	0.00	433.55
45	0.42	0.41	586640.55	162.96	0.00	433.59
46	0.42	0.42	588138.15	163.37	0.00	433.63
47	0.42	0.42	589641.15	163.79	0.00	433.67
48	0.42	0.42	591147.75	164.21	0.00	433.70
49	0.46	0.44	592729.95	164.65	0.00	433.74
50	0.51	0.49	594481.35	165.13	0.00	433.79
51	0.55	0.53	596400.15	165.67	0.00	433.83
52	0.59	0.57	598448.55	166.24	0.00	433.88
53	0.61	0.60	600597.75	166.83	0.00	433.94
54	0.63	0.62	602824.35	167.45	0.00	433.99
55	0.69	0.66	605202.15	168.11	0.00	434.05
56	0.77	0.73	607833.75	168.84	0.00	434.12
57	0.83	0.80	610706.55	169.64	0.00	434.19
58	0.97	0.90	613948.35	170.54	0.00	434.27
59	1.14	1.06	617746.35	171.60	0.00	434.36
60	1.51	1.32	622514.55	172.92	0.00	434.48
61	3.41	2.46	631370.55	175.38	0.00	434.70
62	4.12	3.77	644924.55	179.15	0.00	435.09
63	3.70	3.91	653417.52	183.06	3.11	435.53
64	3.25	3.48	653945.62	183.43	3.55	435.56
65	2.80	3.03	653193.17	182.90	2.92	435.52
66	2.40	2.60	652674.76	182.59	2.57	435.49
67	2.09	2.25	651888.26	182.26	2.36	435.45
68	1.80	1.95	650900.18	181.85	2.09	435.40
69	1.55	1.68	649914.91	181.44	1.82	435.35
70	1.36	1.46	649047.47	181.08	1.58	435.30
71	1.21	1.29	648340.41	180.79	1.38	435.26

72	1.09	1.15	647779.24	180.55	1.23	435.23
73	1.00	1.05	647339.78	180.37	1.11	435.21
74	0.89	0.95	646949.97	180.21	1.00	435.19
75	0.79	0.84	646557.70	180.05	0.90	435.17
76	0.71	0.75	646198.33	179.90	0.80	435.15
77	0.64	0.67	645900.71	179.77	0.71	435.14
78	0.59	0.62	645663.76	179.68	0.65	435.12
79	0.55	0.57	645477.48	179.60	0.60	435.11
80	0.52	0.54	645332.46	179.54	0.56	435.11
81	0.50	0.51	645220.69	179.49	0.53	435.10
82	0.48	0.49	645133.44	179.46	0.50	435.10
83	0.47	0.48	645065.33	179.43	0.49	435.09
84	0.46	0.46	645012.14	179.41	0.47	435.09
85	0.45	0.45	644971.24	179.39	0.46	435.09
86	0.44	0.44	644929.67	179.37	0.45	435.09
87	0.42	0.43	644878.24	179.35	0.43	435.08
88	0.41	0.41	644825.88	179.33	0.42	435.08
89	0.40	0.40	644780.44	179.31	0.41	435.08
90	0.39	0.39	644743.36	179.29	0.40	435.08
91	0.38	0.39	644715.14	179.28	0.39	435.07
92	0.38	0.38	644693.53	179.27	0.38	435.07
93	0.37	0.38	644675.37	179.27	0.38	435.07
94	0.37	0.37	644661.99	179.26	0.37	435.07
95	0.37	0.37	644652.64	179.26	0.37	435.07
96	0.00	0.19	644201.28	179.07	0.25	435.05

Appendix 3: Skjellbreia Dam Routing Q1000=18.12m3/s

Time, hr	Dicharge in	Im	S	G	Discharge out	Water level
	(m3/s)	(m3/s)	(m3)	(m3/s)	(m3/s)	(m)
Maximum	18.12	18.06	2566411.76	720.14	14.49	226.95
1	0.23		2415937.99	671.09	0.00	225.55
2	0.27	0.25	2416307.73	671.34	0.29	225.55706
3	0.34	0.30	2416328.59	671.35	0.30	225.55746
4	0.41	0.37	2416432.36	671.42	0.38	225.55944
5	0.48	0.44	2416518.56	671.48	0.45	225.56109
6	0.54	0.51	2416605.44	671.54	0.52	225.56274
7	0.61	0.58	2416689.21	671.59	0.58	225.56434
8	0.67	0.64	2416769.74	671.65	0.65	225.56588
9	0.73	0.70	2416848.56	671.70	0.71	225.56739
10	0.79	0.76	2416924.67	671.75	0.77	225.56884
11	0.85	0.82	2416998.23	671.80	0.82	225.57024
12	0.99	0.92	2417137.47	671.89	0.93	225.5729
13	1.21	1.10	2417385.00	672.06	1.13	225.57763
14	1.40	1.30	2417648.23	672.23	1.33	225.58266
15	1.56	1.48	2417871.34	672.38	1.50	225.58692

16	1.71	1.63	2418065.89	672.51	1.66	225.59063
17	1.83	1.77	2418232.96	672.62	1.79	225.59382
18	1.94	1.88	2418377.60	672.72	1.90	225.59658
19	2.03	1.98	2418503.49	672.80	2.00	225.59899
20	2.43	2.23	2419199.86	673.04	2.08	225.61228
21	3.11	2.77	2421427.19	673.73	2.23	225.65481
22	3.70	3.41	2425211.04	674.91	2.48	225.72706
23	4.56	4.13	2430513.98	676.56	2.83	225.82831
24	5.66	5.11	2437828.97	678.83	3.32	225.96799
25	11.84	8.75	2455278.01	684.26	4.48	226.30116
26	18.00	14.92	2487899.65	694.70	7.23	226.6428
27	18.12	18.06	2521312.51	705.52	10.32	226.74624
28	17.44	17.78	2544325.88	712.98	12.45	226.84813
29	16.49	16.96	2558267.17	717.50	13.74	226.90985
30	15.33	15.91	2564984.65	719.67	14.36	226.93959
31	14.31	14.82	2566411.76	720.14	14.49	226.94591
32	13.19	13.75	2564123.07	719.39	14.28	226.93578
33	11.98	12.59	2558901.22	717.70	13.79	226.91266
34	10.94	11.46	2551692.84	715.37	13.13	226.88075
35	10.03	10.48	2543521.62	712.72	12.37	226.84457
36	9.24	9.63	2535058.91	709.98	11.59	226.8071
37	8.55	8.89	2526733.58	707.28	10.82	226.77025
38	7.86	8.21	2518665.37	704.67	10.07	226.73453
39	7.17	7.52	2510777.81	702.11	9.34	226.69961
40	6.58	6.88	2503158.23	699.64	8.64	226.66587
41	6.06	6.32	2495990.95	697.32	7.98	226.64779
42	5.61	5.83	2489373.74	695.18	7.37	226.64371
43	5.22	5.41	2483345.60	693.22	6.81	226.63999
44	4.88	5.05	2477908.17	691.46	6.31	226.63663
45	4.58	4.73	2473042.56	689.88	5.86	226.53254
46	4.32	4.45	2468713.67	688.48	5.45	226.51338
47	4.10	4.21	2464845.65	687.24	5.12	226.48384
48	3.91	4.00	2461262.65	686.12	4.88	226.41543
49	3.74	3.82	2457866.37	685.07	4.65	226.35058
50	3.54	3.64	2454599.15	684.05	4.44	226.2882
51	3.30	3.42	2451325.68	683.03	4.22	226.22569
52	3.10	3.20	2448047.30	682.01	4.00	226.1631
53	2.92	3.01	2444856.67	681.02	3.79	226.10217
54	2.77	2.84	2441815.39	680.07	3.59	226.0441
55	2.63	2.70	2438963.80	679.19	3.40	225.98966
56	2.52	2.57	2436320.79	678.37	3.22	225.93919
57	2.41	2.46	2433893.13	677.61	3.06	225.89284
58	2.33	2.37	2431682.94	676.92	2.91	225.85063
59	2.25	2.29	2429682.26	676.30	2.78	225.81243
60	2.18	2.22	2427879.99	675.74	2.66	225.77802
61	2.13	2.16	2426264.20	675.24	2.55	225.74717

62	2.03	2.08	2424749.97	674.77	2.45	225.71826
63	1.99	2.01	2423347.70	674.33	2.36	225.69148
64	1.96	1.98	2422131.47	673.95	2.27	225.66826
65	1.93	1.95	2421075.93	673.62	2.20	225.6481
66	1.91	1.92	2420159.54	673.34	2.14	225.63061
67	1.89	1.90	2419363.77	673.09	2.09	225.61541
68	1.87	1.88	2418670.83	672.88	2.04	225.60218
69	1.85	1.86	2418329.54	672.69	1.86	225.59566
70	1.84	1.84	2418303.01	672.67	1.84	225.59516
71	0.00	0.92	2416919.97	671.75	0.76	225.56875
72	0.00	0.00		670.98		

Appendix 4: Skjellbreia Flood routing after 2.55m water level reduction

Time, hr	Dicharge in	Im	S	G	Discharge out	Water level
	(m3/s)	(m3/s)	(m3)	(m3/s)	(m3/s)	(m)
Maximum	18.12		2565278.38	719.77	14.38	226.94
1	0.23		2282388.39	634.00	0.00	223.00
2	0.27	0.25	2283275.79	634.24	0.00	223.02
3	0.34	0.30	2284361.19	634.54	0.00	223.04
4	0.41	0.37	2285703.99	634.92	0.00	223.06
5	0.48	0.44	2287295.19	635.36	0.00	223.09
6	0.54	0.51	2289129.39	635.87	0.00	223.13
7	0.61	0.58	2291199.39	636.44	0.00	223.17
8	0.67	0.64	2293496.19	637.08	0.00	223.21
9	0.73	0.70	2296014.39	637.78	0.00	223.26
10	0.79	0.76	2298746.79	638.54	0.00	223.31
11	0.85	0.82	2301686.19	639.36	0.00	223.37
12	0.99	0.92	2304989.19	640.27	0.00	223.43
13	1.21	1.10	2308941.99	641.37	0.00	223.51
14	1.40	1.30	2313625.59	642.67	0.00	223.60
15	1.56	1.48	2318949.99	644.15	0.00	223.70
16	1.71	1.63	2324830.59	645.79	0.00	223.81
17	1.83	1.77	2331189.99	647.55	0.00	223.93
18	1.94	1.88	2337963.39	649.43	0.00	224.06
19	2.03	1.98	2345096.79	651.42	0.00	224.20
20	2.43	2.23	2353128.39	653.65	0.00	224.35
21	3.11	2.77	2363109.39	656.42	0.00	224.54
22	3.70	3.41	2375367.39	659.82	0.00	224.78
23	4.56	4.13	2390233.59	663.95	0.00	225.06
24	5.66	5.11	2408624.19	669.06	0.00	225.41
25	11.84	8.75	2440116.99	677.81	0.00	226.01
26	18.00	14.92	2481818.37	692.73	6.67	226.64
27	18.12	18.06	2516966.69	704.12	9.92	226.73
28	17.44	17.78	2541220.26	711.97	12.16	226.83
29	16.49	16.96	2556047.83	716.78	13.53	226.90

30	15.33	15.91	2563398.67	719.16	14.21	226.93
31	14.31	14.82	2565278.38	719.77	14.38	226.94
32	13.19	13.75	2563313.13	719.13	14.20	226.93
33	11.98	12.59	2558322.42	717.52	13.74	226.91
34	10.94	11.46	2551279.22	715.23	13.09	226.88
35	10.03	10.48	2543226.03	712.62	12.34	226.84
36	9.24	9.63	2534847.68	709.91	11.57	226.81
37	8.55	8.89	2526582.64	707.23	10.81	226.77
38	7.86	8.21	2518557.50	704.63	10.06	226.73
39	7.17	7.52	2510700.72	702.09	9.34	226.70
40	6.58	6.88	2503103.14	699.62	8.63	226.67
41	6.06	6.32	2495951.58	697.31	7.97	226.65
42	5.61	5.83	2489345.61	695.17	7.36	226.64
43	5.22	5.41	2483325.50	693.22	6.81	226.64
44	4.88	5.05	2477893.81	691.46	6.30	226.64
45	4.58	4.73	2473032.30	689.88	5.85	226.53
46	4.32	4.45	2468706.34	688.48	5.45	226.51
47	4.10	4.21	2464840.19	687.24	5.12	226.48
48	3.91	4.00	2461258.36	686.12	4.88	226.42
49	3.74	3.82	2457862.99	685.07	4.65	226.35
50	3.54	3.64	2454596.50	684.05	4.44	226.29
51	3.30	3.42	2451323.60	683.03	4.22	226.23
52	3.10	3.20	2448045.66	682.01	4.00	226.16
53	2.92	3.01	2444855.39	681.02	3.79	226.10
54	2.77	2.84	2441814.38	680.07	3.59	226.04
55	2.63	2.70	2438963.01	679.19	3.40	225.99
56	2.52	2.57	2436320.16	678.37	3.22	225.94
57	2.41	2.46	2433892.63	677.61	3.06	225.89
58	2.33	2.37	2431682.56	676.92	2.91	225.85
59	2.25	2.29	2429681.96	676.30	2.78	225.81
60	2.18	2.22	2427879.75	675.74	2.66	225.78
61	2.13	2.16	2426264.01	675.24	2.55	225.75
62	2.03	2.08	2424749.82	674.77	2.45	225.72
63	1.99	2.01	2423347.58	674.33	2.36	225.69
64	1.96	1.98	2422131.38	673.95	2.27	225.67
65	1.93	1.95	2421075.86	673.62	2.20	225.65
66	1.91	1.92	2420159.49	673.34	2.14	225.63
67	1.89	1.90	2419363.72	673.09	2.09	225.62
68	1.87	1.88	2418670.79	672.88	2.04	225.60
69	1.85	1.86	2418329.53	672.69	1.86	225.60
70	1.84	1.84	2418303.01	672.67	1.84	225.60
71	0.00	0.92	2416919.97	671.75	0.76	225.57
72	0.00	0.00		670.98		

Appendix 5: Leirsjøen Flood Routing for Q1000= 28.55m3/s

Time, hr		Im	S	G	Discharge	Water level

					out	
	(m3/s)	(m3/s)	(m3)	(m3/s)	(m3/s)	(m)
Maximum	28.55		1068378.85	310.93	28.32	200.85
1	0.23		793005.84	220.28	0.00	198.13
2	0.53	0.38	794305.50	220.66	0.04	198.14
3	0.58	0.55	796075.18	221.18	0.09	198.16
4	0.70	0.64	797964.06	221.73	0.14	198.17
5	0.82	0.76	800074.66	222.35	0.20	198.19
6	0.93	0.87	802360.89	223.01	0.27	198.21
7	1.04	0.98	804800.42	223.73	0.34	198.23
8	1.15	1.09	807373.06	224.48	0.42	198.25
9	1.25	1.20	810059.09	225.26	0.49	198.28
10	1.36	1.31	812839.68	226.08	0.57	198.30
11	1.46	1.41	815700.19	226.91	0.66	198.33
12	1.62	1.54	818720.15	227.79	0.74	198.35
13	1.86	1.74	822118.75	228.79	0.84	198.38
14	2.11	1.98	826030.41	229.93	0.95	198.42
15	2.34	2.23	830382.15	231.20	1.08	198.45
16	2.55	2.44	835047.63	232.57	1.21	198.49
17	2.74	2.64	839606.03	233.99	1.53	198.53
18	2.91	2.82	843673.98	235.28	1.85	198.57
19	3.07	2.99	847280.95	236.42	2.13	198.60
20	3.33	3.20	850682.40	237.49	2.39	198.63
21	3.78	3.56	854376.38	238.66	2.67	198.66
22	4.44	4.11	858923.85	240.10	3.02	198.70
23	5.30	4.87	864776.11	241.95	3.47	198.75
24	6.40	5.85	872302.08	244.33	4.05	198.82
25	9.81	8.10	885119.51	248.38	5.04	198.93
26	15.10	12.46	910016.52	255.80	6.04	199.14
27	20.77	17.94	951163.58	267.70	6.97	199.50
28	23.97	22.37	999767.39	283.10	10.77	199.92
29	26.14	25.06	1036589.79	297.39	18.89	200.46
30	27.53	26.84	1055284.75	305.33	24.40	200.72
31	28.28	27.90	1063490.15	308.84	26.85	200.80
32	28.55	28.42	1067145.63	310.40	27.95	200.84
33	28.40	28.47	1068378.85	310.93	28.32	200.85
34	27.90	28.15	1067985.38	310.76	28.20	200.84
35	27.23	27.57	1066503.38	310.13	27.76	200.83
36	26.46	26.85	1064374.59	309.22	27.12	200.81
37	25.64	26.05	1061873.82	308.15	26.37	200.78
38	24.76	25.20	1059134.61	306.98	25.55	200.76
39	23.82	24.29	1056185.29	305.72	24.67	200.73
40	22.84	23.33	1053054.22	304.38	23.73	200.69
41	21.87	22.35	1049831.96	303.00	22.77	200.65
42	20.93	21.40	1046629.94	301.63	21.81	200.62
43	20.03	20.48	1043518.61	300.30	20.88	200.57

44	19.18	19.60	1040539.85	299.03	19.98	200.52
45	18.38	18.78	1037656.69	297.82	19.17	200.47
46	17.63	18.00	1034813.68	296.66	18.42	200.43
47	16.95	17.29	1032080.71	295.53	17.69	200.38
48	16.38	16.67	1029602.66	294.51	17.03	200.34
49	15.84	16.11	1027369.58	293.60	16.43	200.31
50	15.29	15.56	1025250.71	292.73	15.87	200.27
51	14.73	15.01	1023163.72	291.87	15.31	200.24
52	14.17	14.45	1021065.15	291.01	14.75	200.20
53	13.62	13.89	1018971.65	290.15	14.20	200.17
54	13.09	13.36	1016927.12	289.31	13.65	200.13
55	12.59	12.84	1014956.50	288.50	13.13	200.10
57	12.12	12.35	1013075.78	287.72	12.63	200.07
58	11.67	11.89	1011293.88	286.99	12.15	200.04
59	11.25	11.46	1009613.47	286.30	11.70	200.01
60	10.86	11.06	1007830.87	285.65	11.40	199.99
61	10.49	10.68	1005556.10	284.93	11.22	199.97
62	10.15	10.32	1002728.86	284.04	11.00	199.95
63	9.83	9.99	999553.54	283.03	10.75	199.92
64	9.53	9.68	996174.72	281.96	10.49	199.89
65	9.25	9.39	992713.34	280.86	10.22	199.86
66	9.17	9.21	989540.24	279.86	9.97	199.83
67	8.59	8.88	986104.54	278.77	9.70	199.80
68	8.38	8.48	982264.74	277.55	9.40	199.77
69	8.18	8.28	978729.44	276.43	9.12	199.74
70	7.86	8.02	975243.27	275.33	8.85	199.71
71	7.70	7.78	971861.19	274.25	8.59	199.68
72	0.76	4.23	958121.10	269.90	7.51	199.56

Appendix 6: Leirsjøen Dam flood routing after 3m water level reduction

Time, hr	Dicharge in	Im	S	G	Discharge out	Water level
	(m3/s)	(m3/s)	(m3)	(m3/s)	(m3/s)	(m)
Maximum	28.55		1068343.01	310.91	28.31	200.85
1	0.23		703740.00	195.48	0.00	195.00
2	0.53	0.38	705107.26	195.86	0.00	195.05
3	0.58	0.55	707104.20	196.42	0.00	195.12
4	0.70	0.64	709410.63	197.06	0.00	195.20
5	0.82	0.76	712146.83	197.82	0.00	195.29
6	0.93	0.87	715287.35	198.69	0.00	195.40
7	1.04	0.98	718826.98	199.67	0.00	195.53
8	1.15	1.09	722760.45	200.77	0.00	195.67
9	1.25	1.20	727080.83	201.97	0.00	195.82
10	1.36	1.31	731780.12	203.27	0.00	195.98
11	1.46	1.41	736852.76	204.68	0.00	196.16
12	1.62	1.54	742390.72	206.22	0.00	196.36

13	1.86	1.74	748641.19	207.96	0.00	196.57
14	2.11	1.98	755784.96	209.94	0.00	196.82
15	2.34	2.23	763798.65	212.17	0.00	197.11
16	2.55	2.44	772595.10	214.61	0.00	197.41
17	2.74	2.64	782103.03	217.25	0.00	197.75
18	2.91	2.82	792259.78	220.07	0.00	198.10
19	3.07	2.99	803018.50	223.06	0.00	198.22
20	3.33	3.20	813477.49	226.26	0.59	198.31
21	3.78	3.56	823619.33	229.23	0.88	198.40
22	4.44	4.11	834654.52	232.45	1.20	198.49
23	5.30	4.87	846332.87	236.12	2.05	198.59
24	6.40	5.85	858346.02	239.92	2.98	198.70
25	9.81	8.10	874558.91	245.05	4.22	198.84
26	15.10	12.46	901270.32	253.28	5.85	199.07
27	20.77	17.94	943104.93	265.37	6.78	199.43
28	23.97	22.37	992996.80	280.95	10.24	199.86
29	26.14	25.06	1032657.01	295.77	17.84	200.39
30	27.53	26.84	1053954.28	304.76	24.00	200.71
31	28.28	27.90	1063091.34	308.67	26.73	200.80
32	28.55	28.42	1067026.08	310.35	27.91	200.83
33	28.40	28.47	1068343.01	310.91	28.31	200.85
34	27.90	28.15	1067974.64	310.76	28.20	200.84
35	27.23	27.57	1066500.16	310.13	27.75	200.83
36	26.46	26.85	1064373.62	309.22	27.12	200.81
37	25.64	26.05	1061873.53	308.15	26.37	200.78
38	24.76	25.20	1059134.53	306.98	25.55	200.76
39	23.82	24.29	1056185.26	305.72	24.67	200.73
40	22.84	23.33	1053054.22	304.38	23.73	200.69
41	21.87	22.35	1049831.95	303.00	22.77	200.65
42	20.93	21.40	1046629.94	301.63	21.81	200.62
43	20.03	20.48	1043518.61	300.30	20.88	200.57
44	19.18	19.60	1040539.85	299.03	19.98	200.52
45	18.38	18.78	1037656.69	297.82	19.17	200.47
46	17.63	18.00	1034813.68	296.66	18.42	200.43
47	16.95	17.29	1032080.71	295.53	17.69	200.38
48	16.38	16.67	1029602.66	294.51	17.03	200.34
49	15.84	16.11	1027369.58	293.60	16.43	200.31
50	15.29	15.56	1025250.71	292.73	15.87	200.27
51	14.73	15.01	1023163.72	291.87	15.31	200.24
52	14.17	14.45	1021065.15	291.01	14.75	200.20
53	13.62	13.89	1018971.65	290.15	14.20	200.17
54	13.09	13.36	1016927.12	289.31	13.65	200.13
55	12.59	12.84	1014956.50	288.50	13.13	200.10
57	12.12	12.35	1013075.78	287.72	12.63	200.07
58	11.67	11.89	1011293.88	286.99	12.15	200.04
59	11.25	11.46	1009613.47	286.30	11.70	200.01

60	10.86	11.06	1007830.87	285.65	11.40	199.99
61	10.49	10.68	1005556.10	284.93	11.22	199.97
62	10.15	10.32	1002728.86	284.04	11.00	199.95
63	9.83	9.99	999553.54	283.03	10.75	199.92
64	9.53	9.68	996174.72	281.96	10.49	199.89
65	9.25	9.39	992713.34	280.86	10.22	199.86
66	9.17	9.21	989540.24	279.86	9.97	199.83
67	8.59	8.88	986104.54	278.77	9.70	199.80
68	8.38	8.48	982264.74	277.55	9.40	199.77
69	8.18	8.28	978729.44	276.43	9.12	199.74
70	7.86	8.02	975243.27	275.33	8.85	199.71
71	7.70	7.78	971861.19	274.25	8.59	199.68
72	0.76	4.23	958121.10	269.90	7.51	199.56

Appendix 7: M50-Design flood for Kvistingen dam 24h

Time hr	P mm	X mm	Q1 mm	Q2 mm	QT mm	Q (M3/S)
0		11.09712				
1	0.68	11.25648	0.401114	0.12242	0.523534	0.174511
2	0.68	11.38728	0.401114	0.150988	0.552102	0.184034
3	0.68	11.49462	0.401114	0.174435	0.575549	0.19185
4	0.68	11.58273	0.401114	0.193679	0.594793	0.198264
5	0.68	11.65504	0.401114	0.209473	0.610587	0.203529
6	0.68	11.71439	0.401114	0.222436	0.62355	0.20785
7	0.68	11.76309	0.401114	0.233075	0.634189	0.211396
8	0.68	11.80307	0.401114	0.241807	0.642921	0.214307
9	0.68	11.83588	0.401114	0.248973	0.650087	0.216696
10	0.68	11.86281	0.401114	0.254855	0.655969	0.218656
11	0.68	11.88491	0.401114	0.259682	0.660796	0.220265
12	0.68	11.90305	0.401114	0.263644	0.664758	0.221586
13	0.68	11.91794	0.401114	0.266896	0.66801	0.22267
14	0.68	11.93016	0.401114	0.269565	0.670679	0.22356
15	0.68	11.94018	0.401114	0.271755	0.672869	0.22429
16	0.68	11.94841	0.401114	0.273553	0.674667	0.224889
17	0.68	11.95517	0.401114	0.275028	0.676142	0.225381
18	0.68	11.96071	0.401114	0.276239	0.677353	0.225784
19	0.68	11.96526	0.401114	0.277233	0.678347	0.226116
20	0.68	11.969	0.401114	0.278049	0.679163	0.226388
21	0.68	11.97206	0.401114	0.278718	0.679832	0.226611
22	0.89	12.14272	0.401114	0.315994	0.717108	0.239036
23	0.89	12.28279	0.401114	0.346587	0.747701	0.249234
24	0.89	12.39774	0.401114	0.371696	0.77281	0.257603
25	0.89	12.49209	0.401114	0.392304	0.793418	0.264473
26	0.89	12.56953	0.401114	0.409217	0.810331	0.27011
27	0.89	12.63308	0.401114	0.423099	0.824213	0.274738
28	0.89	12.68524	0.401114	0.434492	0.835606	0.278535
29	0.89	12.72805	0.401114	0.443842	0.844956	0.281652

30	0.89	12.76319	0.401114	0.451517	0.852631	0.28421
31	0.89	12.79203	0.401114	0.457815	0.858929	0.28631
32	0.89	12.81569	0.401114	0.462985	0.864099	0.288033
33	0.89	12.83512	0.401114	0.467228	0.868342	0.289447
34	1.50	13.35549	0.401114	0.580888	0.982002	0.327334
35	1.50	13.78258	0.401114	0.674173	1.075287	0.358429
36	1.50	14.1331	0.401114	0.750735	1.151849	0.38395
37	1.50	14.42079	0.401114	0.813572	1.214686	0.404895
38	1.50	14.65691	0.401114	0.865144	1.266258	0.422086
39	1.50	14.8507	0.401114	0.907472	1.308586	0.436195
40	2.32	15.68232	0.401114	1.089115	1.490229	0.496743
41	2.32	16.36486	0.401114	1.238196	1.63931	0.546437
42	2.32	16.92504	0.401114	1.360552	1.761666	0.587222
43	4.30	19.01019	0.401114	1.815992	2.217106	0.739035
44	4.30	20.72154	0.401114	2.189787	2.590901	0.863634
45	6.56	23.97568	0.401114	2.90056	3.301674	1.100558
46	26.22	42.78821	0.401114	7.009611	7.410724	2.470241
47	4.30	40.23698	0.401114	6.452368	6.853482	2.284494
48	4.30	38.1431	0.401114	5.995021	6.396135	2.132045
49	2.32	34.79919	0.401114	5.264642	5.665756	1.888585
50	2.32	32.05473	0.401114	4.665195	5.066309	1.68877
51	2.32	29.80226	0.401114	4.173208	4.574322	1.524774
52	1.50	27.28101	0.401114	3.622513	4.023627	1.341209
53	1.50	25.21173	0.401114	3.170539	3.571653	1.190551
54	1.50	23.5134	0.401114	2.799589	3.200703	1.066901
55	1.50	22.11953	0.401114	2.495137	2.896251	0.965417
56	1.50	20.97552	0.401114	2.245263	2.646376	0.882125
57	1.50	20.0366	0.401114	2.040182	2.441296	0.813765
58	0.89	18.76157	0.401114	1.761688	2.162802	0.720934
59	0.89	17.7151	0.401114	1.533118	1.934232	0.644744
60	0.89	16.85623	0.401114	1.345523	1.746637	0.582212
61	0.89	16.15133	0.401114	1.191557	1.592671	0.53089
62	0.89	15.57279	0.401114	1.065192	1.466306	0.488769
63	0.89	15.09796	0.401114	0.961479	1.362593	0.454198
64	0.89	14.70825	0.401114	0.876359	1.277473	0.425824
65	0.89	14.38841	0.401114	0.806498	1.207612	0.402537
66	0.89	14.1259	0.401114	0.749161	1.150275	0.383425
67	0.89	13.91045	0.401114	0.702102	1.103216	0.367739
68	0.89	13.73362	0.401114	0.663479	1.064593	0.354864
69	0.89	13.58849	0.401114	0.63178	1.032894	0.344298
70	0.68	13.30124	0.401114	0.569038	0.970152	0.323384
71	0.68	13.06548	0.401114	0.517543	0.918657	0.306219
72	0.68	12.87198	0.401114	0.475279	0.876393	0.292131
73	0.68	12.71317	0.401114	0.440592	0.841706	0.280569
74	0.68	12.58283	0.401114	0.412123	0.813237	0.271079
75	0.68	12.47586	0.401114	0.388758	0.789872	0.263291

76	0.68	12.38806	0.401114	0.369581	0.770695	0.256898
77	0.68	12.316	0.401114	0.353842	0.754956	0.251652
78	0.68	12.25686	0.401114	0.340924	0.742038	0.247346
79	0.68	12.20832	0.401114	0.330322	0.731436	0.243812
80	0.68	12.16849	0.401114	0.321621	0.722735	0.240912
81	0.68	12.13579	0.401114	0.314479	0.715593	0.238531
82	0.68	12.10895	0.401114	0.308618	0.709732	0.236577
83	0.68	12.08693	0.401114	0.303808	0.704922	0.234974
84	0.68	12.06885	0.401114	0.299859	0.700973	0.233658
85	0.68	12.05402	0.401114	0.296619	0.697733	0.232578
86	0.68	12.04184	0.401114	0.293959	0.695073	0.231691
87	0.68	12.03185	0.401114	0.291777	0.692891	0.230964
88	0.68	12.02365	0.401114	0.289985	0.691099	0.230366
89	0.68	12.01692	0.401114	0.288515	0.689629	0.229876
90	0.68	12.01139	0.401114	0.287308	0.688422	0.229474
91	0.68	12.00686	0.401114	0.286318	0.687432	0.229144
92	0.68	12.00314	0.401114	0.285505	0.686619	0.228873
93	0.68	12.00008	0.401114	0.284838	0.685952	0.228651
94	0.68	11.99757	0.401114	0.28429	0.685404	0.228468
95	0.68	11.99552	0.401114	0.283841	0.684955	0.228318
96	0.68	11.99383	0.401114	0.283472	0.684586	0.228195

Appendix 8: M50-Design flood Skjellbreia Dam 24hr

Time hr	P mm	X mm	Q1 mm	Q2 mm	QT mm	Q (M3/S)
0		9.962503				
1	0.68	10.18131	0.346055	0.111142	0.457197	0.800094
2	0.68	10.36413	0.346055	0.147116	0.49317	0.863048
3	0.68	10.5169	0.346055	0.177175	0.52323	0.915652
4	0.68	10.64456	0.346055	0.202292	0.548347	0.959607
5	0.68	10.75122	0.346055	0.22328	0.569334	0.996335
6	0.68	10.84035	0.346055	0.240816	0.586871	1.027025
7	0.68	10.91482	0.346055	0.25547	0.601525	1.052669
8	0.68	10.97705	0.346055	0.267715	0.613769	1.074096
9	0.68	11.02905	0.346055	0.277946	0.624001	1.092001
10	0.68	11.0725	0.346055	0.286495	0.63255	1.106962
11	0.68	11.10881	0.346055	0.293639	0.639693	1.119463
12	0.88	11.3086	0.346055	0.33295	0.679005	1.188259
13	0.88	11.47555	0.346055	0.365799	0.711854	1.245744
14	0.88	11.61505	0.346055	0.393247	0.739301	1.293777
15	0.88	11.73161	0.346055	0.416182	0.762236	1.333914
16	0.88	11.82901	0.346055	0.435346	0.781401	1.367451
17	0.88	11.91039	0.346055	0.451359	0.797414	1.395475
18	0.88	11.9784	0.346055	0.46474	0.810795	1.418891
19	0.88	12.03522	0.346055	0.475921	0.821975	1.438457
20	0.88	12.0827	0.346055	0.485263	0.831318	1.454806
21	0.88	12.12238	0.346055	0.49307	0.839124	1.468468

22	0.88	12.15553	0.346055	0.499593	0.845647	1.479883
23	0.88	12.18323	0.346055	0.505043	0.851098	1.489421
24	1.49	12.71475	0.346055	0.609625	0.95568	1.67244
25	1.49	13.15888	0.346055	0.697013	1.043068	1.825369
26	1.49	13.52999	0.346055	0.770033	1.116088	1.953154
27	1.49	13.84008	0.346055	0.831048	1.177103	2.05993
28	1.49	14.0992	0.346055	0.882031	1.228086	2.149151
29	1.49	14.31571	0.346055	0.924632	1.270687	2.223703
30	2.30	15.17445	0.346055	1.0936	1.439655	2.519396
31	2.30	15.89201	0.346055	1.234787	1.580842	2.766473
32	2.30	16.49159	0.346055	1.352762	1.698816	2.972928
33	4.26	18.63068	0.346055	1.773652	2.119706	3.709486
34	4.26	20.41807	0.346055	2.125342	2.471397	4.324945
35	6.49	23.77563	0.346055	2.78598	3.132035	5.481061
36	25.96	42.84906	0.346055	6.538893	6.884948	12.04866
37	4.26	40.65468	0.346055	6.107123	6.453178	11.29306
38	4.26	38.82108	0.346055	5.746341	6.092396	10.66169
39	2.30	35.65085	0.346055	5.122564	5.468619	9.570083
40	2.30	33.00185	0.346055	4.601344	4.947398	8.657947
41	2.30	30.78838	0.346055	4.165817	4.511872	7.895776
42	1.49	28.261	0.346055	3.668526	4.014581	7.025517
43	1.49	26.14914	0.346055	3.252995	3.59905	6.298338
44	1.49	24.38451	0.346055	2.905783	3.251837	5.690715
45	1.49	22.90999	0.346055	2.615656	2.96171	5.182993
46	1.49	21.67791	0.346055	2.373229	2.719284	4.758746
47	1.49	20.64839	0.346055	2.17066	2.516715	4.404251
48	0.88	19.27977	0.346055	1.901368	2.247423	3.932989
49	0.88	18.13616	0.346055	1.67635	2.022405	3.539209
50	0.88	17.18058	0.346055	1.488328	1.834383	3.21017
51	0.88	16.3821	0.346055	1.331219	1.677274	2.93523
52	0.88	15.71491	0.346055	1.199941	1.545996	2.705492
53	0.88	15.15741	0.346055	1.090246	1.436301	2.513526
54	0.88	14.69156	0.346055	0.998586	1.344641	2.353122
55	0.88	14.30231	0.346055	0.921997	1.268051	2.21909
56	0.88	13.97706	0.346055	0.857999	1.204054	2.107094
57	0.88	13.70528	0.346055	0.804523	1.150578	2.013512
58	0.88	13.47818	0.346055	0.75984	1.105895	1.935315
59	0.88	13.28842	0.346055	0.722503	1.068557	1.869975
60	0.68	12.96041	0.346055	0.657962	1.004016	1.757029
61	0.68	12.68632	0.346055	0.604032	0.950087	1.662651
62	0.68	12.45729	0.346055	0.558969	0.905023	1.583791
63	0.68	12.26592	0.346055	0.521315	0.867369	1.517896
64	0.68	12.10602	0.346055	0.489851	0.835906	1.462835
65	0.68	11.9724	0.346055	0.463561	0.809615	1.416827
66	0.68	11.86075	0.346055	0.441593	0.787647	1.378383
67	0.68	11.76746	0.346055	0.423236	0.769291	1.346259

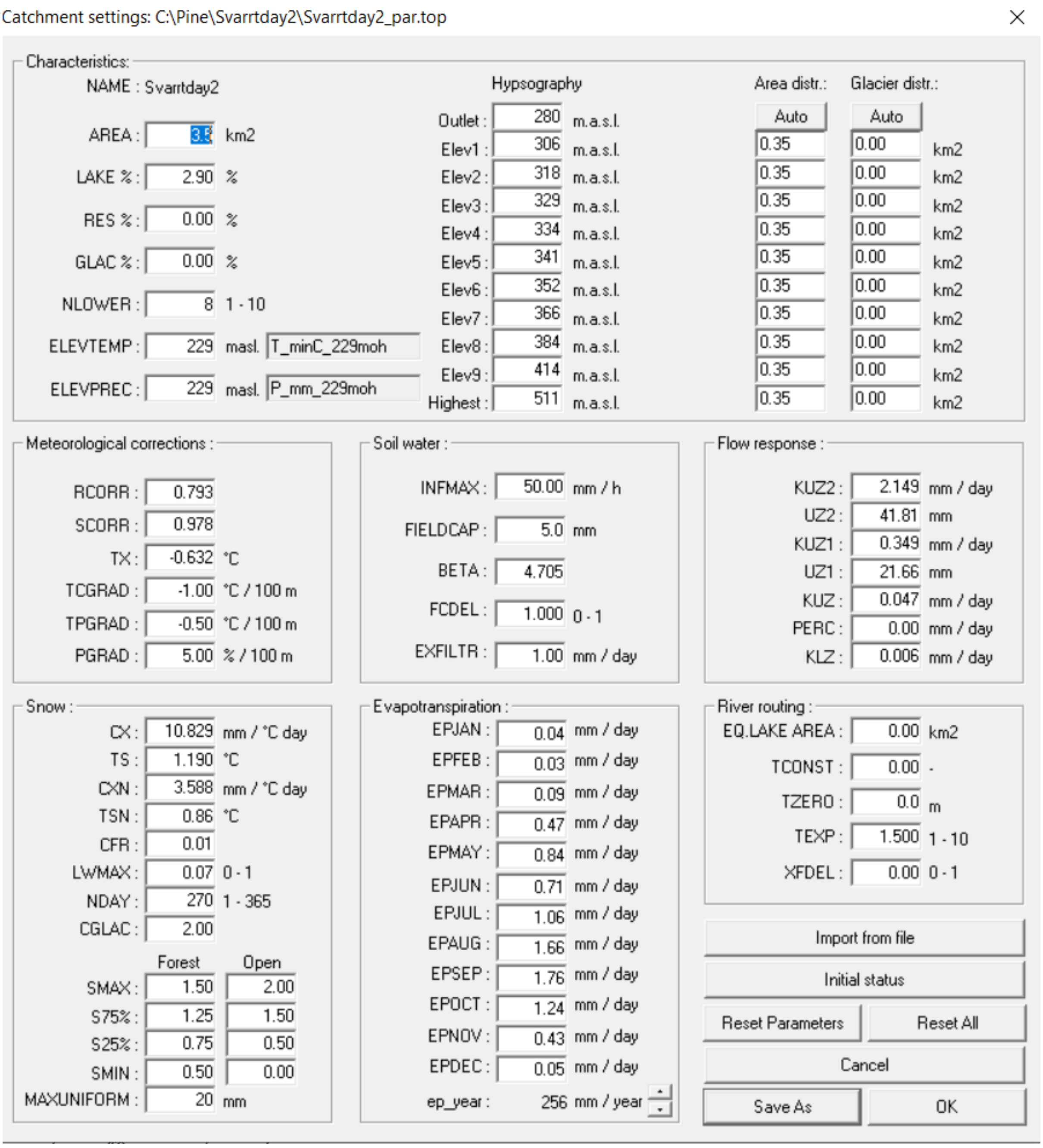
68	0.68	11.68951	0.346055	0.407898	0.753953	1.319418
69	0.68	11.62437	0.346055	0.395082	0.741136	1.296989
70	0.68	11.56994	0.346055	0.384372	0.730427	1.278247
71	0.68	11.52446	0.346055	0.375424	0.721479	1.262587
72	0.68	11.48646	0.346055	0.367947	0.714001	1.249502

Appendix 9: M50-Design flood for Leirsjøen Dam 24hr

Time hr	P mm	X mm	Q1 mm	Q2 mm	QT mm	Q (M3/S)
0		11.87047				
1	0.68	12.1021	0.360672	0.08369	0.444362	0.999815
2	0.68	12.30506	0.360672	0.112367	0.473039	1.064338
3	0.68	12.4829	0.360672	0.137494	0.498166	1.120874
4	0.68	12.63871	0.360672	0.15951	0.520182	1.17041
5	0.68	12.77524	0.360672	0.178801	0.539473	1.213814
6	0.68	12.89486	0.360672	0.195703	0.556375	1.251844
7	0.68	12.99968	0.360672	0.210513	0.571185	1.285166
8	0.68	13.09152	0.360672	0.223489	0.584161	1.314362
9	0.68	13.17199	0.360672	0.234859	0.595531	1.339944
10	0.68	13.24249	0.360672	0.244821	0.605493	1.362359
11	0.68	13.30427	0.360672	0.25355	0.614222	1.381999
12	0.88	13.53609	0.360672	0.286305	0.646977	1.455698
13	0.88	13.73921	0.360672	0.315005	0.675677	1.520273
14	0.88	13.91719	0.360672	0.340152	0.700824	1.576854
15	0.88	14.07313	0.360672	0.362186	0.722858	1.62643
16	0.88	14.20977	0.360672	0.381492	0.742164	1.669868
17	0.88	14.32949	0.360672	0.398407	0.759079	1.707929
18	0.88	14.43438	0.360672	0.413229	0.773901	1.741277
19	0.88	14.5263	0.360672	0.426216	0.786888	1.770497
20	0.88	14.60683	0.360672	0.437594	0.798266	1.796099
21	0.88	14.67739	0.360672	0.447565	0.808236	1.818532
22	0.88	14.73922	0.360672	0.4563	0.816972	1.838188
23	0.88	14.79339	0.360672	0.463955	0.824627	1.85541
24	1.49	15.37393	0.360672	0.545982	0.906654	2.039972
25	1.49	15.88261	0.360672	0.617855	0.978527	2.201686
26	1.49	16.3283	0.360672	0.68083	1.041502	2.343379
27	1.49	16.71882	0.360672	0.736008	1.09668	2.46753
28	1.49	17.06099	0.360672	0.784355	1.145027	2.57631
29	1.49	17.3608	0.360672	0.826716	1.187388	2.671624
30	2.30	18.33427	0.360672	0.964262	1.324934	2.981101
31	2.30	19.18721	0.360672	1.084779	1.445451	3.252264
32	2.30	19.93456	0.360672	1.190375	1.551047	3.489856
33	4.26	22.30709	0.360672	1.5256	1.886272	4.244113
34	4.26	24.38589	0.360672	1.819324	2.179996	4.90499
35	6.49	28.16195	0.360672	2.352861	2.713533	6.105449
36	25.96	48.52902	0.360672	5.230622	5.591294	12.58041
37	4.26	47.36149	0.360672	5.065656	5.426328	12.20924

38	4.26	46.3385	0.360672	4.921113	5.281785	11.88402
39	2.30	43.72447	0.360672	4.551763	4.912435	11.05298
40	2.30	41.43405	0.360672	4.22814	4.588812	10.32483
41	2.30	39.4272	0.360672	3.944582	4.305253	9.68682
42	1.49	36.95802	0.360672	3.5957	3.956372	8.901838
43	1.49	34.79454	0.360672	3.290011	3.650683	8.214037
44	1.49	32.8989	0.360672	3.022167	3.382839	7.611388
45	1.49	31.23794	0.360672	2.787483	3.148155	7.083348
46	1.49	29.78261	0.360672	2.581853	2.942525	6.620681
47	1.49	28.50746	0.360672	2.40168	2.762352	6.215293
48	0.88	26.85709	0.360672	2.168492	2.529164	5.69062
49	0.88	25.41105	0.360672	1.964174	2.324846	5.230903
50	0.88	24.14402	0.360672	1.78515	2.145822	4.8281
51	0.88	23.03386	0.360672	1.62829	1.988962	4.475164
52	0.88	22.06114	0.360672	1.490849	1.851521	4.165923
53	0.88	21.20884	0.360672	1.370424	1.731096	3.894967
54	0.88	20.46206	0.360672	1.264908	1.62558	3.657555
55	0.88	19.80773	0.360672	1.172455	1.533127	3.449536
56	0.88	19.23441	0.360672	1.091448	1.45212	3.267269
57	0.88	18.73207	0.360672	1.020469	1.381141	3.107568
58	0.88	18.29192	0.360672	0.958278	1.31895	2.967638
59	0.88	17.90626	0.360672	0.903787	1.264459	2.845032
60	0.68	17.39065	0.360672	0.830934	1.191606	2.681114
61	0.68	16.93888	0.360672	0.767101	1.127773	2.537489
62	0.68	16.54304	0.360672	0.71117	1.071842	2.411645
63	0.68	16.1962	0.360672	0.662164	1.022836	2.301381
64	0.68	15.8923	0.360672	0.619225	0.979897	2.204768
65	0.68	15.62603	0.360672	0.581602	0.942274	2.120116
66	0.68	15.39272	0.360672	0.548637	0.909308	2.045944
67	0.68	15.18829	0.360672	0.519752	0.880424	1.980955
68	0.68	15.00918	0.360672	0.494444	0.855116	1.924011
69	0.68	14.85223	0.360672	0.472269	0.832941	1.874117
70	0.68	14.71472	0.360672	0.452839	0.813511	1.8304
71	0.68	14.59423	0.360672	0.435815	0.796487	1.792096
72	0.68	14.48866	0.360672	0.420898	0.78157	1.758533

Appendix 10: Calibrated Svarrtjørnbekken Catchment Parameters



Catchment settings: C:\Pine\Svarrtday2\Svarrtday2_par.top

Characteristics:

NAME : Svarrtday2

AREA :	3.5	km2	
LAKE % :	2.90	%	
RES % :	0.00	%	
GLAC % :	0.00	%	
NLOWER :	8	1 - 10	
ELEVTEMP :	229	masl.	T_minC_229moh
ELEVPREC :	229	masl.	P_mm_229moh

Hypsography			Area distr.:	Glacier distr.:	
			Auto	Auto	
Outlet :	280	m.a.s.l.			
Elev1 :	306	m.a.s.l.	0.35	0.00	km2
Elev2 :	318	m.a.s.l.	0.35	0.00	km2
Elev3 :	329	m.a.s.l.	0.35	0.00	km2
Elev4 :	334	m.a.s.l.	0.35	0.00	km2
Elev5 :	341	m.a.s.l.	0.35	0.00	km2
Elev6 :	352	m.a.s.l.	0.35	0.00	km2
Elev7 :	366	m.a.s.l.	0.35	0.00	km2
Elev8 :	384	m.a.s.l.	0.35	0.00	km2
Elev9 :	414	m.a.s.l.	0.35	0.00	km2
Highest :	511	m.a.s.l.	0.35	0.00	km2

Meteorological corrections :

RCORR :	0.793	
SCORR :	0.978	
TX :	-0.632	°C
TCGRAD :	-1.00	°C / 100 m
TPGRAD :	-0.50	°C / 100 m
PGRAD :	5.00	% / 100 m

Soil water :

INFMAX :	50.00	mm / h
FIELDCAP :	5.0	mm
BETA :	4.705	
FCDEL :	1.000	0 - 1
EXFILTR :	1.00	mm / day

Flow response :

KUZ2 :	2.149	mm / day
UZ2 :	41.81	mm
KUZ1 :	0.349	mm / day
UZ1 :	21.66	mm
KUZ :	0.047	mm / day
PERC :	0.00	mm / day
KLZ :	0.006	mm / day

Snow :

CX :	10.829	mm / °C day
TS :	1.190	°C
CXN :	3.588	mm / °C day
TSN :	0.86	°C
CFR :	0.01	
LWMAX :	0.07	0 - 1
NDAY :	270	1 - 365
CGLAC :	2.00	

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

MAXUNIFORM : 20 mm

Evapotranspiration :

EPJAN :	0.04	mm / day
EPFEB :	0.03	mm / day
EPMAR :	0.09	mm / day
EPAPR :	0.47	mm / day
EPMAY :	0.84	mm / day
EPJUN :	0.71	mm / day
EPJUL :	1.06	mm / day
EPAUG :	1.66	mm / day
EPSEP :	1.76	mm / day
EPOCT :	1.24	mm / day
EPNOV :	0.43	mm / day
EPDEC :	0.05	mm / day
ep_year :	256	mm / year

River routing :

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

Import from file

Initial status

Reset Parameters | Reset All

Cancel

Save As | OK

Appendix 11: Met.no. Personal communication

Meteorologisk institutt **INC2303 0315**

Hei / Hello ,

Din sak INC2303 0315: "PMF" er fullført. Under finner du vår løsning. / Your case INC2303 0315: "PMF" is resolved. Here is our solution.

Svar / Answer:
Hei,

Gamle PMP-beregninger har ofte overraskende lang holdbarhet. Umiddelbart synes jeg en årsnedbør på 1200 mm virker noe høyt, men en slik verdi vil uansett være på den sikre siden.

Vennlig hilsen
Jostein Mamen
dagens klimavakt

Opprinnelig forespørsel / Initial request**:**
Avsender: knut.alfredsen@ntnu.no
Dato sendt: 16.mar.2023 18:43
Til: "klimavakten@met.no" <klimavakten@met.no>
Emne: PMF

Hei,
Eg skulle hatt 500-årsnedbør og PMF for nedbørfeltet Kvistingen i Trondheim for ei masteroppgåve ved NTNU. Er det nokon plass eg kan laste ned eller bestille dette?

Helsing
Knut Alfredsen

__
Knut Alfredsen, Professor

knut.alfredsen@ntnu.no - https://www.ntnu.edu/employees/knut.alfredsen