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ABSTRACT

The main objective of the research is to evaluate the feasibility use of hydropower production as means of flood regulation in Stryn - a national salmon river. To achieve the objective above, a distributed hydrological model of the Stryn catchment was set up using both historical climate data and GIS data. Two gauging stations in the catchment Strynsvatn and Grasdøla were used for model calibration. Model calibration produced a R2 of 0.803 for Strynsvatn and 0.703 for Grasdøla. The validation period showed an improvement in Strynsvatn R2 of 0.829 whereas a poorer performance was registered for Grasdøla (R2 = 0.639).

Results from the hydrological model were used to evaluate floods in Stryn catchment, hydropower potential, and effects of climate change on the catchment hydrology.

The study analysed a feasible intake location upstream for diverting flood water from Stryn catchment to the Nord Fjord hence bypassing the downstream flood prone areas. Several intake locations 600, 400, 325, 225, 150, 88 m.a.s.l at downstream of the Oppstrynsvatnet lake were investigated. The hydropower potential from the all the intakes was evaluated in comparison with the cost analysis. Effect of flood reduction and effect of regulation on hydrological alteration have been assessed with regards to the population of salmon in Stryn river.

From the study, a trade-off between hydropower production, flood reduction and effects on the salmon population is assessed. By diverting water at higher intakes (600 m.a.s.l), the hydropower potential is great with 437.7 GWh/yr and a B/C ratio of 2.16. In diverting water immediately downstream of Oppstrynsvatnet lake gave an energy production of 37.4 GWh/yr. and B/C ratio of 0.63. However, due to reduced catchment area from upstream intakes, the average flood reduction potential is 22 % at D600 as compared to 41.48% at DStrynsvatnet. Increasing the tunnel capacities increase the flood regulation potential however to with an added cost. .

The effect of regulation on the changes in lowest weekly average in Stryn is negligible since Q95 is maintained in the river at all times, As the more smaller tributaries flow into the bypass section, regulation effects are dampened..

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LIST OF ABBREVIATIONS

AMS	Annual Maximum Series
B/C	Benefit to Cost
DEM	Digital Elevation Map
D&B	Drill and Blast
GIS	Geographical Information System
IDW	Inverse Distance Method
NPV	Net Present Value
NVE	Norwegian Water Resources and Energy Directorate
O&M	Operation and Maintenance
TBM	Tunnel Boring Machine

1. INTRODUCTION

1.1 Introduction

Floods are major occurring natural disasters causing millions of damages to public infrastructures, residential places. Changes due to climate change will increase the magnitude and frequency of floods unless major systems are put in place to control the likely damage caused by flooding in the flood plains. Hydropower systems, reservoir regulation can be efficiently used for flood routing and control. This requires a timely hydrological forecasting, controlled released of water downstream to minimise the impact of floods downstream.

1.2 Problem Description

Stryn lies in Vestland Norway downstream of Oppstrynsvatnet lake. The river meanders through a fertile valley with farmlands and established settlements. The river is national salmon river hence protected against hydropower development. However, the region is prone to flooding, posing risk of destruction to existing property and future developments. This requires a need for flood protection without significant effect to the salmon population.

1.3 Research objectives

The main objective of the study is evaluate the feasibility use of hydropower production as means of flood regulation in Stryn catchment. Stryn is national salmon river hence the study will assess the effect of regulation on the likelihood impact of salmon population.

To meet the research objective, the sub objectives included;

1. Flood frequency analysis in Stryn catchment.
    i. Understand the hydrology and possible cause of floods in Stryn catchment.
    ii. Extend of the catchment area, sub-catchments, and contribution to flooding and inflow into the catchment area.
    iii. Compute the flood frequency and flood magnitude in Stryn and flood.
2. Evaluation of the hydropower potential of the region
3. Evaluate flood reduction with proposed hydropower development
    i. Potential water diversion through tunnel system
    ii. Hydropower potential and operation strategy

4. Conduct an economic and cost analysis of proposed solution
5. Assess the effect of flow regulation on salmon population
6. Assess the effect of climate change on the flooding in Stryn and to the proposed solution

2. LITERATURE REVIEW

2.1 Floods

There are several definitions of flood. NVE defines flood as a relatively large flow of water in the river; when the water levels in lakes and rivers exceed normal causing the water to overflow beyond the riverbanks. Roald, (2012) similarly defines a flood as an event when water level in rivers or lakes starts flowing over a defined level or over the riverbanks and starts causing damages. Flood prone areas are located on the bank of rivers, river meanders, low lying valleys, river near the cost. Most settlements, developments and agricultural activities are located near riverbanks hence high-risk flood prone areas. Flood causes devastating damage to buildings, farmlands, private houses and loss of life.

Damage due to floods constitute heavy economic losses. Flood damage comprises a third of the economic losses inflicted by natural hazards worldwide, and between 1980 and 2018, the global direct economic losses due to floods exceeded $1 trillion and more than 223,000 people lost their lives (Juárez et al., 2021).

Climate change will increase the magnitude and frequency of floods hence need to develop solutions to mitigate and reduce the impact of floods.

2.1.1 Flood damage is Norway

In 1995 the biggest floods in this century occurred in Norway, in a two-week period from May 27th to June 10th creating damage in the order of 1800 Mill. NOK, equivalent to 300 Mill. US $ (Å. Killingtveit, 1997). Similarly in October 2014, an extreme precipitation event hit western Norway, causing flooding and landslides and resulted in severe damage to infrastructure and houses (Amundsen & Dannevig, 2021). Such are examples of extreme historical flood events in Norway causing major damages. The losses due to floods have been calculated to approximately 100 mill. Euro annually since 2011 (Multiconsult, 2018). Flood damages have increased dramatically the last decades, and the costs are now (2011-2016) estimated to be 4 times higher than in the period 1980-2010 (Bakken et al., 2019). Increased settlement and development in the flood prone areas and changes in the climate pose a likelihood of increase in the economic losses due to flood damage.

The Figure 2.1 shows cost associated with flood damages for between 2008 to 2017 .

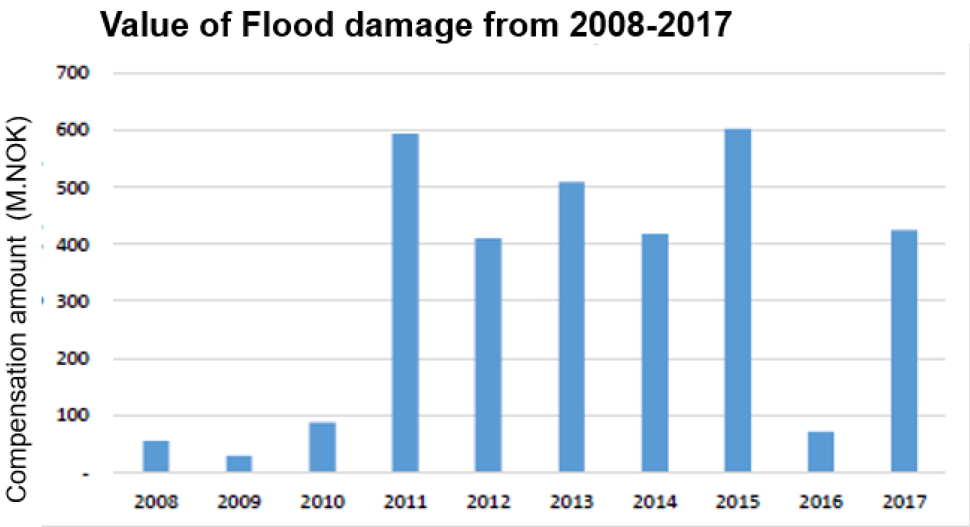


Figure 2. 1: Flood damages in Norway

Source: (Multiconsult, 2018)

2.1.2 Causes of Floods in Norway

Floods result from heavy precipitation and high discharges in the river channel causing the river to burst out of its banks. In most parts of Norway, precipitation falls as snow, rain or mixture of snow and rain. Mean annual precipitation (1971- 2000) for Norway is estimated to be 1600 mm, and has increased by ca. 18 % since 1900 (Hanssen-Bauer et al., 2017a). Annual precipitation is highest (>3500 mm) in central parts in western Norway (Hanssen-Bauer et al., 2017a). The cause of floods has been classified into snowmelt floods, rainfall floods, combination of rain and snow melt floods, ice jam floods, flood caused by slides , floods from glacier dammed lakes and dam break floods among others (Roald, 2012) and (Å. Killingtveit, 1997).

Snowmelt floods; During winter, most of the precipitation falls as snow and is spatially distributed depending on the topography of the catchment. Due to a negative temperature lapse rate, there is high snow accumulation in the mountains than in lower parts of the catchment. Start of snowmelt is dependent on the increase in air temperature and overall energy balance in the snowpack due to radiation, and energy transfer by wind, air masses and sensible heat from the surrounding environment (Roald, 2012).

Snowmelt floods occur during early spring and autumn and can last typically several days, developing gradually and often starting in a part of the catchment, gradually extending to larger part as more tributaries contribute to the flood in the main river (Roald, 2012). However , floods with a major snowmelt contribution may predominantly occur during the summer season, depending on the location, altitude and the percentage glacial cover in the catchment (Wilson et al., 2011).

Rainfall Floods: Heavy intense rainfall in a short period of time can cause flooding within a catchment. Most floods in Norway are caused by rainfall, possibly in combination with snowmelt (Roald, 2012). These normally during spring, autumn and in summer. Rainfall floods are caused by local intense precipitation and can be locally distributed depending on the local topography.

Combination of Snow melt floods and Rain: In many regions within Norway, the critical extreme flood events are generated by a combination of extreme precipitation and simultaneous snowmelt (Wilson et al., 2011). These cause devasting floods in the river basin. Abrupt increase in air temperature with rainfall increases the energy pack of snow. The melting of snow occurring simultaneously with local precipitation leads to high volumes of water in the river channel. High discharge in the river streams result into riverbank bursts and flooding. Snow melt and rain floods normally occur in early spring with snowmelt from the mountains and precipitation in the lower parts of the catchment.

Other causes of floods can be ice jams during melt and ice breakup leading to constriction or blockage of a river channel causing floods in the riverbanks, clay slides and dam breaks (Roald, 2012).

2.1.3 Flood frequency Analysis

Flood frequency analysis is a statistical approach used to determine the magnitude of a flood event with a certain occurrence probability or return period (Wilson et al., 2011). The estimation of the frequency of floods and magnitude of floods is crucial in planning and possible reduction the damages caused by floods. A study by Wilson et al., (2011) classified flood estimation into two groups, Flood frequency analysis using statistical methods and Rainfall-runoff modelling.

Flood frequency analysis is based on the analysis of observed historical flood events and estimates the magnitudes of floods with a given return period (Wilson et al., 2011). This requires a long and accurate timeseries of observed runoff for accurate flood estimation.

Statistical analysis involves uses of Annual Maxima Series(AMS) or Partial Duration series to statically determine the magnitude of the flood and return period for a given flood.

For catchments with no on less required data, regional flood frequency analysis is used to estimate the floods (Wilson et al., 2011). Norway is divided into different flood regions (Figure 2.2). Regional flood frequency analysis based on the index flood method hence comprises three steps: (1) identification of regions or similar sites, (2) calculation of the index flood and (3) calculation of the growth curve (Wilson et al., 2011). The flood frequency curve for the site of interest (QT) is then constructed as the product of the index flood (QM) and the growth curve (XT) (Wilson et al., 2011). where $Q_T = Q_M . X_T$. The index flood for a given catchment can be computed from the equations in the Table 1.

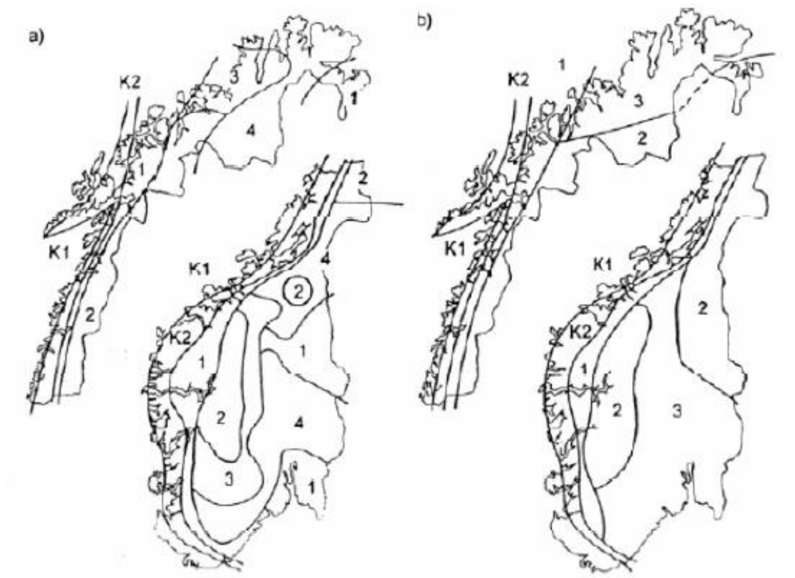
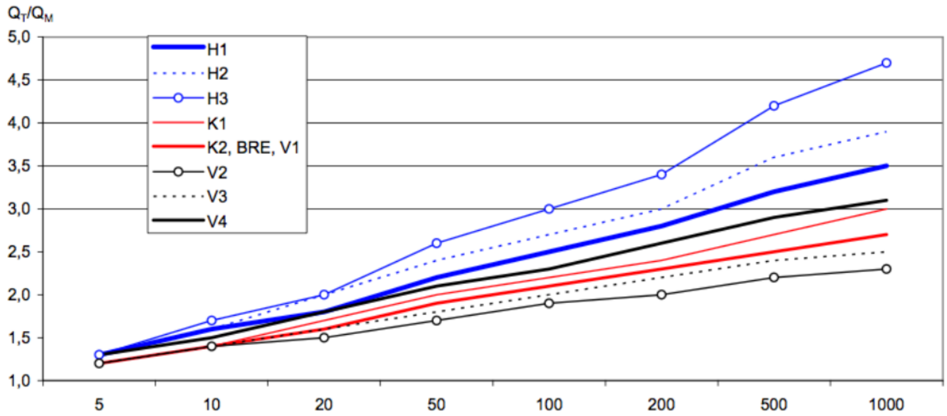


Figure 2. 2: Regional Curves for Flood Analysis a) Spring Flood, b) Autumn Flood

Source: (Wilson et al., 2011)

Table 1: Flood frequency factors

	Q_5/Q_M	Q_{10}/Q_M	Q_{20}/Q_M	Q_{50}/Q_M	Q_{100}/Q_M	Q_{200}/Q_M	Q_{500}/Q_M	Q_{1000}/Q_M
H1	1,3	1,6	1,8	2,2	2,5	2,8	3,2	3,5
H2	1,3	1,6	2,0	2,4	2,7	3,0	3,6	3,9
H3	1,3	1,7	2,0	2,6	3,0	3,4	4,2	4,7
K2/ bre	1,2	1,4	1,6	1,9	2,1	2,3	2,5	2,7
K1	1,2	1,4	1,7	2,0	2,2	2,4	2,7	3,0
V1	1,2	1,4	1,6	1,9	2,1	2,3	2,5	2,7
V2	1,2	1,4	1,5	1,7	1,9	2,0	2,2	2,3
V3	1,2	1,4	1,6	1,8	2,0	2,2	2,4	2,5
V4	1,3	1,5	1,8	2,1	2,3	2,6	2,9	3,1



Source:(Wilson et al., 2011)

Floods in Norway are divided into two; spring floods and autumn floods hence different equations are applied to compute the expected flood magnitude (Table 2).

Table 2: Regional formulas for derivation of Index flood QM (l/s/km²)

Spring flood regions	
1	$\ln Q_M = 0.2722 \bullet \ln S_T - 0.1406 \bullet \ln A_{SE} + 0.1006 \bullet \ln A_{SF} + 0.6172 \bullet \ln Q_N + 2.11$
2	$\ln Q_M = 0.0930 \bullet \ln S_T - 0.0816 \bullet \ln A_{SE} + 0.0281 \bullet \ln A_{SF} + 0.5076 \bullet \ln Q_N + 3.59$
3	$\ln Q_M = 0.3066 \bullet \ln S_T - 0.0220 \bullet \ln A_{SE} + 0.0939 \bullet \ln A_{SF} + 0.3252 \bullet \ln Q_N + 3.09$
4	$\ln Q_M = 0.1848 \bullet \ln S_T - 0.0137 \bullet \ln A_{SE} + 0.0873 \bullet \ln A_{SF} + 0.5143 \bullet \ln Q_N + 2.77$
Autumn flood regions	
1	$\ln Q_M = 1.2805 \bullet \ln Q_N - 0.2267 \bullet \ln(A/L_F) + 0.0664 \bullet A_{SE} + 0.0053 \bullet S_T + 1.00$
2	$\ln Q_M = 1.2910 \bullet \ln Q_N - 0.1602 \bullet \ln(A/L_F) + 0.0508 \bullet A_{SE} + 0.0065 \bullet S_T + 0.65$
3	$\ln Q_M = 1.2014 \bullet \ln Q_N - 0.0819 \bullet \ln(A/L_F) + 0.0268 \bullet A_{SE} + 0.0013 \bullet S_T + 1.07$
Glacier and annual flood regions	
BRE	$\ln Q_M = 0.0119 \bullet Q_N - 0.0848 \bullet A_{SE} + 0.0165 \bullet L_F + 5.81$
K1	$\ln Q_M = 1.5212 \bullet \ln Q_N - 1.1516 \bullet \ln P_N - 0.0569 \bullet A_{SE} - 0.0093 \bullet L_F + 8.80$
K2	$\ln Q_M = 1.1524 \bullet \ln Q_N - 0.0463 \bullet A_{SE} + 1.57$

Where: A = catchment area (km²), Q_N = mean specific annual runoff ($ls^{-1}km^2$), P_N = mean annual precipitation (mm), A_{SE} = effective lake (%), A_{SF} = exposed bedrock (%), L_F = catchment length (km), S_T = gradient of the main river (m/km).

Source : Wilson et al, (2012)

v) Instantaneous flood

Flood intensity varies with time; with high intense flood events occurring over a short duration. Using a daily flood dampens the flood peak by averaging flood values in a day (24 hours). Instantaneous flood equations are used to measure the peak flood. Wilson et al, (2012) proposed equations (Table 3) to determine the instantaneous flood in autumn and summer.

Table 3: Regression equations for the ratio of the instantaneous flood peak Q_i and the maximum daily flow Q_d

Spring flood:	$Q_i / Q_d = 1.72 - 0.17 \bullet \log A - 0.125 \bullet A_{SE}^{0.5}$
Autumn/summer flood:	$Q_i / Q_d = 2.29 - 0.29 \bullet \log A - 0.270 \bullet A_{SE}^{0.5}$

A = catchment area

A_{SE} = effective lake percentage

Source : Wilson et al, (2012)

Rainfall-runoff modelling, converts a rainfall into a surface runoff using a model of the catchment based on model parameters which are either calibrated based on observed data or are estimated from the catchment characteristics (Wilson et al., 2011).

2.1.4 Floods and Climate change

Climate change projections for Norway indicate changes in both temperature and precipitation regimes in the future (Hanssen-Bauer, *et al*., 2009). The average temperature is expected to increase in all seasons throughout the country, and the average annual temperature will increase by between 2.3 and 4.6 °C by the end of the century (Lawrence & Hisdal, 2011).

The mean annual precipitation is expected to increase by 7 to 23 percent under continued high emissions and by 3-14% under the more moderate scenario with the largest increases in precipitation occurring in the autumn and winter (Roald, 2012).

Increase in temperature and precipitation will affect the runoff and magnitude of floods. Higher temperatures indicate more precipitation will fall as rain as opposed to snow. The snow will start to accumulate later in the autumn and will melt earlier in the spring. The total volume of snow will decrease in lowland areas as result of more frequent rainfall events in the winter (Roald, 2012). For the spring season, a large increase in runoff is expected at high altitudes because snowmelt will shift from early summer in the present-day climate to spring in the future and at low altitudes, spring runoff is expected to decrease, as there will be no snowmelt contributing to spring runoff in a future climate (Hanssen-Bauer et al., 2017b).

Increase in temperature and precipitation is likely to affect the timing and magnitude of floods. Winter floods will be more common and winter runoff will therefore increase over all of Norway (Roald, 2012).

Regional climate projections for Norway indicate likely increases in temperature and precipitation (Hanssen-Bauer et al., 2017). The mean temperature is projected to increase in all seasons between 3.4° and 6.0°C by the end of the 21st Century under climate scenario RCP 8.5 and by 1.7 – 3.7°C if for RCP 4.5 (Hanssen-Bauer et al., 2017).

Lawrence & Hisdal, (2011) provide guidelines for projected changes in the regional floods in Norway. A projected increases for the 200-year flood exceed 40% for some of the catchments in western Norway and in Nordland and large decreases are projected for inland regions such as Hedmark and in Finnmark (Lawrence & Hisdal, 2011). The Figure 2.3 shows projected change in the flood magnitude for RCP 8.5.

Catchments located in western and south-western regions (Vestlandet) and coastal regions of southern and south-eastern Norway (Sørlandet and Østlandet) will experience an increase in the mean annual flood (Lawrence & Hisdal, 2011). The largest percentage increases in flood magnitudes are expected to occur in Western Norway and in Nordland county (Roald, 2012).

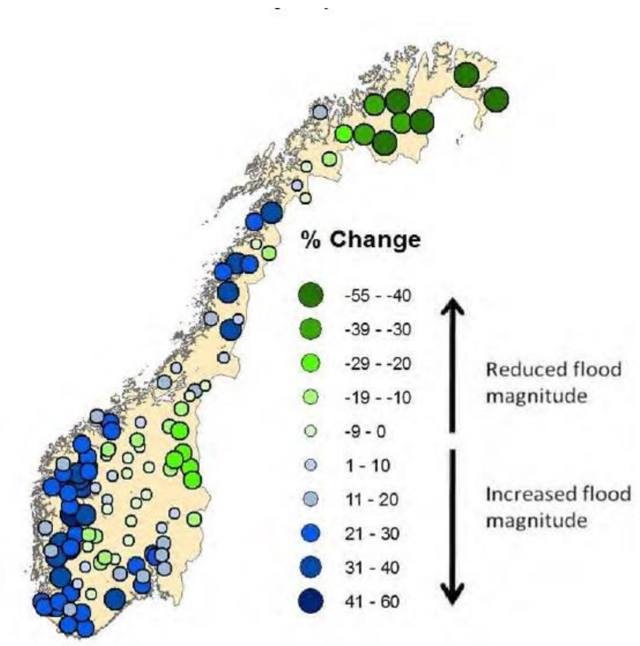


Figure 5.2 Projected percentage changes in the mean annual flood between the 1961-1990 reference period and the 2071-2100 future period, based on the median of the ensemble of hydrological projections for each catchment. Green indicates a reduced flood magnitude and blue indicates an increase in flood magnitude.

Figure 2. 3 Projected Percentage changes in the mean annual flood

Source: Lawrence & Hisdal, (2011).

Therefore, climate change will play a leading role is shaping the runoff and floods in the future, leading to more rainfall dominated floods, high intensity events and increase in the number of extreme events. Careful analysis, forecasting and planning of infrastructure is crucial to mitigate the likely damages caused by floods.

2.1.5 Existing Flood mitigation

Floods cause major destruction to both life and property. To reduce the impact and damages due to floods, measures have been put in place to reduce the damages caused by floods. These include flood frequency analysis to determine the magnitude and frequency of future floods, timely forecast, early warmings, structural modification to riverbanks and flow regulation to reduce the impact of floods downstream. The existing mitigation have been classified into the following;

Flood Forecasting and Flood zone mapping

Flood mitigation and reduction of the impact of flood requires accurate and time forecasting. NVE provides data on the water levels and discharges, as well as projections of the expected development during the flood in co-operation with the hydropower companies (Roald, 2012). Through accurate forecasts, hydropower reservoirs can be prepared to receive and reduce flood peaks downstream, emergency warnings are issued and if necessary, evacuation in flood prone areas are done (Roald, 2012).

Flood analysis is made depending on historical data and future forecasted floods. Crucial infrastructure is designed to withstand a flood of a given magnitude and return period. In Norway, flood frequency analysis is undertaken in connection with flood hazard mapping, for which the 200-year flood is used (Lawrence & Hisdal, 2011).

Flood hazard maps are an important tool for planning developments in flood prone areas. The consequences of climate change on the estimate of the 200-year return period flood is now usually taken into account when preparing flood hazard maps in Norway by applying a climate change allowance evacuation (Roald, 2012). This allowance distinguishes between three categories: 1) areas in which no increase in flood hazard is expected (0% allowance); 2) areas in which a moderate increase is expected (20% allowance); and 3) areas in which a large increase in flood hazard is expected (40% allowance). These are used as guides by authorities to issue emergency warning and carry out early evacuation (Roald, 2012).

Structural measures for flood control

Flood control infrastructure is used to prevent floods. These include dams for flood control, construction on dikes along riverbanks, diversion culverts for flood, among others. These infrastructures are designed to withstand a flood of a particular magnitude and maintenance of these constructions is crucial to avoid flood damages (Roald, 2012). Embankments are constructed along riverbanks to prevent the water from entering key residential, agricultural, or urban floodplain areas (Juárez et al., 2021).

In urban areas, flood water in diverted through culverts and underground storm water drainage structures. Green roofs have also been used to reduce the flood peaks in urban areas. Climate change coupled with increasing urbanization has made extensive green roofs, both for retrofitting and new developments, an attractive way to bring nature back to cities, while managing stormwater (Johannessen et al., 2018).

Changes to river morphology have also been used as means to control flooding. These include dredging and channel straightening. These methods however can have unintended side-effects on the river system. Several studies have shown that dredging can increase flood risk for communities downstream, destabilize riverbanks, cause erosion, and damage infrastructure (Juárez et al., 2021).

Flood Control Dams

Dams and reservoirs have the capacity to storage large volumes of water. They can temporarily store water during flood peaks and release in a controlled manner downstream to reduce the impacts of flood. Each dam is operated by a specific water control plan for routing floods through the basin without damage. This means lowering of the reservoir level to create more storage before the rainy season. This strategy eliminates flooding (ICOLD, 2022). Flood control is a significant purpose for many of the existing dams and continues as a main purpose for some of the major dams of the world with 2539 dams with a sole purpose of flood control (ICOLD, 2022).

2.2 Hydropower and Flood Regulation

Hydropower plants are primarily dependent on the inflow volumes for hydropower production. Due to seasonal variation of inflow with large volumes in spring due to snow melt and autumn from rainfall events, and reduced volume in winter, water storage has been part of hydropower systems. Hydropower reservoirs with dams store large volume of water and release water in a regulated manner to meet the energy demands. Flow regulation alters discharges downstream of the river course and in the bypass sections. The initial regulation increased winter flows and reduced summer flows and major floods (Saltveit et al., 2019). Therefore, flow regulation in hydropower plants plays a great role in regulating flows and reducing peak flows and floods downstream. Long-term series in heavily regulated rivers show a marked decline in the flood peaks after regulation has taken place(Roald, 2012).

The ability of hydropower to regulate flow is warranted in flood control. In emergency situations, authorities (in Norway, maybe also other countries) can instruct the hydropower producers to operate their reservoirs in such a way that they reduce the downstream losses and damages to a minimum (Bakken et al., 2019). In other cases, reservoirs can be regulated with early drawdowns or spill if hydrological forecast predicts a flood. Advance release of water downstream to provide sufficient storage for retaining the peak flood can significantly reduce the flood magnitude downstream and expected resultant damages.

Minimum Flows in regulated rivers.

Hydropower is exclusively dependant on the water**.** Due to increased environmental concerns, there is need to manage water needs between the hydropower sector and the flow in the river course to limit impacts of regulation to the natural environment (Bakken et al., 2019). In new river regulation schemes, minimizing impacts on in-stream ecology is usually the goal of setting ecologically acceptable flows to provide (Neachell, 2014).

New hydropower licenses require a mandatory minimum flow in the downstream bypass section on the river. Q95% corresponding to the discharge exceeded 95% of the time is used a based line for minimum flows in rives (Bakken et al., 2019).

In addition, Forseth & Harby, (2014) specifies environmental design in salmon regulated rivers to limit habitant deterioration and reduce the impact on the population on Salmon (discussed further in section 2.3).

2.3 Flow Regulation in Salmon Rivers

Atlantic salmon (Salmo salar) is the most economically important freshwater fish in Norway (Saltveit et al., 2019). Norway has more than 400 watercourses with Atlantic salmon and supports a large proportion of the world's wild Atlantic salmon (Forseth et al., 2017). Among the 45 Norwegian salmon populations that have been lost, 19 (42%) were lost due to hydropower development (Hansen et al., 2008). According to Hansen et al. (2008), the most common negative effects of hydropower development are the permanent or partial drying of the riverbed, frequent changes in water flow leading to the stranding of fish, and smolt mortality during downstream migration through turbines.

The government designated 29 fjords distributed along the entire coastline as “national Atlantic salmon fjords” and 52 rivers draining into these fjords as “national Atlantic salmon rivers”, to protect the wild Atlantic salmon (Forseth et al., 2017). These rivers, representing 72% of the conservation limits (CLs) for Atlantic salmon in Norway, were given protection against further hydropower development, water abstractions and flood control measures (Forseth et al., 2017).

Flow regulation in rivers causes changes to physical conditions in the river. Hydrological conditions in the river determine the size of the living area (water-covered area) available to a population, and its quality in terms of temperature and water velocity (Forseth & Harby, 2014). Alternation of the hydrology of the river can create major bottlenecks to the survival of salmon.

To limit the effect of regulation on the salmon population in regulated rivers Forseth & Harby (2014) recommends diagnosis to identify habitat-related and hydrologic bottlenecks affecting salmon production, together with bottlenecks which result from the interaction between habitat-related and hydrologic factors. These include identification of hydrologic bottlenecks is based on analyses of water-covered area as a function of flow, analysis of hydrologic alteration, the modelling of temperature changes ,and the modelling of biological responses to temperature changes (Forseth & Harby, 2014).

The scope of the work is focus on the analysis of hydrological alteration as result of regulation due to hydropower production and flow diversion especially during flood events.

2.3.1 Effect of alteration of hydrological flow

Changes in the hydrology of the river can have a major effect on the population of salmon. Depending on the correlation with flow, low-water periods in summer and winter will result in reduced water-covered area and increases in fish density, which in turn may lead to reduced summer growth rates and/ or lower summer and winter survival rates (Forseth & Harby, 2014). Changes for high flows to low flows can lead to stranding of fish as well drying out of eggs during the spawning period. It is assumed that one week's duration is sufficient to produce a negative impact, and for this reason analyses are usually based on average weekly flow data. (Forseth & Harby, 2014). Table 4 shows the extent at which alteration on flow is likely to affect the salmon population.

Table 4: Impact of Flow alteration on Population

Season	Change in lowest weekly average	Impact on population
Summer	Increase	Positive
	Reduction < 20%	No bottleneck
	Reduction 20-40%	Weak bottleneck
	Reduction 41-60%	Moderate bottleneck
	Reduction < 60%	Severe bottleneck
Winter	Increase	Positive
	Reduction < 10%	No bottleneck
	Reduction 10-30%	Weak bottleneck
	Reduction 31-50%	Moderate bottleneck
	Reduction < 50%	Severe bottleneck

Source: Forseth & Harby, (2014)

2.3.2 Effect of reduction in the frequency of Flood:

Whereas the main purpose of the study is to reduce flood within the catchment, the effect of flood reduction in the river course should be assessed. River courses have a natural flood cycle with benefits clearing the fish habitant through desiltation and declogging of habitants and spawning areas improving the habitant for fish. A study by Saltveit et al., (2019) showed the absence of major floods after regulation led to increased sedimentation and encouraged carpet mosses. This reduced interstitial spaces, creating a poor habitat for salmon fry (Saltveit et al., 2019). The reduced flow and reduction in the size of the floods reduced the sediment transport capacity and increased the likelihood of sedimentation of fine material (Saltveit et al., 2019).

Regulation of flow aimed at long term reduction of flooding events may result into habitant quality by silting of spawning habitants and the clogging of sheltered habitants (Forseth & Harby, 2014). Table 5 provides guidelines to access the effect of reduction in flood to the habitant deterioration.

Table 5: The probability of changes in flood frequency to habitant deterioration

Reduction in flood magnitude		Reduction in flood frequency		
		Minor	**Moderate**	**Major**
	Minor	Low	Moderate	Moderate
	Moderate	Low	Moderate	High
	Major	Moderate	High	High

Source: Forseth & Harby, (2014)

The hydrological analysis of flood events before and after regulation will be carried to determine reduction in the frequency of the flooding and the effect on habitant deterioration (Table 11,(Forseth & Harby, 2014).

3. STUDY AREA

3.1 Location

Stryn Kommune is located in Vestland Norway in the inner part of the Nordfjord (Figure 3.1). Most of the settlement is along Stryn river which flows from downstream of Oppstrynsvatnet lake to the Nordfjord. Along the river meanders are farmlands, and established settlement. Stryn river is national salmon river hence protected against hydropower production.

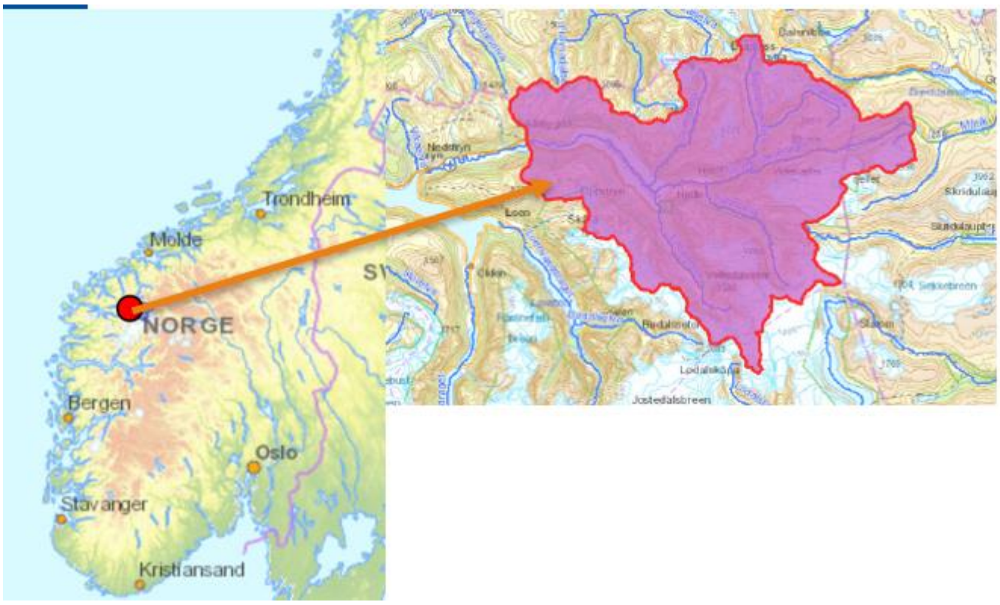
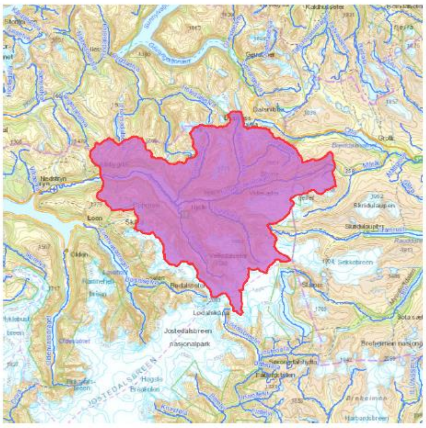


Figure 3. 1: Stryn Catchment

3.2 Hydrology

Stryn river lies downstream of Oppstrynsvatnet Lake. It has a catchment area of 478km^2 with average annual runoff of 60.5 l/s.km^2. The elevation distribution of the catchment ranges from 29 m.a.s.l to the highest point of 1933 m.a.s.l in the glacier covered mountains. The Figure 3.2 shows the catchment characteristics of Stryn. The annual precipitation of Stryn is approximately 1353mm with more than half falling during winter.



Nedbørfeltparametere

Vassdragsnr.:	088.B11
Kommune.:	Stryn
Fylke.:	Vestland
Vassdrag.:	Strynevassdraget

Feltparametere		
Areal (A)	478	km²
Effektiv sjø (A_{SE})	4.91	%
Elvleengde (E_L)	43.3	km
Elvegradient (E_G)	34.0	m/km
Elvegradent $_{1085}$ ($E_{G,1085}$)	32.8	m/km
Helning	24.3	°
Dreneringstetthet (D_T)	1.2	km^{-1}
Feltlengde (F_L)	33.2	km

Arealklasse		
Bre (A_{BRE})	14.7	%
Dyrket mark (A_{JORD})	1.3	%
Myr (A_{MYR})	0.2	%
Leire (A_{LEIRE})	0.1	%
Skog (A_{SKOG})	16.5	%
Sjø (A_{SJO})	6.3	%
Snaufjell (A_{SF})	56.5	%
Urban (A_U)	0.0	%
Uklassifisert areal (A_{REST})	4.5	%

Hypsografisk kurve		
Høyde $_{MIN}$	29	m
Høyde $_{10}$	214	m
Høyde $_{20}$	575	m
Høyde $_{30}$	818	m
Høyde $_{40}$	1006	m
Høyde $_{50}$	1143	m
Høyde $_{60}$	1262	m
Høyde $_{70}$	1390	m
Høyde $_{80}$	1506	m
Høyde $_{90}$	1601	m
Høyde $_{MAX}$	1933	m

Klima- /hydrologiske parametere		
Avrenning 1961-90 (Q_N)	60.5	l/s*km²
Sommernedbør	465	mm
Vinternedbør	888	mm
Årstemperatur	1.1	°C
Sommertemperatur	5.2	°C
Vintertemperatur	-1.8	°C

Figure 3. 2: Stryn Catchment and Catchment Attributes

The main tributaries into Oppstrynsvatnet are Hjelledøla with a catchment area of 236km^2 contributing more than 50 percentage of the annual flow, Erdalselva with catchment area 80.5km^2 and Glomsdøla of 39.5km^2 contributing the least. Table 6 shows the percentage of average volume and catchment areas contributed by the different rivers flowing into Oppstrynsvatnet.

Table 6: Percentage area and volume of Upstream tributaries

Tributary	Percentage area	Percentage volume
Hjelledøla	48	52
Erdalselva	16	18
Glomsdøla	8	8
Others	28	22

Hjelledøla, the largest inflow has three major tributaries, Sunndøla of catchment area 76.6 km^2, Skerdingdsdøla of catchment area 72.1 km^2 and Videdøla with area of 60.5 km^2 as shown in Figure 3.3

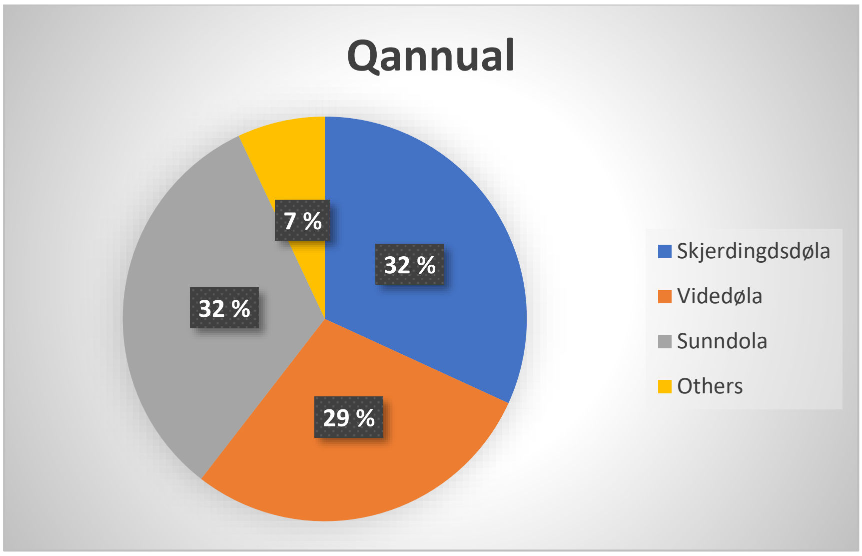


Figure 3. 3: Runoff distribution in Hjelledøla subcatchments

Within the catchment area of Stryn lies two gauging stations; Strynsvatn located at the outlet of Oppstrynsvatnet lake with a runoff series of from 1982 to present and Grasdøla measuring station located on Grasdøla, tributary to Hjelledøla.

3.3 Flood in Stryn

Stryn has experienced major historical floods. The extreme flood in West Norway in December 1743 is known as *Storeflaumen* in Hardanger. A rain flood in July 1941 at Stryn in West Norway is known as *Fløda* (Roald, 2012). Figure 3.4 below shows an existing flood caution map for Stryn catchment. As seen from the figure, a number of farmlands, and settlement are high prone to floods in river meander and downstream.

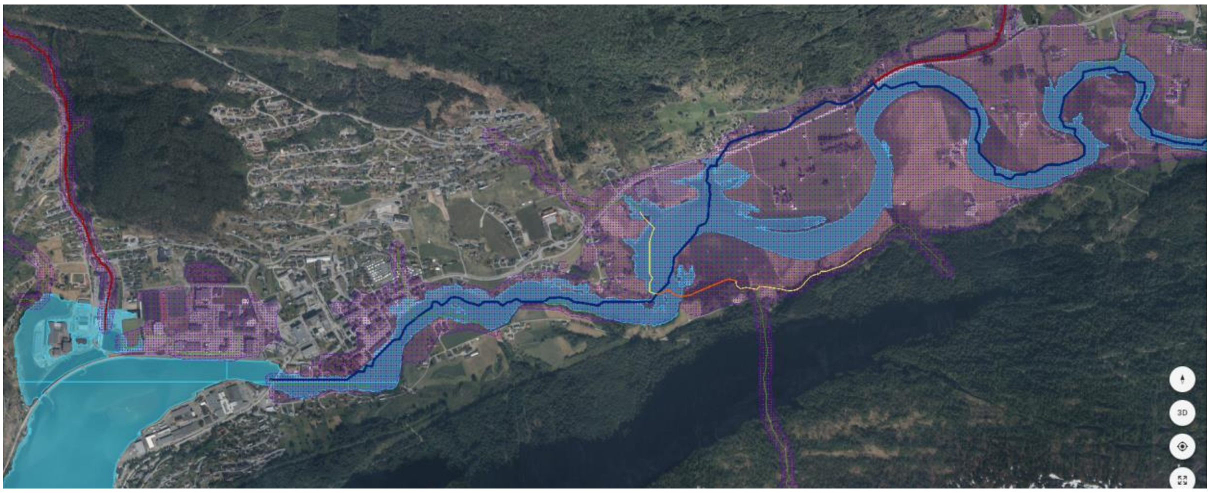


Figure 3. 4: Flood Hazard map of Stryn

Source: https://temakart.nve.no/link/?link=flomaktsomhet

A study has been conducted to update the flood zones maps of Stryn river and Hjelledøla taking into account storm water surges, sea level rise and climate change by NGI, (2018). Table 7 below shows the expected flood values in m^3/s with a climate surcharge for 20% for different return periods. The mean flood in Stryn is 124 m^3/s and a 200 year flood of 260m^3/s (NGI, 2018).

Table 7: Flood values (m3/s) for Stryn given different return periods with a climate surcharge of 20%

Sted	Areal/km^2	QM	Q5	Q10	Q20	Q50	Q100	Q200	Q500	Q1000
Hjelledøla est. (20%)	233	140	171	197	221	253	275	359	398	424
Strynevatn (20%)	484	124	142	156	171	190	203	260	281	297
Strynevatn NN2000	-	***29.41***	***29.49***	***29.65***	***29.75***	***29.88***	***29.97***	***30.32***	***30.43***	***30.52***
Stryn oppst. Ytree.	516	137	174	190	208	231	248	286	309	327
Ytreeidselva (40%)	6.8	5.6	9.7	11	13	16	17	28	31	35
Stryn nedst. Ytree.	523	150	183	202	221	246	265	314	340	362
Strynselva utløp	537	160	202	222	244	271	291	345	374	398
Vikaelva (40%)	21.8	26	31	37	42	50	56	87	100	111
Sunddøla (20%)	60.9	37	53	63	72	86	96	129	148	163

Source:(NGI, 2018).

According to the report, climate change and more extreme weather will lead to increased storm activity, and sea level rise may increase the storm surge further. The combination of high water levels, waves, and high current velocities can lead to flooding, erosion and destruction of coastal structures (NGI, 2018). More bridges will be more exposed to future floods. Lunde and Sætre bridge are most exposed and can have problems with flood (NGI, 2018). In Hjelledøla is only Kleivbrua has good capacity for all floods. Nygård bridge, Bolstad bridge and the bridge at Grov could have problems with flooding (NGI, 2018).

Findings from the report and the existing flood caution map calls for a need to put in place flood control plan and strategy to reduce the likely damages due to an extreme flood event.

3.4 Climate change in Stryn

Stryn catchment lies with Sogn and Fjordane. Climate of Stryn is both affected by coastal climate and mountainous climate. Climate projection for the region have been adopted for Climate profile 1971-2000. The average temperature is expected to increase by about 4.0 ° C with an increase of 4.0 ° C in autumn, winter and spring (low: 3.5 ° C, high: 5.0 ° C) and increase of 3.5 ° C in summer (low: 2.5 ° C, high 5.0 ° C) (Norsk Klimaservicesenter, 2017). Increase in air temperature will likely cause a delay in snow accumulation in the catchment.

Snow melt events are also expected to occur much earlier hence shorter periods of snow within the catchment.

Annual precipitation of the region is expected to increase by about 15%. The expected precipitation changes for four seasons have been calculated to Winter: +10% (low: -5%, high: +25%), Spring: + 10% (low: 0%, high: + 15%), Summer: +15% (low: +5%, high: +25%) and Autumn +15% (low: +5%, high: +35%) (Norsk Klimaservicesenter, 2017). Annual increase in precipitation will increase the amount of water in the catchment hence increase in the runoff in the catchment.

Increase in annual temperature and precipitation intensity lead to more rain induced floods. The amount of snow will reduce, and more intense rainfall events expected within the region. There is a likelihood increase in the frequency of landslides associated with rain/sleet, snowfall and snowmelt (Norsk Klimaservicesenter, 2017).

Climate change will therefore influence the hydrology of Stryn. Floods are expected increase due to more intense precipitation. Shift in the snowmelt and accumulation will lead to more flooding in autumn and early spring. Other flood induced disasters such landslides, avalanches are likely to increase.

3.5 Regulation in Salmon Rivers

Stryn is a natural salmon river is part of protection plan for watercourses therefore protected against hydropower development. Figure 3.5 show protected area for the catchment. Stryn river is currently unregulated. However upstream tributaries into Oppstrynsvatnet comprise of three developed hydropower plants on Hjelledøla and Glomsdøla tributaries namely Glomnes, Hjelledøla and Aaning as seen in Figure 3.5

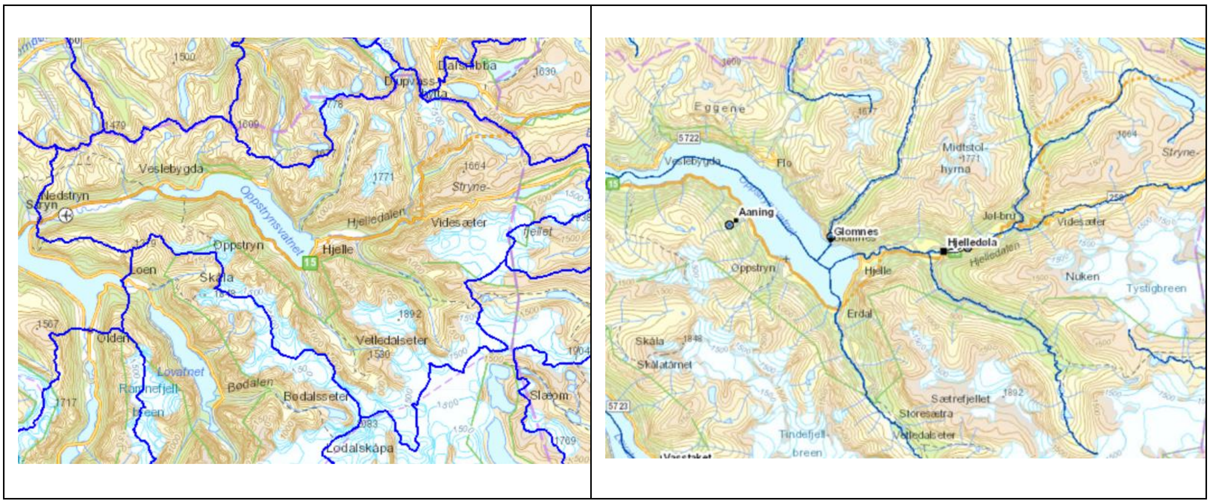


Figure 3. 5: Protected area and Hydropower developments in Stryn catchment

Source: https://nevina.nve.no/

4. METHODOLOGY

This chapters covers the methods and procedures used to meet the research objective. It describes data used for the study, data collection and data quality. Use of a distributed hydrological Modelling-ENKI Model for the catchment. Flood frequency analysis is conducted. The hydropower production potential of the catchment is evaluated through different proposed diversion intakes and economic analysis is conducted for the respective alternatives. Effect of regulation on flood regulation and the hydrological indicators for salmon population is evaluated from the most feasible option. The effects of the climate change on inflow, flood regulation and hydropower potential are evaluated.

4.1 Data Collection

To create a hydrological model of the catchment, hydrological data is needed as simulate runoff. ENKI model (distributed hydrological model) was used in the study. Data required for the model includes precipitation, temperature, wind, relative humidity, global radiation, and observed runoff timeseries for model calibration. GIS data (DEM, land use, and vegetation cover) is required to setup the model in ENKI.

4.1.1 Hydrological Data

Runoff data is required for model calibration and historical flood analysis of the Stryn river. Runoff timeseries was obtained from https://sildre.nve.no/. There are two active discharge gauging stations within the catchment; Strynsvatn with a timeseries from 01.09.1981 and Grasdøla gauging station with a timeseries from 01.01.1979. The runoff series were used to calibrate the hydrological model. Figure 4.1 shows the location of discharge measurement stations within the catchment.

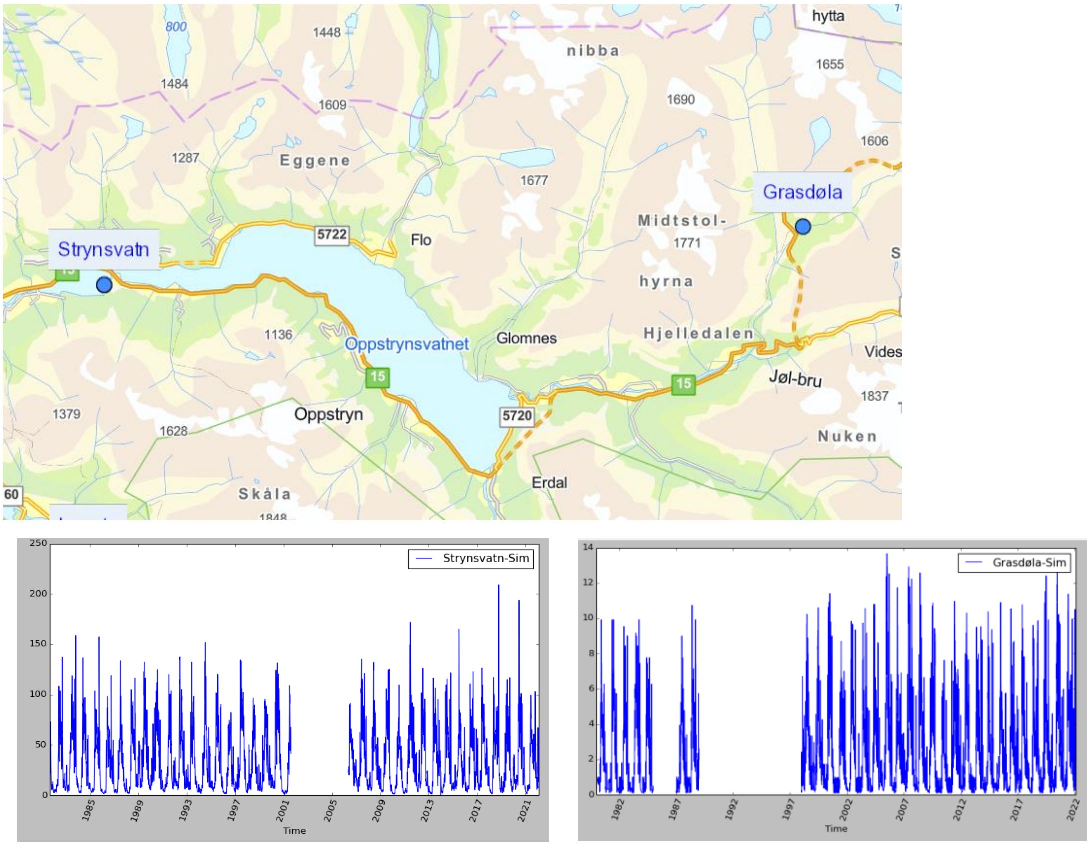


Figure 4. 1: Discharge measurement Station in Stryn catchment

Climate data

Climate data forms the basis of simulation and prediction of hydrological responses (discharge) in the catchment. The following climate data was obtained for the model.

i. **Precipitation data**; Precipitation timeseries was obtained from http://www.senorge.no/ for four gauging stations within the catchment and surrounding the catchment, these included, Strynkroken, Stryn, RV15 Fosnes and RV15Skjærindsdalen. Figure 4.2 shows the location and input precipitation data from the measuring stations.

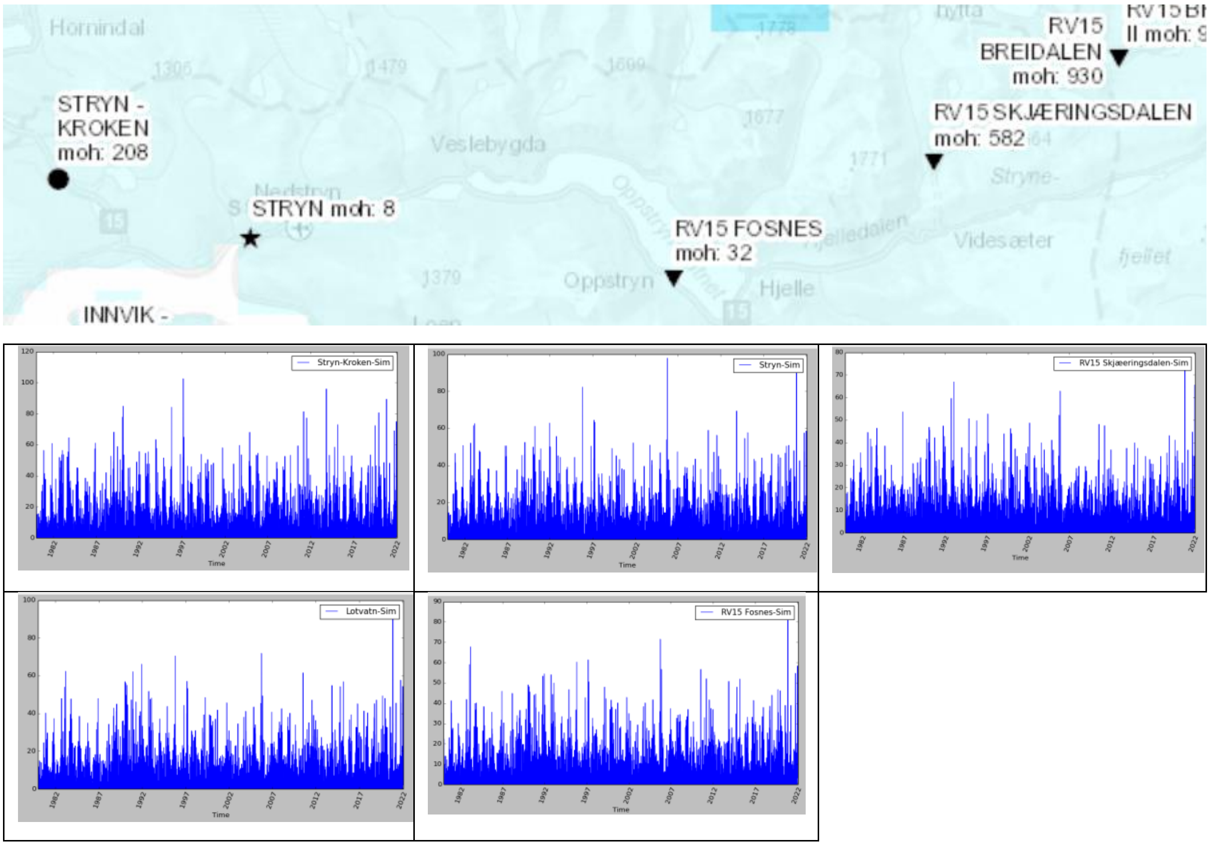


Figure 4. 2: Precipitation gauging stations

ii. **Temperature data**; Timeseries for temperature for Stryn-Kroken, RV15, Strynsvatn, Skjæeringsdalen, RV15 Fosnes, Grasdøla and Lotvan was obtained from http://www.senorge.no/ . Figure 4.3 shows the location of the measurement stations.

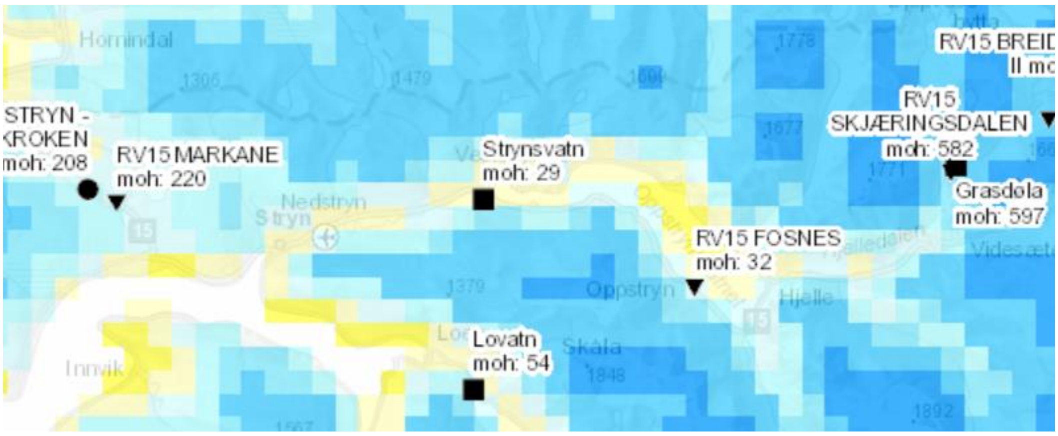


Figure 4. 3: Temperature measuring stations

iii. **Wind data**.

Sensible heat and latent heat are dependent on the energy transport by wind for snow energy pack and snow melt. Wind data used in the hydrological model was obtained from Oppstryn

Stryn – Kroken, Sandane, Sandane-Lufthamm, Østra-Eitrefjell and Åkernest point measuring stations from https://seklima.met.no/(Figure 4.4)

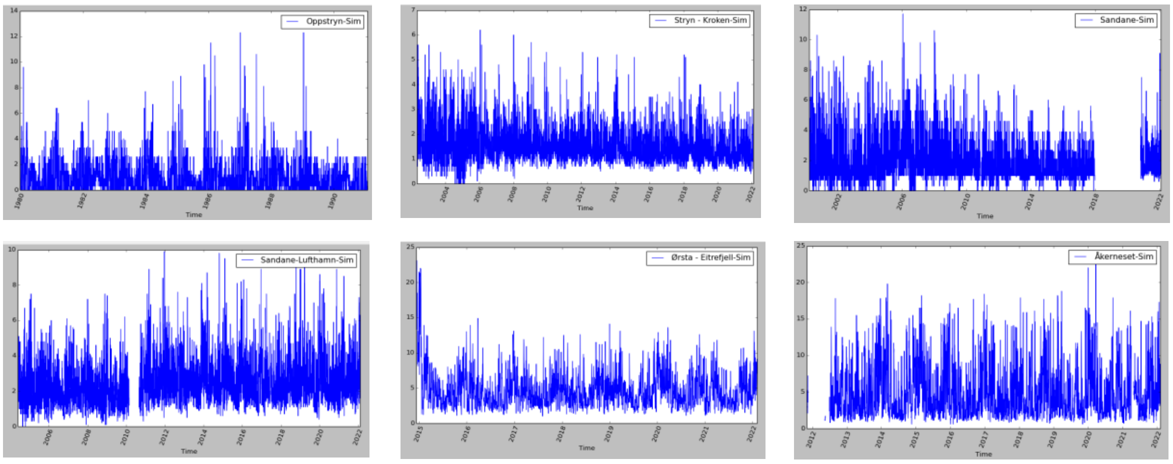
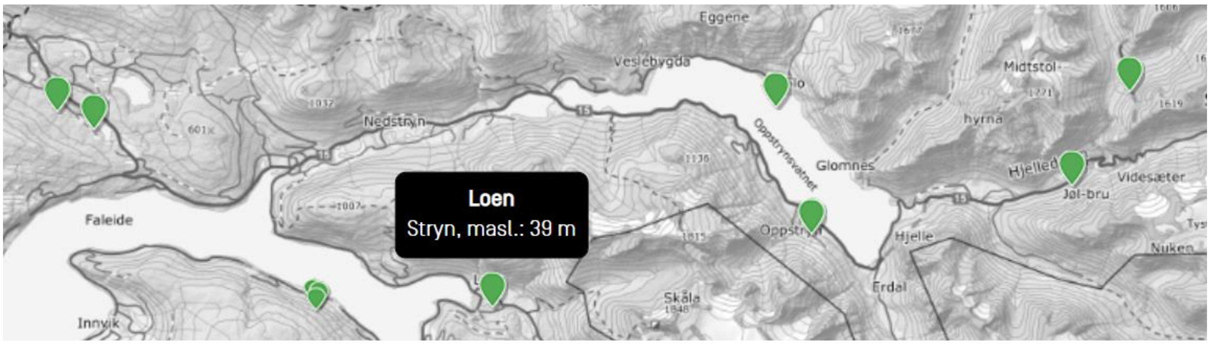


Figure 4. 4: Wind timeseries

iv.Relative Humidity

Latent heat is a function of relative humidity (saturated air pressure). Time series for relative humidity was obtained from six stations; Oppstryn, Flo, StrynKroken, Grotli iii, Åkerneset, and Ørsta-Eitrefjell (Figure 4.5)



Source: https://seklima.met.no/

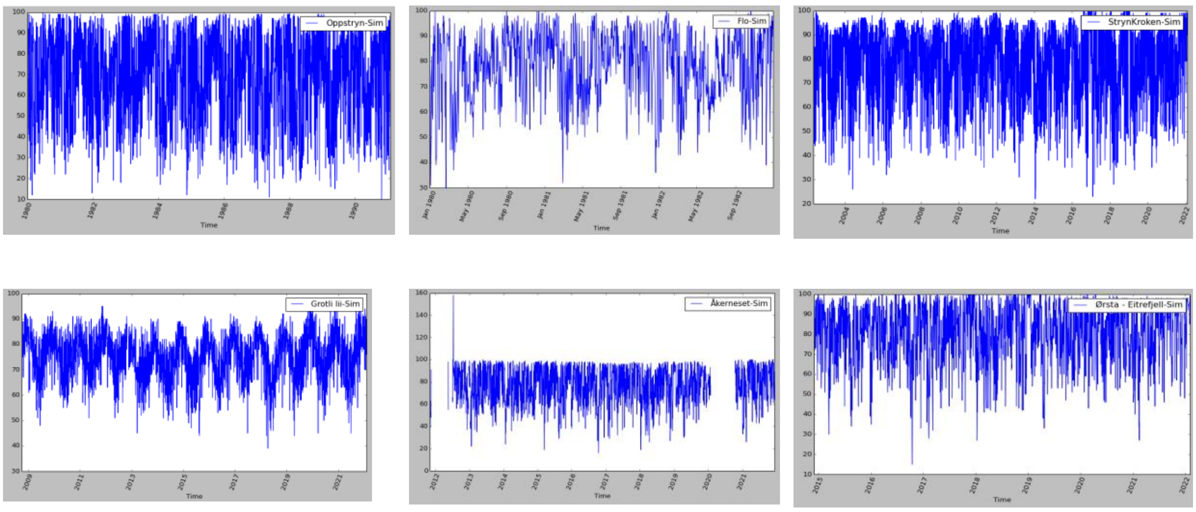


Figure 4. 5: Relative Humidity Stations and measurements

v. Global radiation

Within the catchment of Stryn, there is no global radiation measuring station. Radiation data was therefore extrapolated from the nearest stations to the catchment; Sandane, Linge, Balestrand (owned by NIBIO) and Juvvashøe. The Figure below shows the available timeseries with Juvvashøe and Linge having at least daily timeseries from 2015.

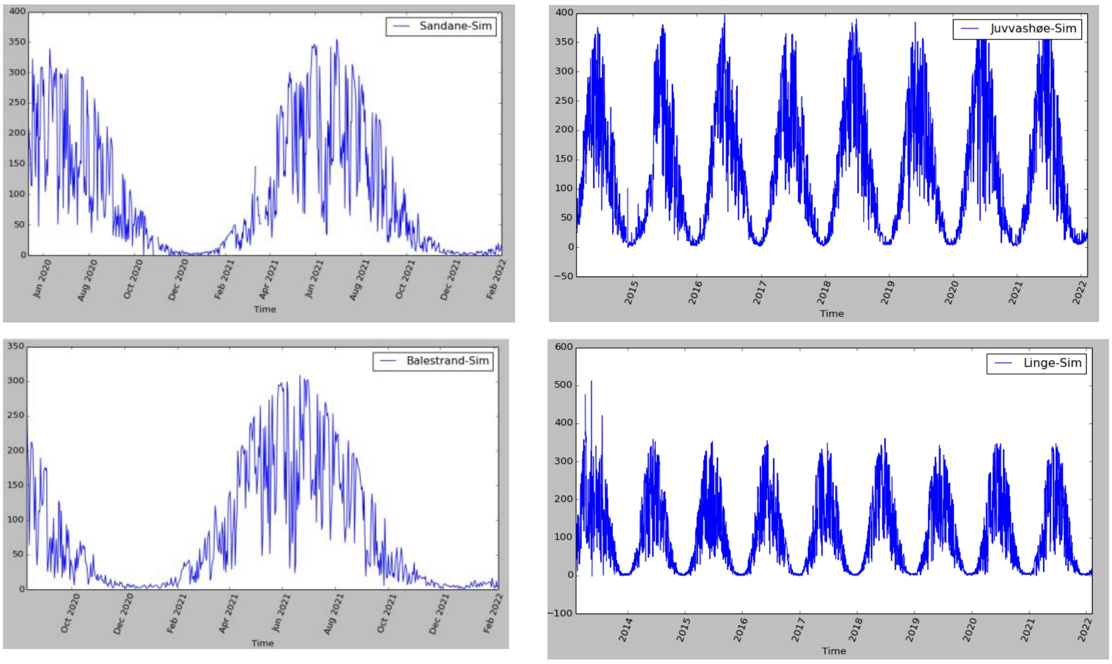


Figure 4. 6: Global radiation measurements

4.1.2 DEM and GIS Data for Stryn Catchment

A digital elevation map of the catchment was obtained from https://hoydedata.no/LaserInnsyn/. To set up a distributed model, gridded data is needed for the catchment. A digital elevation map (DEM) of the catchment was obtained from https://hoydedata.no/ and a shape file for the catchment from https://nevina.nve.no/. From https://nevina.nve.no/, the catchment area, specific runoff and hygroscopic curve of study catchment were obtained. The land use of the area was obtained from https://www.geonorge.no/. GIS data was for the catchment was processes in ArcMap.

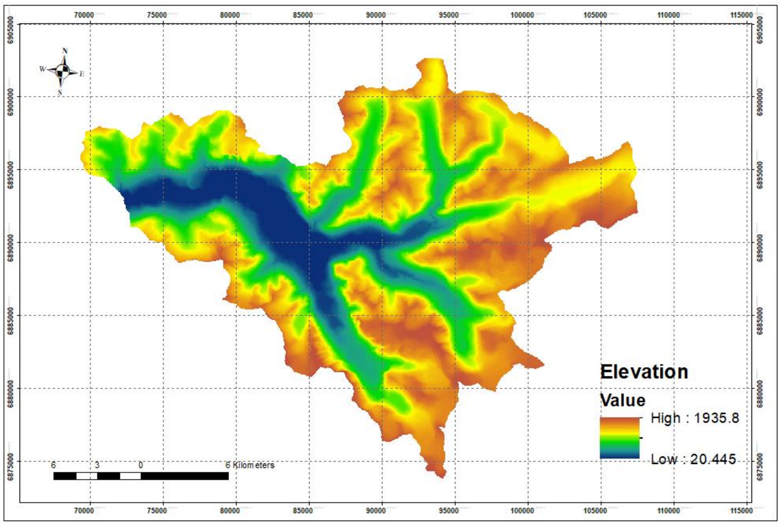
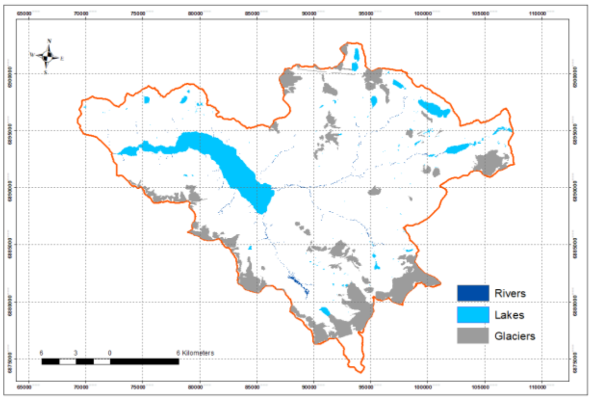
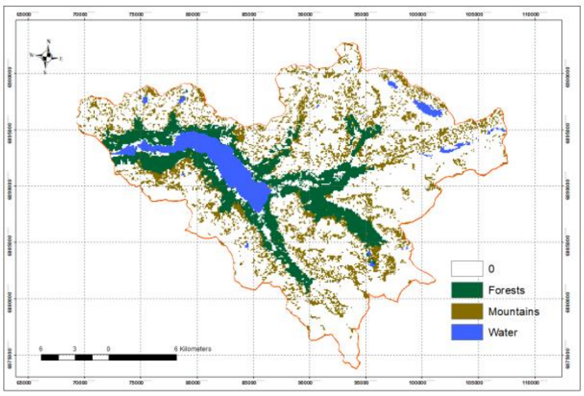


Figure 4. 7: Elevation of Stryn catchment

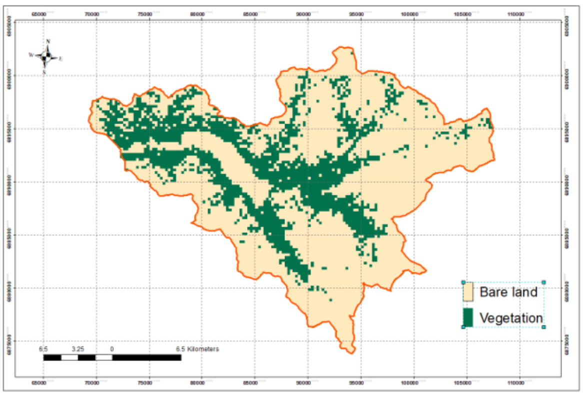
Other input rasters for the hydrological model included a land use raster, glaciers and mountains, and height of vegetation in the catchment (Figure 4.8)



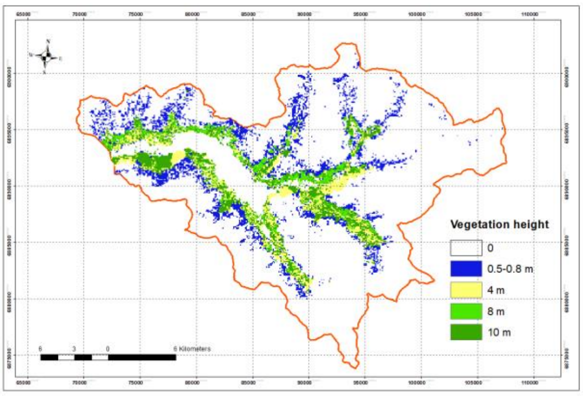
Lakes, Rivers and Glaciers



Vegetation Cover



Vegetation Cover



Height of Vegetation

Figure 4. 8: Input rasters of Stryn

4.1.3 Energy Prices

To conduct an economic analysis, expected revenue from energy sales is required. Energy prices vary between seasons, days of the week and hours of the day. To compute the revenue from energy sales, historical time series for energy prices was obtained from NordPool energy market data (NordPool, 2022). Stryn lies within trading area NO and near Molde . Available daily Energy prices in NOK/MWh from 2016-2021 used to calculate the revenue from daily energy sales. Figure 4.9 shows daily variation in energy prices between 2016 to 2021.

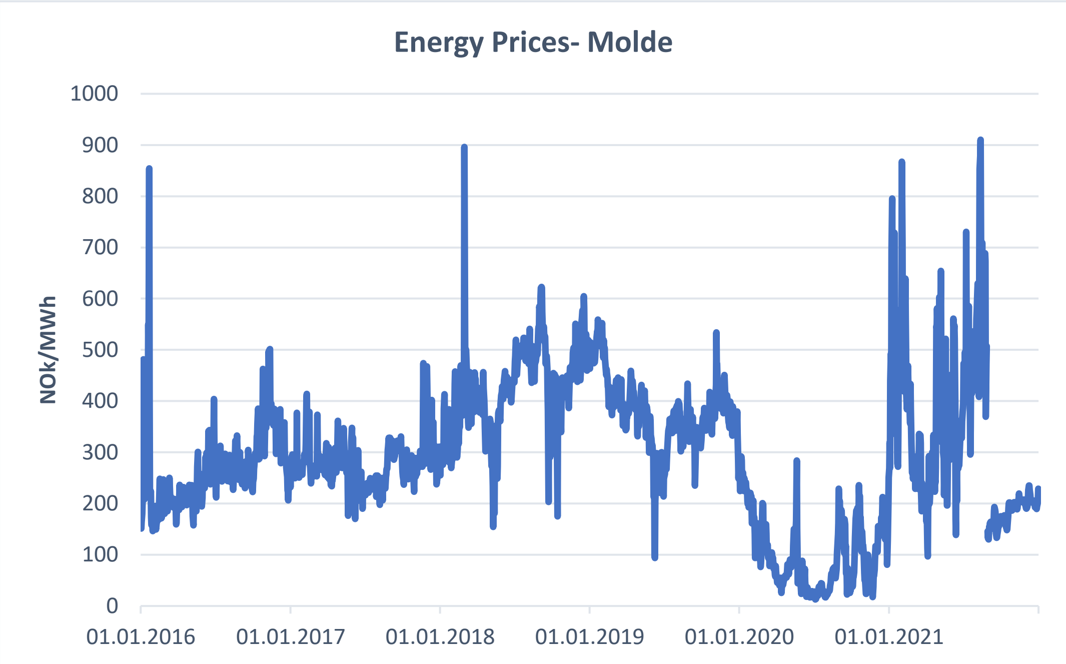


Figure 4. 9: Energy prices of Molde Region

4.1.4 Data Quality

Reliable and accurate data is important to accurately simulate the hydrological response of the catchment. Hydrological timeseries for climate data (precipitation, temperature, wind velocity, relative humidity, global radiation,) and observed runoff were inspected for missing data, unusual trend, spikes within the data and data corrected.

In addition, double mass curves were plotted for similar observations to analyse any unusual change in trend in data. Figure 4.10 below shows double mass for corrected input data into the model

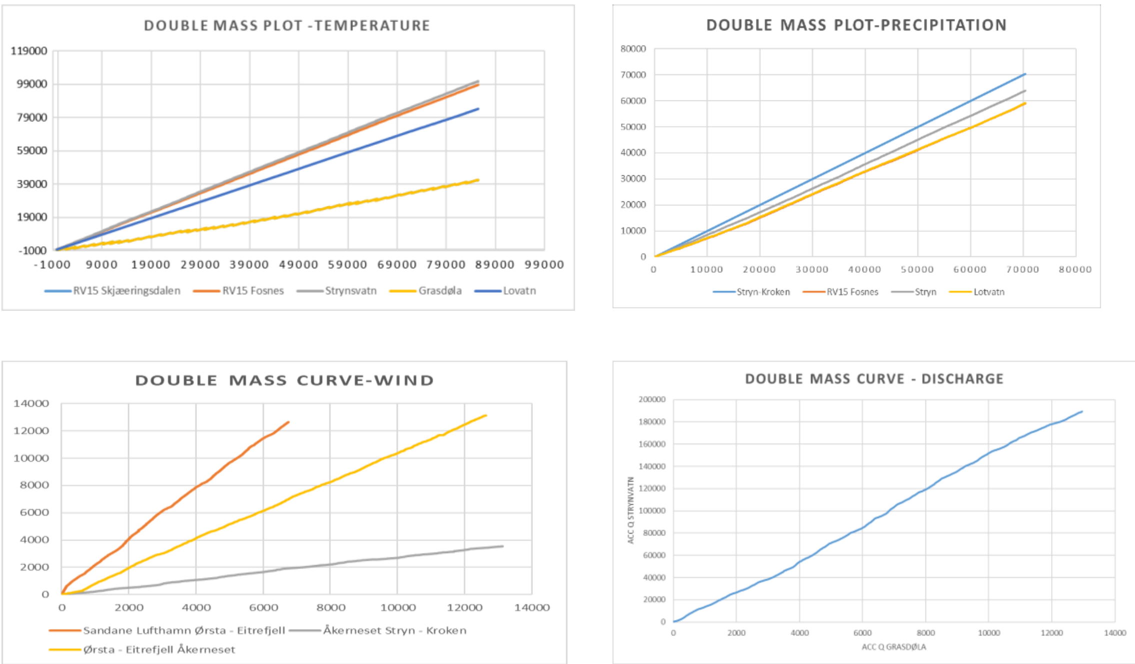


Figure 4. 10: Double Mass plots for input data

The double mass curves give a fairly good linear trend with no slope changes hence better confidence in the accuracy of input data from the various stations.

Extension of timeseries for the input Database

Global radiation, wind and relative humidity had insufficient data for timeseries from accurate runoff simulation. Analysis of available radiation data showed a similar yearly trend in observation. The same data was therefore used to extend the input series on assumption of little deviation from yearly observation.

4.2 Distributed Hydrological Model- ENKI

Hydrological models are used to simulated responses (discharge) given the input conditions. A distributed hydrological Model-ENKI was used to spatially and temporal model runoff responses in the Stryn Catchment. The model consists of various routines which use input data to simulate responses.

4.2.1 Model Routines

Routines are methods which implement equations used in the simulation process. The following routines (Figure 4.11) were used to set up a distributed model of Stryn catchment.

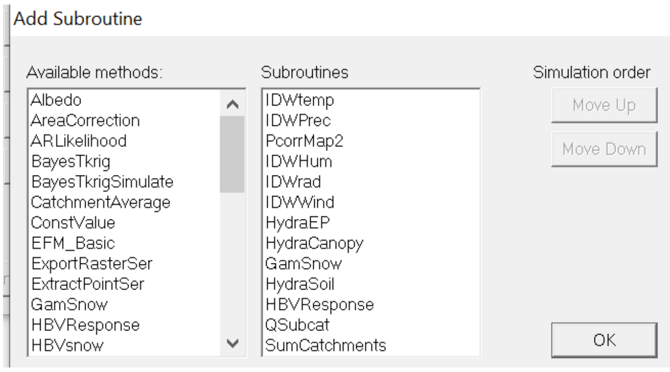


Figure 4. 11: ENKI Model routines

The routines were implemented and simulated in a sequence order such that responses from a previous routines form the input to the following routines until the last routine where simulated runoff is compared against observed runoff. The sequence order of the routine used in the ENKI model is shown in Figure 4.11. The brief explanation of the processes in the model routines follows below.

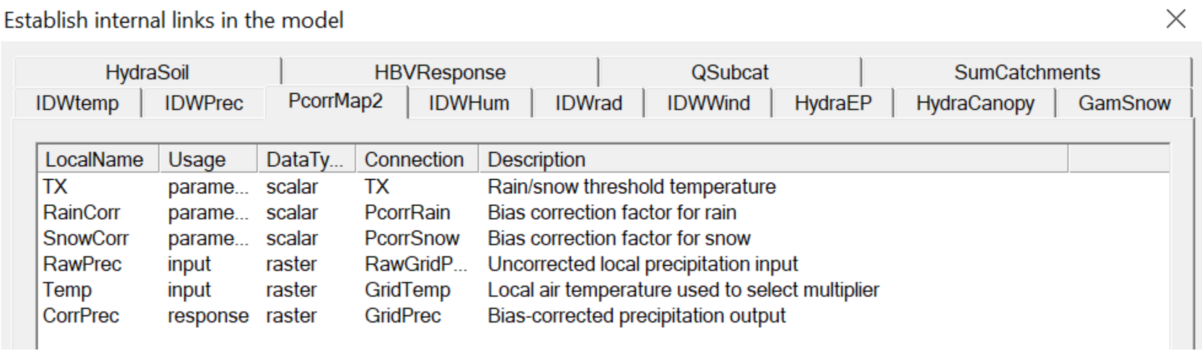
IDWprec, IDWtemp, and IDWrad

Inverse Distance Weighting (IDW) interpolates point measurements to grid data. The weight of the station point measurement is inversely proportional to its squared distance to the grid. This is used to create raster maps from point observations. IDWprec and IDWtemp include an elevation correction i.e. (% per 100m) in IDWPrec, in IDWtemp (°C per 100m).

IDW methods places more weight on nearest stations and can give inaccurate results for target locations located far from the point measurements. To minimize this error, more point measurements have been used in the model. The IDW method is used to create grid rasters for precipitation, temperature, global radiation, wind velocity, and relative humidity.

PcorrMap2

PcorrMap2 Routine applies a correction factor to grid precipitation. A threshold temperature TX distinguishes between rain and snow precipitation. The model routine uses grid temperature to apply different correction parameters for snow and rain i.e., Uncorrected precipitation is multiplied with PcorrRain and PcorrSnow for rain and snow respectively (Figure 4.12).



LocalName	Usage	DataTy...	Connection	Description
TX	parame...	scalar	TX	Rain/snow threshold temperature
RainCorr	parame...	scalar	PcorrRain	Bias correction factor for rain
SnowCorr	parame...	scalar	PcorrSnow	Bias correction factor for snow
RawPrec	input	raster	RawGridP...	Uncorrected local precipitation input
Temp	input	raster	GridTemp	Local air temperature used to select multiplier
CorrPrec	response	raster	GridPrec	Bias-corrected precipitation output

Figure 4. 12: Pcorr routine

Both TX, PcorrRain and PcorrSnow are model calibration parameters.

HydraEP

Hydra EP routines uses input land use, vegetation height rasters to compute the Leaf Area Indices within forested and non-forested areas. Potential Evaporation is computed within this routine from intercepted precipitation on the leaf canopy.

HydraCanopy

Hydra canopy uses input land use, vegetation cover rasters and Leaf area index for high vegetation to compute interception storage within the canopy, actual evaporation and the throughfall from the interception storage.

GammaSnow Routine

As part of Stryn catchment is covered by glaciers, a gamma snow routine is used to compute the distributed grid snow. It uses an energy balance equation for the melting process, and the snow distribution in each grid route by a Gamma distribution. To compute the snow energy pack, the routine requires more input data. Time series for global radiation, wind, relative humidity in addition to temperature and precipitation are needed to compute snow energy pack. The routine simulates the effect of land use, forests and mountains on snow redistribution hence requires input rasters for land use and spatial distribution of forests and mountains with the catchment (figure 4.8). The routine models snow covered area, snow water equivalent (SWE) and computes the Grid Snow out .

HydraSoil

Hydra Soil routine receives Grid snow out and transforms it into soil moisture. It computes actual evaporation and storage in the unsaturated zone. It generates surface runoff and subsurface runoff . The total runoff from the routine is the Grid Soil out.

HBV response

The HBV response comprises of fast response for a linear tank with two outlet and slow response for ground flow. The two responses from the upper drainage and the lower (ground) drainage are summed up to give the grid runoff from each grid. The routines uses calibration parameters k2,k1,k0, perc, and Threshold (for activation of fast runoff) to compute grid runoff.

Qsubcat

Qsubcat routine sums up water in each grid and computes runoff for a catchment. It converts runoff from mm/day m3/s. Qsubcat is used to compute runoff from each sub catchment in the region.

SumCatchments

SumCatchments aggregates all runoff from upstream sub-catchments to the recipient catchment downstream (Figure 4.13). It uses downstream ID to route water to downstream catchment to compute aggregated runoff. Response from this routine forms the basis for comparison between simulated and observed runoff.

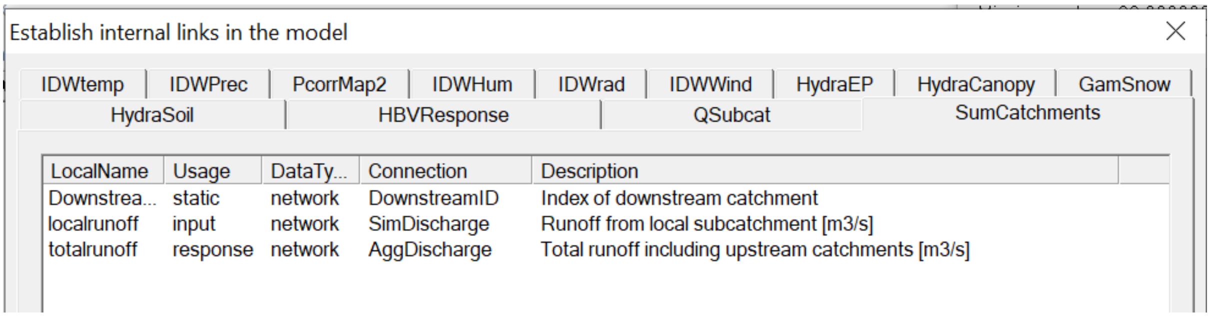


Figure 4. 13: Subcatchment routine

4.2.2 Model Calibration and Validation

Model calibration means determining the set of free parameters in the model that gives the best possible correspondence between observed and simulated runoff for a catchment (A. Killingtveit & Sælthun, 1995). To calibrate ENKI model, the simulated runoff was compared to observed runoff for Strynsvatn and Grasdøla to obtain the best goodness of fit.

Measure of Performance

The measure of model performance was analyzed using both objective and subjective methods

i. Subjective methods: Analysis of the plots of simulated and observed runoff i.e., time series hydrograph, duration curves and accumulated discharge plots.

Due to the high number of model parameters to be calibrated. The model was initially manually calibrated, and resulting performance assessed using subjective methods to get a better correspondence between the observed and simulated plots. Model insensitive parameters were fixed and sensitive parameters used in the automatic calibration. Figure 4.14 shows model parameters used in the calibration

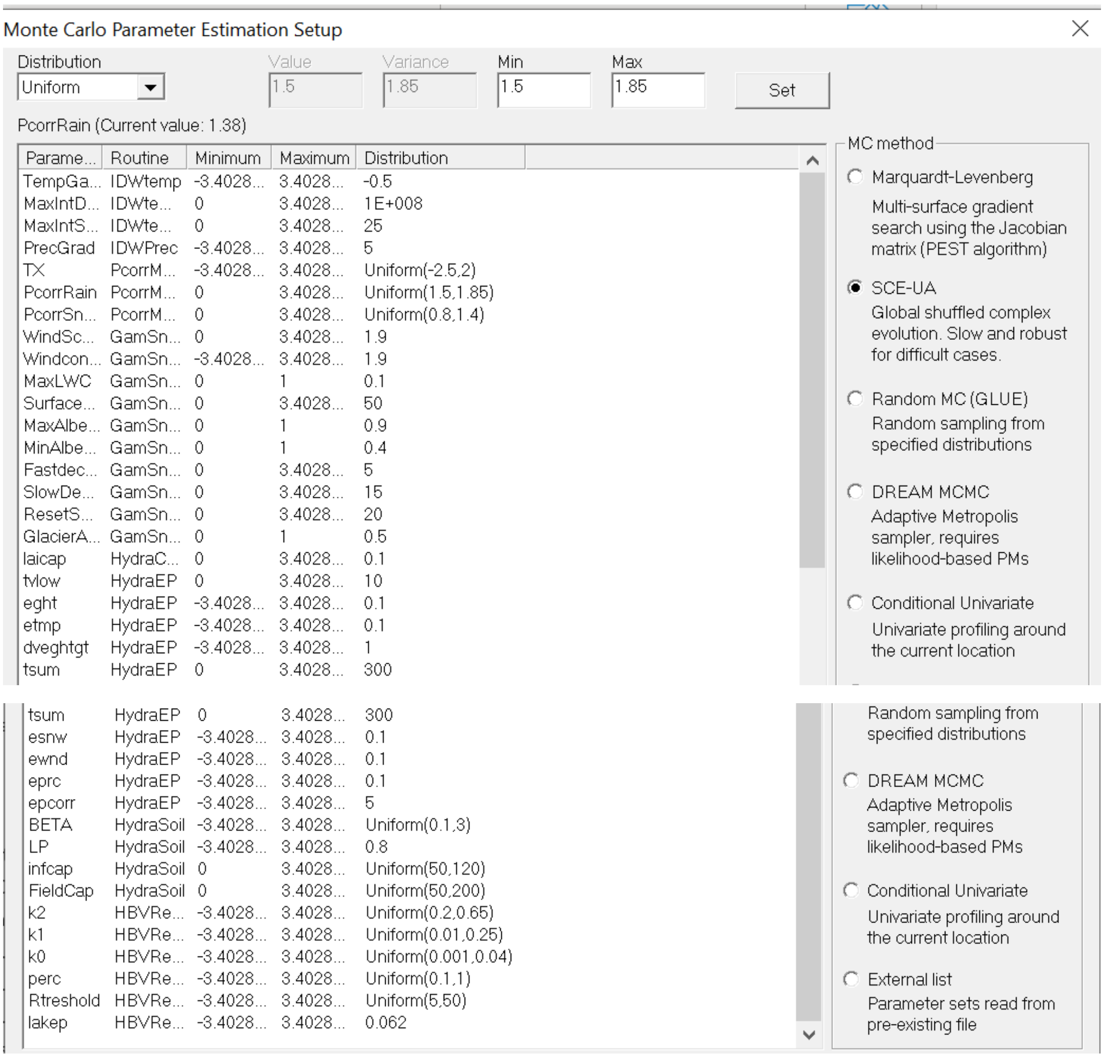


Figure 4. 14: ENKI model calibration

ii. Objective method: Using Nash Sutcliffe efficiency criterion R2.

Temporal R2 is computed (Figure 4.15) from Eq 1. by model as a measure of performance.

$$R2 = \frac{\Sigma(Q_o - Q_{\bar{O}})^2 - \Sigma(Q_S - Q_O)^2}{\Sigma(Q_O - Q_{\bar{O}})^2} \text{ .... Eq 1}$$

Where Q_o = Observed runoff, Q_o^-= Average runoff, Qs = Simulated runoff

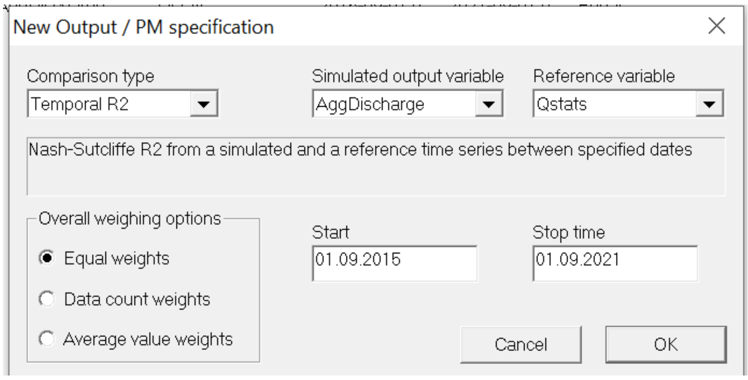


Figure 4. 15: Measure of Performance

A split sample method was used for calibration and validation. The model was calibration for 01.09.2015 to 01.01.2021. The validation period was 01.09.2011 to 01.01.2015

4.3 Flood Estimation

Flood estimation was done basing on the recommendations from NVE for flood frequency estimation (Wilson et al., 2011). In Norway, 200-year flood is used for flood hazard mapping. Estimation of flood was based on three methods;

i. Statistical analysis of observed historical runoff data using annual maximum series
   a) Lmono moments using Rscript
   b) Gumbel (Extreme type iii) distribution

   The mean flood μ and standard deviation σ were obtained from annual maxima series (AMS) for runoff data. A flood of given return period T is obtained from Eq 2;

$$Q_T = \mu + K_T\sigma \text{ ....Eq 2}$$

Where KT (Eq 3) is the frequency factor, which is a function of the return period T, μ is mean flood and σ is standard deviation of the annual flood in AMS.

$$K_T = \frac{-\sqrt{6}}{\pi}\left[0.5772 + \text{In}\left(\text{In}\left(\frac{T}{T-1}\right)\right)\right] \text{..................... Eq 3}$$

ii. Using a Probability plot (graphical analysis) of annual maxima series. The maximum annual discharge is extracted for each year from the timeseries .The annual flood series was sorted in descending order and the values ranked. The probability of exceedance P was calculated from;

$$P = \frac{m}{n+1} \text{...} \text{Eq 4}$$

The return period is the inverse of the probability of exceedance (Eq 5)

$$T = 1/P \text{ ....} \text{Eq 5}$$

where m is the rank position and n is the number of values.

The discharge was plotted against the return period and the graph extrapolated to determine the flood magnitudes as the different return periods.

iii. Regional flood analysis.
iv. Flood frequency analysis using results from simulated runoff from the hydrological model.

The flood estimates from different methods were compared as well as the flood results from historical observations and the runoff model.

4.4 Hydropower Potential of the catchment

The hydropower potential of a river course is dependent on the available head (H), discharge / average flow (Q), and the efficiency of the power system (η). The average discharge is dependent on the catchment area (A) and the specific discharge (Q_N) of the catchment. Available head for energy production depends on the elevation profile (head). The net head (H_{net}) is the difference between the gross head (H_{gross}) and the head losses (due to friction and singular losses). The efficiency of the power system is overall efficiency of the turbine, generator and the transformer. A value of η= 0.90 has been used in the calculation.

$$\text{Power } P(W) = \eta * \rho * Hnet * Q * g \text{....................................} \text{Eq 6}$$

$$\text{Power } P(kWh/day) = \eta * Hnet * Q * g * 24 \text{ ....} \text{Eq 7}$$

where ρ is the density of water

Power production in kWh/day (Eq 7) was computed for each day given the daily inflow into the powerhouse. The annual production is the summation of the daily production in the year.

The hydropower potential is assessed for the different intake locations, i.e., 600, 400, 325, 225, 150 , 88 m.a.s.l and at the outlet of Oppstrynsvatnet.

4.5 Tunnel layout and Cost Optimisation

Stryn catchment has a steep terrain which comprises of high mountains and low valleys. Underground blasted or drilled tunnels are to divert river flow from the intakes to the outlet at Nordfjord, bypassing the densely populated area along the meanders of Stryn. The alignment of tunnel is based on maximising water inflow into the system through intakes from the different tributaries. To optimise the cost of tunnels, tunnels for diversion of flood water have been designed for optimum size in regard to cost and frictional head losses.

4.6 Cost Calculation and Economic Analysis.

To determine the economic feasibility of project, economic analysis and cost optimisation is conducted for the development of the proposed alternatives for flood control and hydropower generation from flood water. Cost calculations have been grouped into waterways (tunnel design and optimisation), intake costs, Electro technical costs, hydromechanical costs, powerhouse costs, access roads and cost of operation and maintenance given a design period of 50 years.

4.6.1 Waterway Optimisation

As part of flood management, excess runoff is diverted through underground tunnels to Nordfjord. Given the terrain of Stryn catchment with mountains and valleys, underground tunnels were more feasible for water diversion. Cost optimisation and calculation of the cost of underground tunnels is done following recommendations from (NVE, 2012).

Design and sizing of the underground tunnels is done on the basis of optimisation of hydropower production by reducing the head losses in the tunnels, and cost of construction. Two alternatives of tunnels, TBM tunnels and Drilled and Blast (D&B) tunnel are considered for waterway. The head losses in tunnel system are computed basing on the Manning Equation for frictional loses. Manning M of 65 for unlined TBM tunnels and 33 for unlined D&B tunnels is used to calculate the frictional head losses in the tunnels (Eq 8).

$Friction\ losses\ hf = (L * Q^2)\ /(M^2 * A^2 * R^{\frac{4}{3}});$ ……………………Eq 8

Where L is the length of the tunnel, Q is the design discharge, A is the tunnel cross sectional area and R is the hydraulic radius given as a ratio of cross-sectional area A and the wetted perimeter P.

Singular losses in tunnels are smaller compared to the fictional head losses have been assumed as 5% of the frictional head losses hf.

From the equation above, area of tunnel is inversely proportional to the head loss due to friction. A large diameter would reduce the energy losses but create an increase in construction costs. The type and optimum diameter of the tunnel is therefore a trade-off between cost of energy losses in the tunnel, and cost of construction. Cost calculation for TBM tunnels and D&B tunnel is done following Cost Base For Hydropower plants with generating capacity of more than 10,000kW (NVE, 2012).

Intake Costs

Due a number of intakes in the different river courses, the intake design capacity (maximum discharge) is taken as twice the average discharge. The cost of the intake is the taken as construction cost and gate cost.

Access roads

Intake locations have been chosen given the ease of access and construction. However, access roads will be required for transportation of material during construction. The cost of access roads has been assumed at 1000 NOK/meter for temporary roads in easy terrain (NVE, 2012)

4.6.2 Powerplant Costs

The outlet at Nordfjord is at sea level, a surface powerhouse has been considered in the cost calculation. Hydromechanical equipment and Electro technical equipment will be placed in the powerhouse. A breakdown of the components follows below.

Hydromechanical costs

Hydromechanical equipment include turbines, inlet gates, trash racks and lifting equipment (electric hoist). The choice of turbine is dependent on the available head and the discharge. For higher heads at intakes D600 and D400, Pelton turbines are selected, for medium head at intakes D325, D225 and D150, Francis turbine has been selected, and for low heads at intakes

(D88 and DStrynsvatn), Kaplan turbines have been selected. The cost of the equipment is based on Cost base Manual for hydropower plants (NVE, 2012).

Electro technical Costs.

Electro technical equipment included in the cost analysis are generator, transformer, control system and auxiliary systems. Cost base for calculation is based on the Cost base Manual for hydropower plants (NVE, 2012) assuming number of revolution N = 500

Powerhouse

A surface powerhouse has been considered in the cost analysis. Cost base for calculation is based on the Cost base Manual for hydropower plants (NVE, 2012)

4.6.3 Economic and Financial analysis

To determine the economic feasibility and financial viability of hydropower development, the total cost of investment and total revenue from Energy sales has been assessed. The total cost of investment is the sum of construction costs and operation and maintenance (O&M) costs. O&M costs are taken as 5% of the total construction costs. Since the Cost Basis (NVE, 2012) is based on Price level for 2010, the price has been compounded to a present (2022) assuming inflation rate of 2.048 % hence multiplying the values by 1.275.

Revenue from the project is considered direct revenue as result of sale of energy. Energy prices in Norway vary between day and night and seasonally (winter and summer), Energy prices in EUR/MWh have been obtained from NordPool Market Data considering historical daily energy prices in Molde- trading area NO (NordPool, 2022).

An asset life of 50 years has been assumed and Present value (PV) of revenue is discounted using Eq 9 .

$$Present\ Value\ PV = \frac{Future\ Value\ FV}{(1+i^{n})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq 9}$$

Where i is the annual interest rate .An annual interest rate of 7% is assumed in the calculation.

To assess the financial viability of the alternatives, the Benefit-Cost (B/C) Ratio is computed by dividing the Total Benefit (Revenue from Energy) by the Total Cost (Total investment Cost plus O&M Costs) for the life period of the project. Projects with a B/C ratio >= 1 are considered financially profitable.

4.7 Effect of Regulation on Flood regulation

The main aim of the study is evaluate a feasible flood reduction downstream alternative in Stryn. With the proposed diversion plans, the reduction in the annual maximum flood is assessed. Methods for flood analysis discussed in Section 4.3 are used to evaluate the expected flood before regulation and changes in flood magnitudes with the proposed regulation.

4.8 Effect of Regulation on Fish Habitant.

To assess the effect of regulation of flow in the river courses during peak flows, discharge in the river course is assessed before and after regulation. The diagnosis tool proposed by Forseth & Harby (2014) is used as a basis to assess the likelihood impact of hydrological alterations on the population of salmon and identify any likely bottleneck to population of salmon.

Changes in the hydrology with the driest year are assessed before and after regulation for both upstream tributaries to Oppstrynsvatnet and in Stryn river. The reduction in lowest weekly average is assessed against the guidelines in Table 4. The alternative with the least impact on the hydrological alternations to lowest weekly average flow is considered as optimum.

4.9 Changes due to Climate Change

To model the effects of climate change on the catchment, changes in precipitation and temperature have been factored into the historical input data. A 10 % increase in winter and spring and 15% increase in precipitation in Summer and Autumn has been considered. A delta change in temperature has been applied to historical data with a 4.0 ^{0}C increase in winter, spring and autumn and 3.5 ^{0}C increase in summer. This approach has been used in the studies by (Saelthun et al., 1990).

Flood analysis due to effect of climate change has been carried and compared with the historical floods. Changes in available water for hydropower production has been studied.

5. HYDROLOGY

5.1 Strynsvatn gauging station

Strynsvatn gauging station lies at the outlet of Oppstrynsvatnet at coordinates 74466 UTM 33 East and 6893124 UTM 33 North. It is an active gauging station with discharge measurements dating back to 01.09.1981. Figure 5.1 shows the timeseries of discharge from Strynsvatn gauging station from Autumn of 1981 to 2021. Between 2001 to 2006, no data was recorded at the station hence these years have been excluded from analysis.

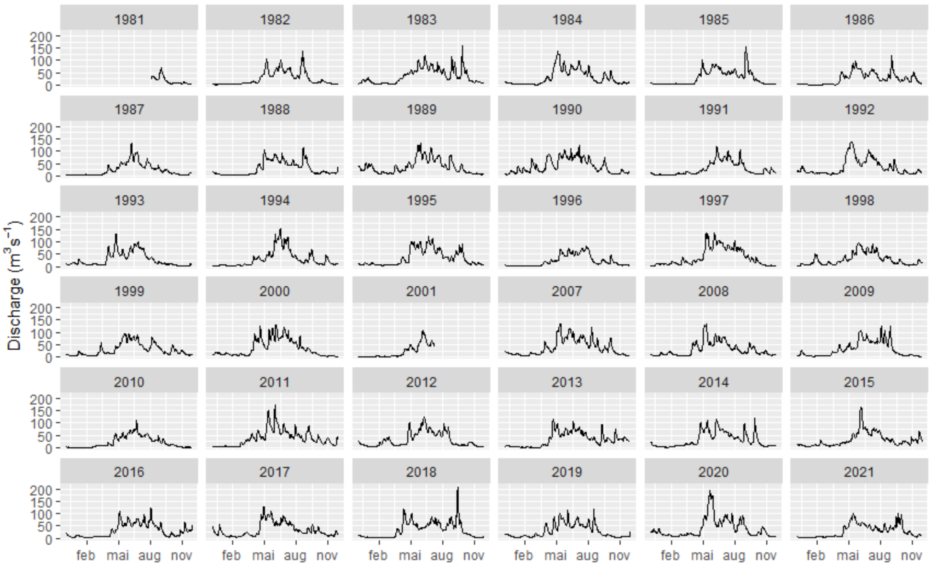


Figure 5. 1: Runoff series for Strynsvatn

From the runoff series, the driest year was 2010 and the wettest year 2020. Percentile distribution of discharge is shown in Figure 5.2 with generally low winter flows between October and March and high flows recorded between May to September.

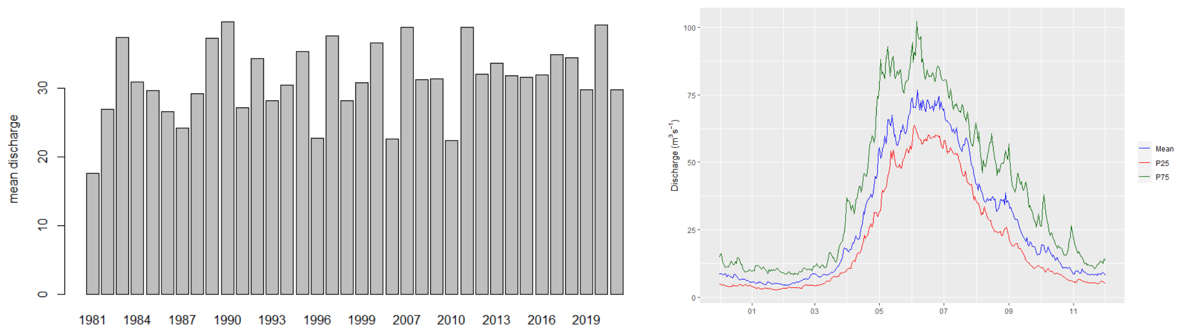


Figure 5. 2: Distribution of Discharge in Strynsvatn

5.2 Grasdøla gauging Station

Grasdøla is an active gauging station is along the tributaries of Strynevassdraget at coordinates 94769 UTM 33 East and 6894794 UTM 33 North.. The discharge time series used in analysis is from 1980 to present (2022) with missing data from 1985 to 1986 and 1989 to 1997. Figure 5.3 shows discharge series for Grasdøla gauging station.

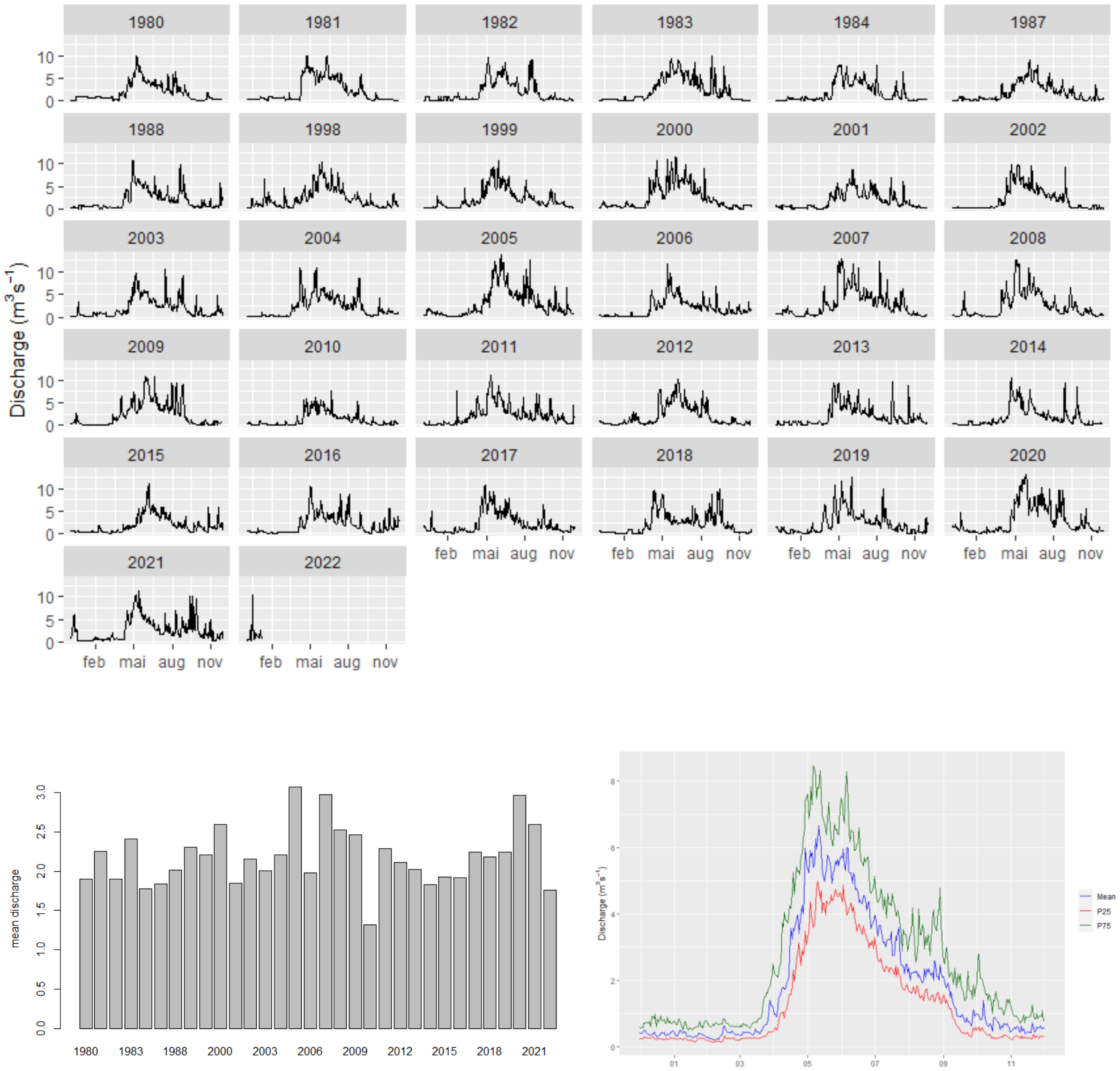


Figure 5. 3: Runoff in Grasdøla

Analysis of discharge series show an agreement during low flows and high flows between Strynsvatn and Grasdøla gauging stations. Both show high runoff between May and September and low flow in November to February.

5.3 Runoff generation within the catchment

To investigate the cause of floods in Stryn, analysis of climate data (precipitation and temperature) was done with reference to the output (discharge). Figure 5.4 shows a plot of discharge (Qstats), precipitation (pstats) and temperature (tstats) for Strynsvatn.

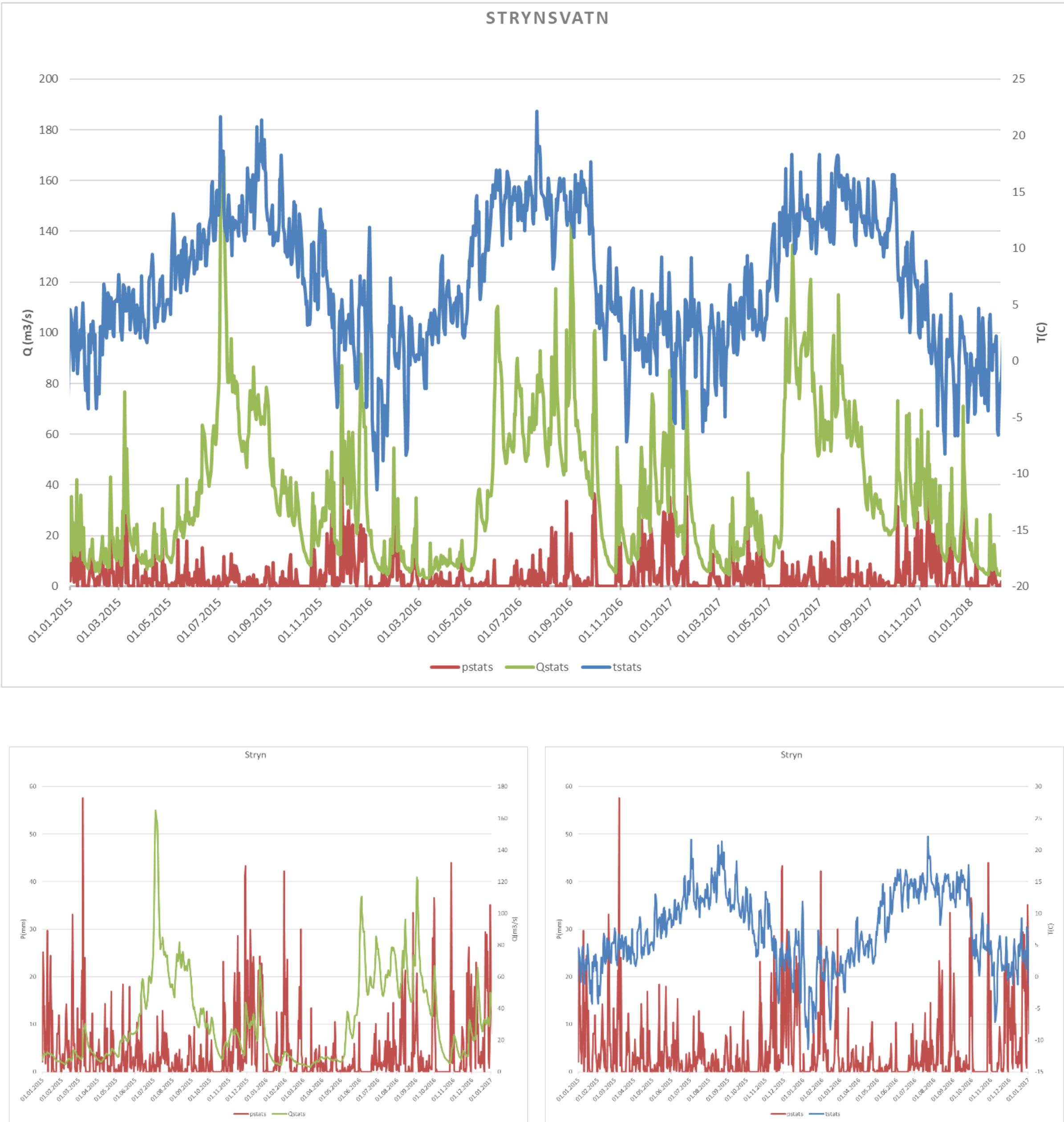


Figure 5. 4: Hydrology of Stryn

As seen in Figure 5.4, the average trend in discharge and precipitation is out of phase. The catchment receives heavy precipitation between November to March with an average air temperature below 0 ^{0}C, however the corresponding runoff is minimum. Runoff peaks in the months of May to September with a corresponding low precipitation and air temperature above 0 ^{0}c.

Analysis of the timeseries for discharge, precipitation and temperature indicates that most of precipitation in the catchment falls as snow. When the air temperature increases, the snow energy pack increases causing snow melt hence high runoff is observed in the rivers during summer. Floods within the river course are therefore a result of snow melt from the high mountains. However, there are also instances of the rainfall during snowmelt periods hence a combination of rain and snowmelt can result into heavy flooding in Stryn.

5.4 Ungauged sub-catchments in Stryn

Catchments where no runoff data are available are termed as ungauged catchments (Blöschl, 2005). Within Stryn catchment, main tributaries flowing into Oppstrynsvatnet are ungauged. These include sub-catchments of Sunndøla, Erdalselva, Skjerdingsdøla, Glomsdøla, and Videdøla. In the study, the possibility of transferring model parameters from gauged catchment was analysed to predict runoff in the ungauged catchments. This was done on the basis that catchments that are close to each other are assumed to behave in hydrologically similar manner and have similar hydrologic responses (Blöschl, 2005). Since the sub-catchments lie in the same region as the gauged catchments, similar runoff and hydrological process are presumed.

The physical attributes of the sub-catchments are compared, i.e., elevation distribution, specific runoff, catchment area and land use type to assess their hydrological similarity. Figure 5.5 shows comparison of ungauged catchment attributes with the gauged catchments of Grasdøla and Strynsvatn.

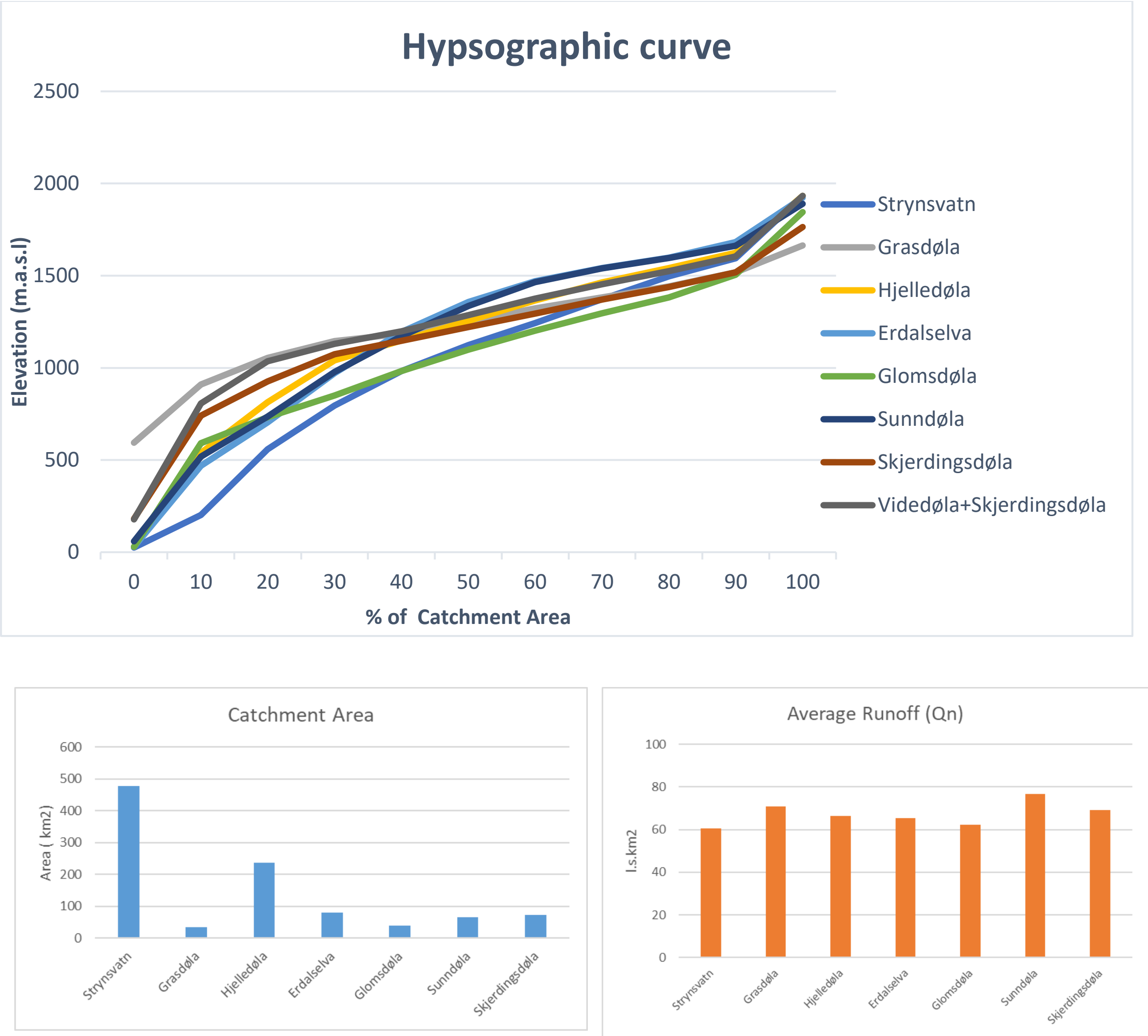
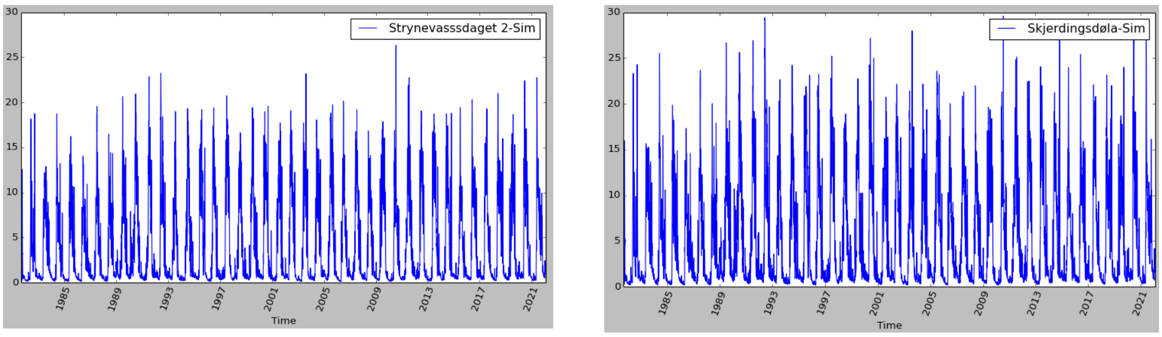


Figure 5. 5: Comparison of subcatchment characteristics

As seen in Figure 5.5, the ungauged catchments have similar physical characteristics, i.e., elevation distribution (hypsographic curve) and the annual average runoff. All the catchments are dominated with low valleys and mountains covered with glaciers. Model calibration parameters (discussed further) from the gauged catchments are transposed to the ungauged catchments to obtain the corresponding runoff series (Figure 5.6).



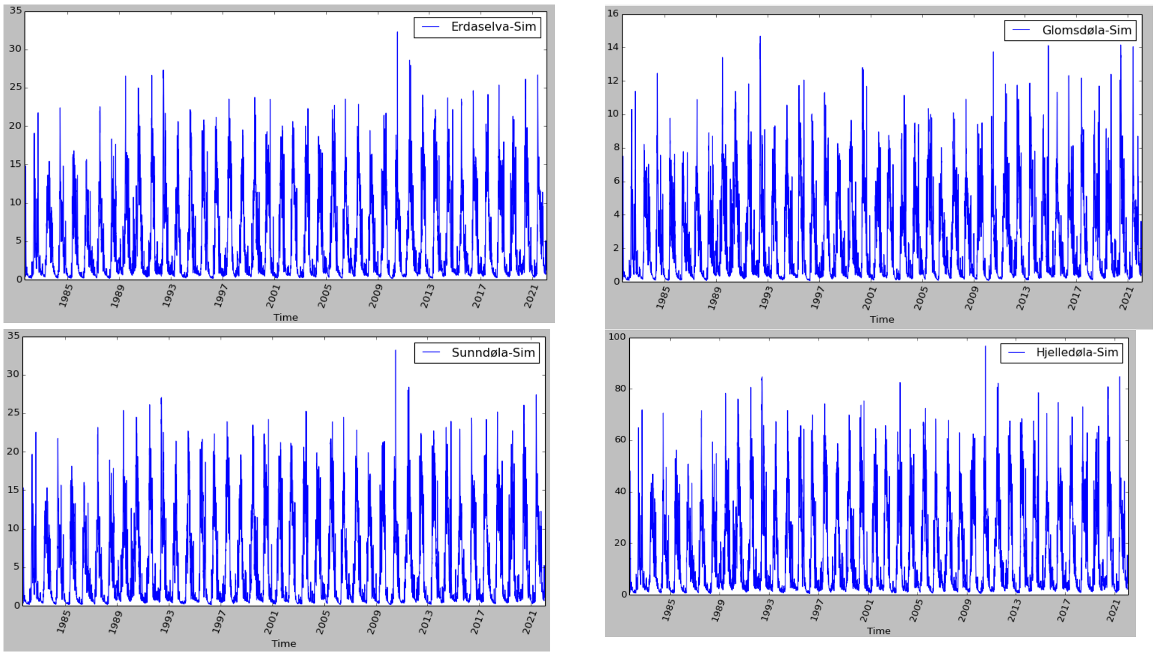
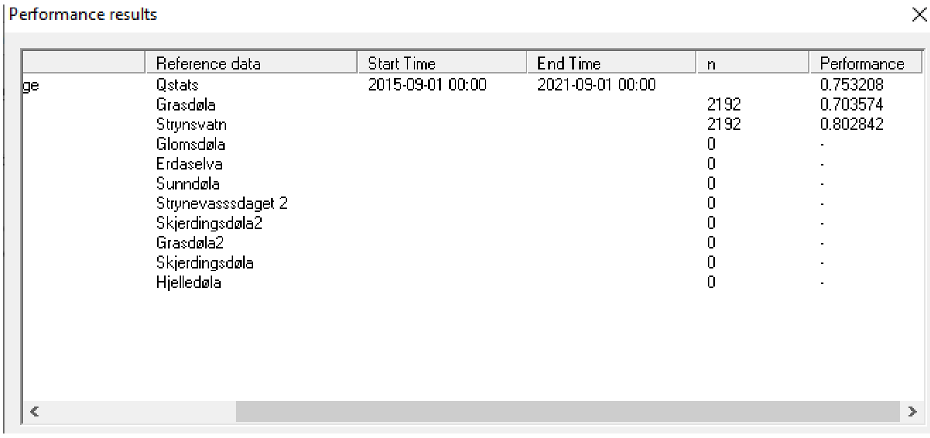


Figure 5. 6: Runoff series for ungauged subcatchments

6. HYDROLOGICAL MODEL- ENKI

6.1 Model Performance and Calibration

To calibrate the model, a runoff series between 09.01.2015 to 09.01.2021 was used for calibration due to the availability of a complete timeseries for all input data for the period. The Nash Sutcliffe temporal R2 from the model is shown in Figure 6.1. Strynsvatn gives a R2 of 0.8028 and Grasdøla of 0.7035. More emphasis in the model was aimed at obtaining a better simulation for the Strynsvatn compared to the Grasdøla (sub catchment of Stryn).


Performance results

	Reference data	Start Time	End Time	n	Performance
ge	Qstats	2015-09-01 00:00	2021-09-01 00:00		0.753208
	Grasdøla			2192	0.703574
	Strynsvatn			2192	0.802842
	Glomsdøla			0	-
	Erdaselva			0	-
	Sunndøla			0	-
	Strynevasssdaget 2			0	-
	Skjerdingsdøla2			0	-
	Grasdøla2			0	-
	Skjerdingsdøla			0	-
	Hjelledøla			0	-

Figure 6. 1: Performance of Calibrated model

6.1.1 Calibrated Parameters

The model calibrated parameters are shown in Figure 6.2.

Parameter	Routine	Minimum	Maximum	Value
TempGard	IDWtemp	-3.40282E+...	3.40282E+0...	-0.5
MaxIntDist	IDWtemp;ID...	0	3.40282E+0...	1E+008
MaxIntStats	IDWtemp;ID...	0	3.40282E+0...	25
PrecGrad	IDWPrec	-3.40282E+...	3.40282E+0...	5
TX	PcorrMap2;...	-3.40282E+...	3.40282E+0...	1.06
PcorrRain	PcorrMap2	0	3.40282E+0...	1.55
PcorrSnow	PcorrMap2	0	3.40282E+0...	0.973
ConstOne	IDWHum;ID...	-3.40282E+...	3.40282E+0...	1
ConstOneRad	IDWrad	-3.40282E+...	3.40282E+0...	1
tvlow	HydraEP	0	3.40282E+0...	10
eght	HydraEP	-3.40282E+...	3.40282E+0...	0.1
etmp	HydraEP	-3.40282E+...	3.40282E+0...	0.1
dveghtgt	HydraEP	-3.40282E+...	3.40282E+0...	1
tsum	HydraEP	0	3.40282E+0...	300
esnw	HydraEP	-3.40282E+...	3.40282E+0...	0.1
ewnd	HydraEP	-3.40282E+...	3.40282E+0...	0.1

Parameter	Routine	Minimum	Maximum	Value
dveghtgt	HydraEP	-3.40282E+...	3.40282E+0...	1
tsum	HydraEP	0	3.40282E+0...	300
esnw	HydraEP	-3.40282E+...	3.40282E+0...	0.1
ewnd	HydraEP	-3.40282E+...	3.40282E+0...	0.1
eprc	HydraEP	-3.40282E+...	3.40282E+0...	0.1
epcorr	HydraEP	-3.40282E+...	3.40282E+0...	5
laicap	HydraCanop...	0	3.40282E+0...	0.1
Lastwinterday	GamSnow	1	366	100
WindScale	GamSnow	0	3.40282E+0...	1.9
Windconst	GamSnow	-3.40282E+...	3.40282E+0...	1.9
MaxLWC	GamSnow	0	1	0.1
SurfaceLayer	GamSnow	0	3.40282E+0...	50
MaxAlbedo	GamSnow	0	1	0.9
MinAlbedo	GamSnow	0	1	0.4
FastdecayRate	GamSnow	0	3.40282E+0...	5
SlowDecay	GamSnow	0	3.40282E+0...	15

ResetSnow	GamSnow	0	3.40282E+0...	20
GlacierAlbedo	GamSnow	0	1	0.5
BETA	HydraSoil	-3.40282E+...	3.40282E+0...	0.139
LP	HydraSoil	-3.40282E+...	3.40282E+0...	0.8
infcap	HydraSoil	0	3.40282E+0...	80
FieldCap	HydraSoil	0	3.40282E+0...	80
k2	HBVRespon...	-3.40282E+...	3.40282E+0...	0.304
k1	HBVRespon...	-3.40282E+...	3.40282E+0...	0.251
k0	HBVRespon...	-3.40282E+...	3.40282E+0...	0.025
perc	HBVRespon...	-3.40282E+...	3.40282E+0...	1
Rtreshold	HBVRespon...	-3.40282E+...	3.40282E+0...	38.1
lakep	HBVRespon...	-3.40282E+...	3.40282E+0...	0.062

Figure 6. 2: Calibrated Parameters

6.1.2 Model Validation

The model calibrated parameters were validated through a period of 01.09.2011 to 01.09.2015. The validation period showed a better performance in Strynsvatn (Table 8) with Nash Sutcliffe R2 increasing to 0.826. However, the model showed a poorly performances for Grasdøla with R2 of 0.59. A second validation was analyzed for the time series between 1982 to 2021. Strynsvatn showed a better calibration R2 of 0.829 compared to Grasdøla of 0.639

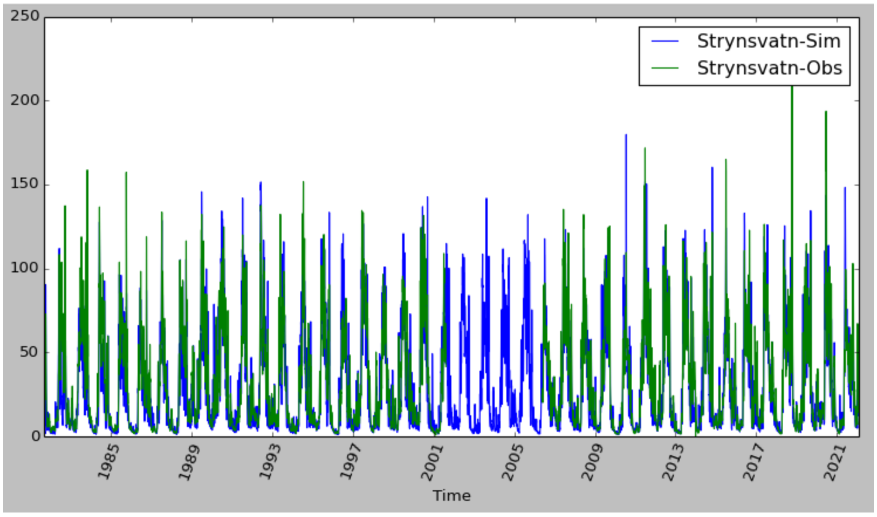
Table 8: Calibrated model performance (R2)

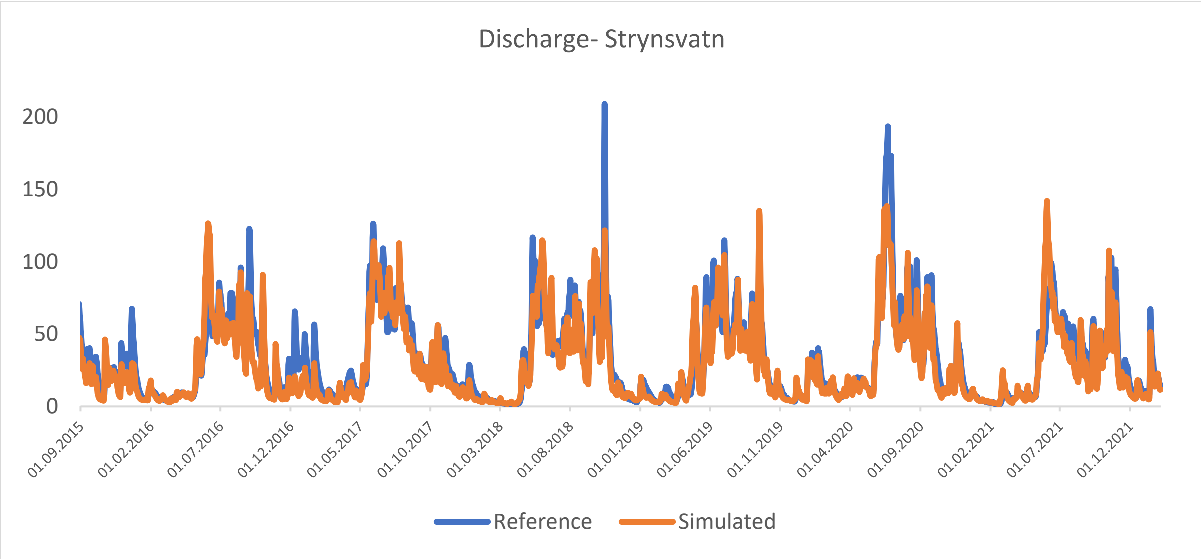
Period	Gauging station	Model Performance R2
2015 to 2021	Grasdøla	0.704
(Calibration)	Strynsvatn	0.803
2011 to 2025	Grasdøla	0.590
(Validation)	Strynsvatn	0.825
1982 to 2021	Grasdøla	0.640
(Time series)	Strynsvatn	0.829

6.1.3 Subjective Methods: Analysis of plots

Figure 6.3 shows graph of observed and simulated runoff. Strynsvatn showed a better goodness of fit between observed and simulated runoff. However, observed flood peaks were not simuated accurately by the model. The deviation in flood values is discussed further in chapter 7. In contrast to Grasdøla, the model overestimates the highest flood peak.

Observed and Simulated runoff





Grasdøla

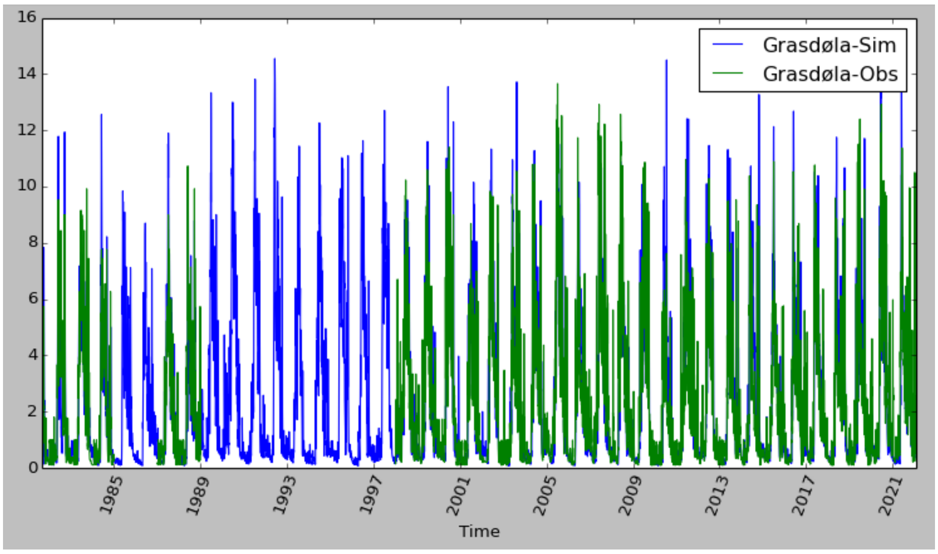


Figure 6. 3: Comparison of Observed and Simulated runoff

Duration curves

To analyze the goodness of fit for high and low runoff values, a duration curves for Strynsvatn and Grasdøla was plotted (Figure 6.4). Strynsvatn shows a good correspondence at high and low peaks with exceedingly high flood peaks poorly simulated. There is also minimal deviation in the mid-range values as seen in Figure 6.4. Grasdøla shows a larger deviation in the simulated high plots.

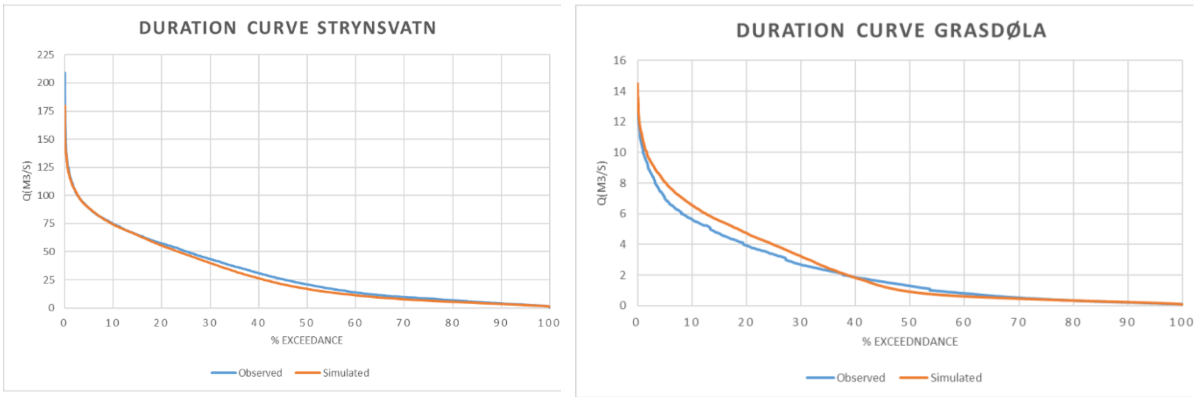


Figure 6. 4: Duration curve Plots

Accumulated Runoff

The correspondence between accumulated runoff gives a fairly good fit between observed and simulated runoff (Figure 6.5). However, the model underestimates and overestimates the simulated runoff in Strynsvatn and Grasdøla respectively.

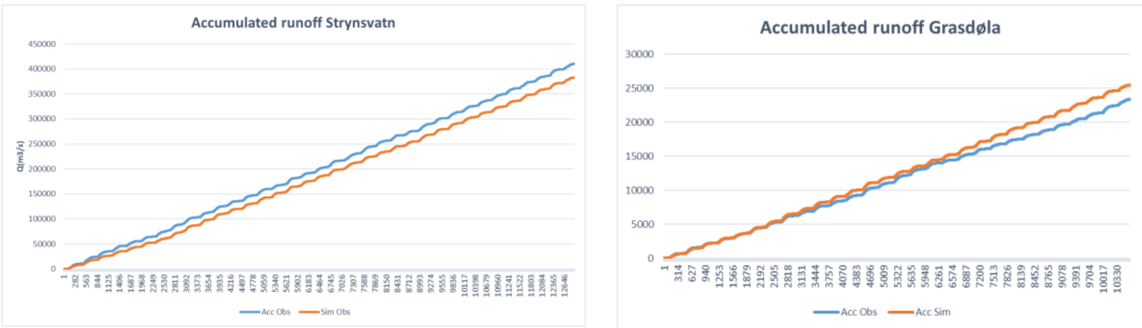


Figure 6. 5: Accumulated Plots

6.2 Potential Sources of Errors

Whereas ENKI model gave a satisfactory performance in simulating runoff in Stryn catchment, possible sources of potential errors in hydrological modelling of the catchment could be attributed to;

i. Limited observations for global radiation for the entire time series.
ii. Errors due Inverse Distance Weighing (The distance from point stations to target locations affects the accuracy of the data. Point measurement used for global radiation are more than 50 km from the Stryn catchment hence a likelihood of loss of accuracy in data .

iii. Extension of series (due to lack of historical data for global radiation, the series was extended assuming a similar historical trend in global radiation.
iv. Use of same parameters for calibration of the different sub catchments
v. Lack of routing in the model in aggregating runoff from sub catchment to the main catchment.

6.3 Discussion

Use of distributed model enabled accounting for spatial characteristics of Stryn catchment i.e., land use, forests, mountains and glaciers and their influence on the hydrological responses of the catchment. Another advantage of the ENKI model is runoff from ungauged sub catchments is simulated which provides reliable basis for analysis of sub catchments and limits the errors due to scaling. However, the ENKI model requires more data input than a traditional lumped HBV model. The available gauging stations had incomplete time series, gauges for global radiation were located several kilometres outside the study catchment. Loss of accuracy in estimation of grid data from the point measurements using Inverse distance method is therefore expected in the modelled results.

Results from the model showed a good correspondence between measured and simulated runoff. The model simulates both low and high peaks (with exception of very high peaks) in Stryn quite accurately. The ENKI model showed better performance for calibration and validation in Strynsvatn than Grasdøla. An explanation to the deviation in performance for the two catchments can be attributed to that fact that ENKI applies the same model parameters to all the catchments. Hydrologically, unless the set of catchments are identical to each other, errors are expected as the same model parameters are applied to different sub-catchments. However, with a Nash Sutcliffe performance above 0.8 for both calibration and validation of Strynsvatn, the simulated runoff was considered reliable for further analysis.

7. FLOOD ANALYSIS

7.1 Flood frequency analysis using historical observations.

a) Statistical analysis of historical observations from the Strynsvatn gauging stations has been used for flood analysis. The AMS from historical observations is shown in **Figure 7.1**. The series consists of discharge measured from 1982 to 2021 (excluding 2001-2006 due to missing data). From the series, the maximum flood is of magnitude 209.07 m^3/s in 2018. The mean annual flood μ equal to 132.10 m^3/s with a standard deviation $\sigma = 25.93$ m^3/s

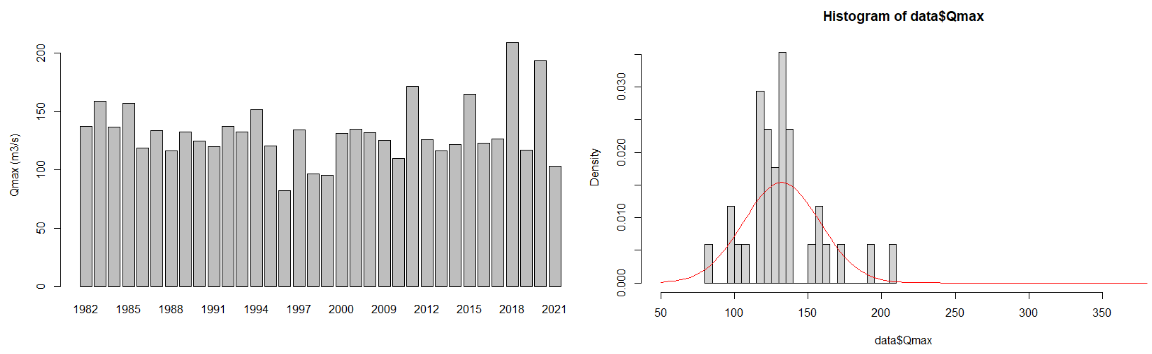


Figure 7. 1: Flood frequency analysis

i) Using probability distribution

Figure 7.2 shows a probability plot of flood values against return period T in years

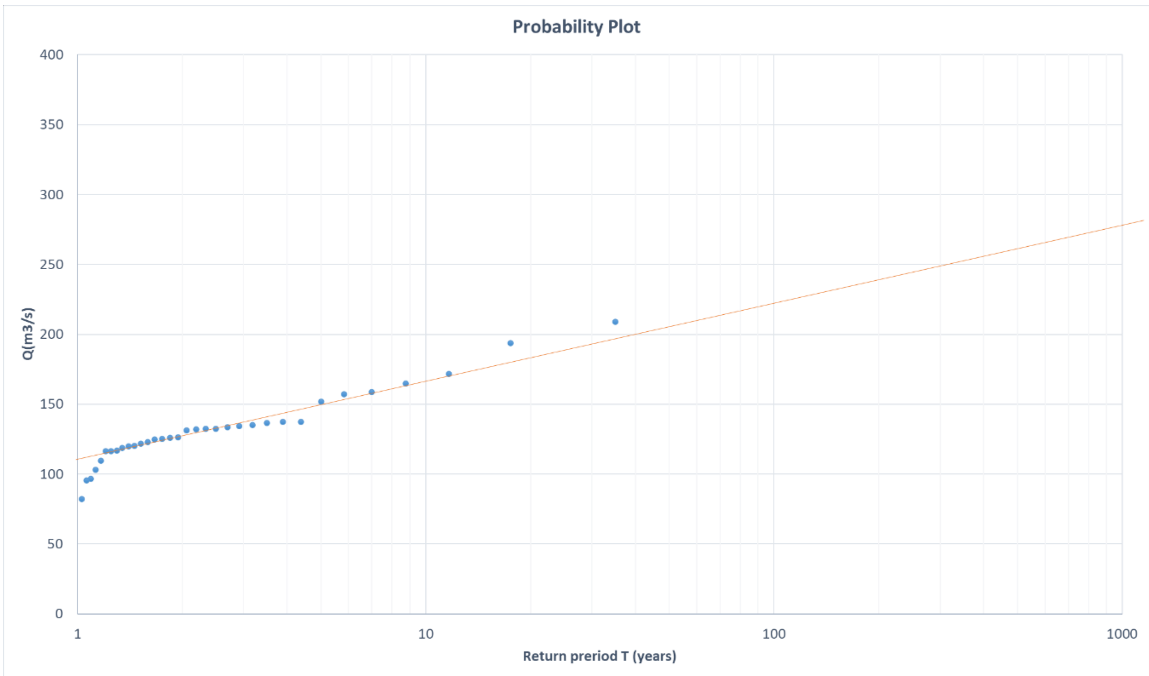


Figure 7. 2 Probability Plot

b) Using regional method

According to the regional curves (Figure 2.2), Stryn catchment lies with region 1 for both spring and autumn floods. Stryn has a catchment area of 478 km^2, Specific runoff Q_N= 60.5 $l/s.km^2$, Annual precipitation P_N=1353 (mm), length of catchment LF= 43.3km, and Effective lake percentage A_{se}= 4.91%. Equations in section 2.1.3 were used to compute the daily flood. Results from the analysis using the regional method are shown in Table 9

Table 9: Comparison of Flood estimates (m3/s) from historical data using different methods

Return period (years)	L-moments	Gumbel	Probability Plot	Regional method	
				Spring	**Autumn**
1000	249	260	270	619	669
200	222	227	234	496	535
50	197	199	202	454	490
5	151	148	148	413	446

The first three methods are relatively in agreement. The regional method however overestimates the flood values for both Spring and Autumn.

7.2 Flood frequency analysis from hydrological Model.

The ENKI model underestimates very high flood peaks. Figure 7.3 shows a comparison of the AMS for observed and simulated discharge in Strynsvatn.

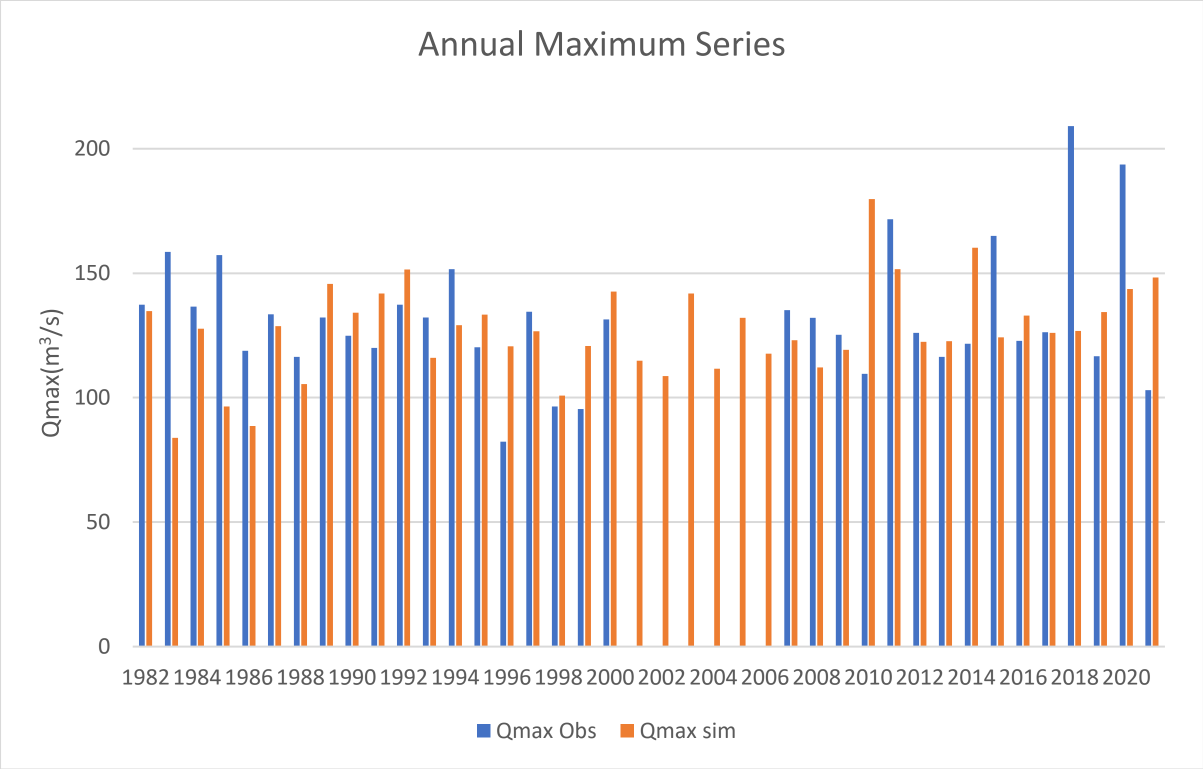


Figure 7. 3: Annual Maxima series for Observed and Simulated runoff

There is fairly good correspondence between observed and simulated peaks. However, there is poor performance for very high peaks (2018 and 2020). As the magnitude of the flood increase, the error between the observed and simulated runoff increases.

7.3 Discussion

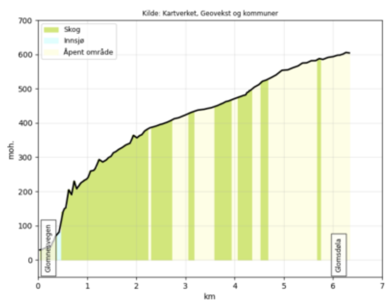
Different methods were used to determine the flood frequency and magnitude from historical data. L-moments, Gumbel distribution and Probability plot gave a fairly good agreement in the flood estimation. The regional method however overestimated the flood. However, it is acknowledged that equations used in the regional method can produce unrealistic values especially in large catchments and catchments with a high lake percentage (Wilson et al., 2011). The results from regional analysis were therefore discarded in further analysis.

From section 6, the performance is the model is very good except for very high peaks, therefore a reduction in extreme flood peaks is expected in the model.

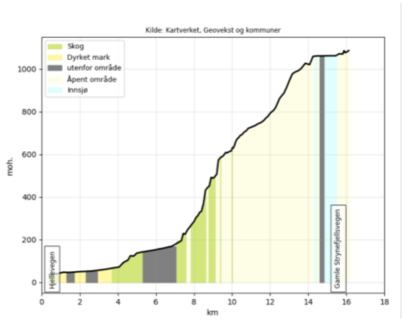
8. HYDROPOWER POTENTIAL AND DESIGN

The hydropower potential of the catchment is dependent on the available head and runoff in the catchment. There are four main tributaries flowing into Oppstrynsvatnet Lake, Hjelledøla, Erdalselva, Glomsdøla and Sunndøla- a tributary to Hjelledøla. The elevation profile and catchment attributed of the upstream tributaries are shown in Figure 8.1.

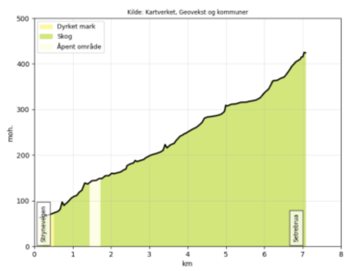
Glomsdøla



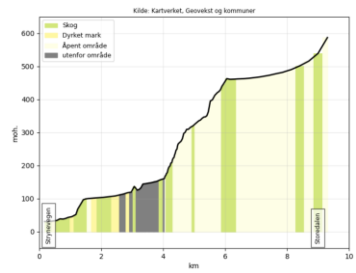
Hjelledøla



Sunndøla



Erdalselva



Parameter	**Stryn**	**Hjelledøla**	**Erdalselva**	**Glomsdøla**	**Sunndøla**
Catchment area (km^2)	478	236	80.5	39.5	66.5
Specific runoff Q_N (l/s)	60.5	66.4	65.3	62.2	76.6
Specific runoff Q_N (m^3/s)	28.92	15.67	5.26	2.46	5.09

Figure 8. 1: Elevation Profile and catchment characteristics of Upstream tributaries

The elevation profile of tributaries (Figure 8.1) shows a steep gradient hence availability of high head. With high head, the rivers have a high potential for hydropower production. The hydropower energy potential from the various tributaries was computed considering diverting water from different intakes. A trade-off between catchment area (available volume of water for energy generation) and loss in head was assessed.

8.1 Diversion Plan

The flood control and hydropower generation from flood diverted water should ensure minimal impact to the salmon in the river and reduce the effect of regulation in the downstream river course. To optimise hydropower production, flood reduction and minimize the effects of flow regulation , several intake locations were evaluated for diverting flood water from upstream of Stryn catchment. These included intake levels at 600 (D600), 400 (D400), 325 (D325), 225 (D225), 150 (D150), 88 (D88) m.a.s.l and the outlet of Oppstrynsvatnet (Dstrynvatn). The aim of the investigation was to maximise the hydropower production potential while assessing the impact on flow regulation and flood reduction.

The Q95 (flow exceeded 95% of the time) is all times maintained in the bypass section of the river course. Analysis of the runoff hydrograph of Stryn (Figure 5.2 chapter 5), shows peak flows occur between the months of May and September and therefore the largest inflow intake is between May and September.

8.2 Waterway (tunnels)

Due to the topography of the catchment (steep mountains), underground tunnels were considered the most feasible option for diverting water. Figure 8.2 shows proposed tunnel layouts for the different intake locations. The hydropower production assessment from the analysis was done basing on the quantity of flood water diverted.

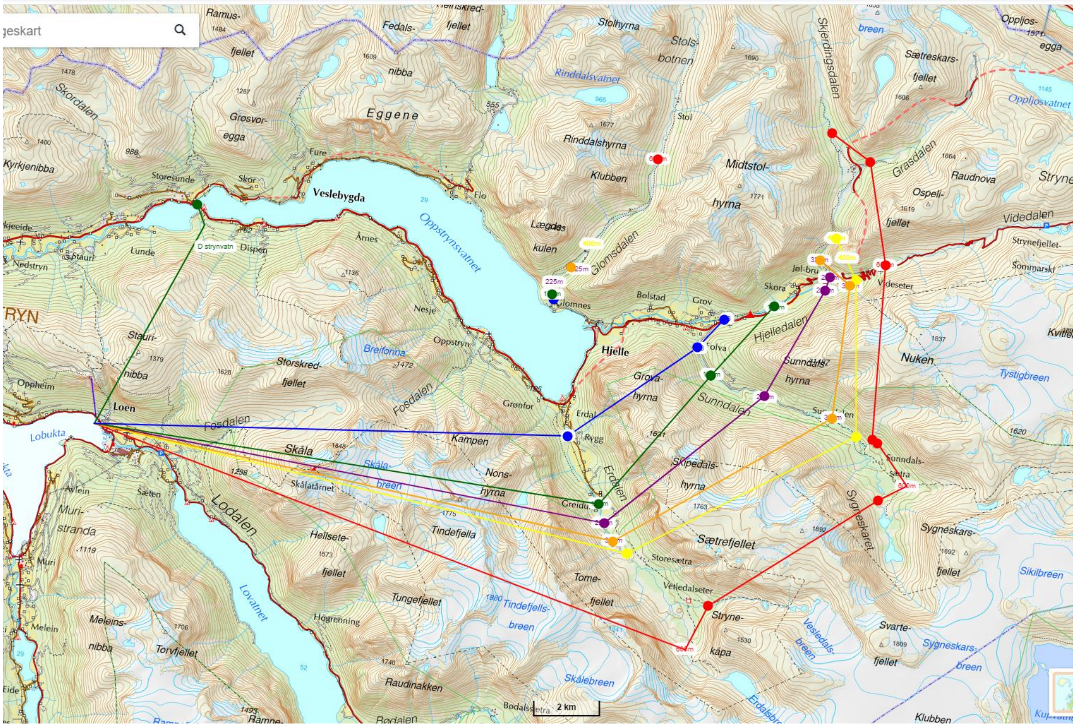


Figure 8. 2: Diversion plan

8.3 Power Production

To assess the hydropower potential of the different river courses, intake location at D600, D400, D325, D225, D150, D88 m.a.s.l and Dstrynvatn. The water is diverted through underground tunnels to a powerhouse at elevation of 5 m.a.s.l. Figure 8.3 shows average yearly production in GWh.

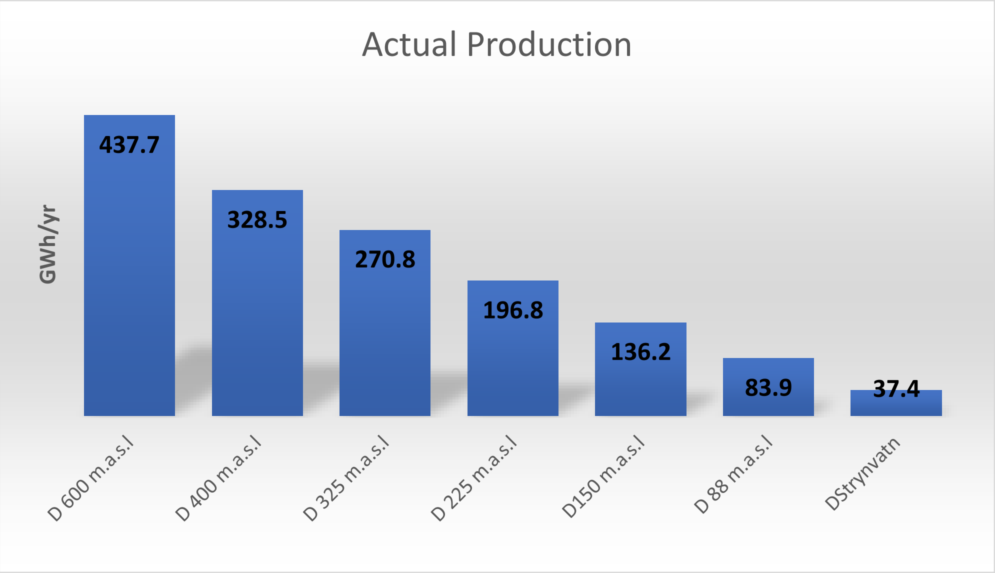


Figure 8. 3: Annual Energy Production

From the Figure 8.3, diversion at 600 m.a.s.l gives the highest annual energy production of 437.7 GWh/yr. This is attributed to overall high head compared to other intake location. Diverting water at outlet of Oppstrynsvatnet (Dstrynvatn) gives the lowest yearly production attributed to a low available head of 25 meters.

8.4 Cost Evaluation

Cost evaluation has been done in reference to Cost Base For Hydropower plants with generating capacity of more than 10,000kW (NVE, 2012). Detailed cost calculations are attached in appendix. Table 10 shows a summary of the total cost of construction for the different intakes.

Table 10: Summary of Total cost of Construction

Intake	Tunnel cost	Intake Cost	Road	Electro technical	Hydromechanical	Powerhouse	Total Cost(M.NOK)
D 600 m.a.s.l	838.4	22.3	2.4	109.0	81.0	13.1	1066.2
D 400 m.a.s.l	715.5	16.7	0.5	93.8	59.2	17.0	902.6

D 325 m.a.s.l	676.7	16.6	0.6	83.1	56.8	17.5	851.3
D 225 m.a.s.l	651.7	17.3	0.3	68.4	50.6	18.9	807.2
D150 m.a.s.l	609.8	16.5	0.4	53.9	45.8	20.5	746.9
D 88 m.a.s.l	530.1	17.3	0.2	39.8	75.5	23.0	685.8
DStrynsvatn (30)	232.3	12.0	0.0	24.2	29.0	14.3	311.7

Revenue

Cost evaluation is dependent on the revenue from energy sales and total investment cost (Construction and O&M). Price of energy has been obtained from historical day ahead prices from NordPool. A daily price series between 2016 to 2021 for region NO (Molde) has been used in the calculation. Figure 8.4 shows the average price fluctuations in the within the year.

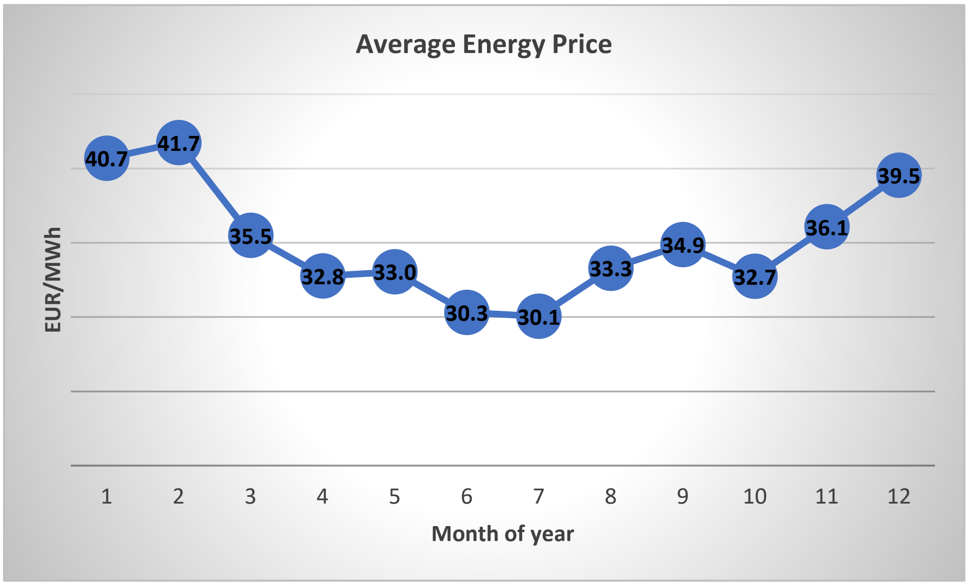


Figure 8. 4: Monthly variation of Energy prices in the year

The energy prices are high in winter during periods of reduced flows in the rivercourses and increased demand for heating. The energy prices lowers during spring and summer due to high volumes of water from snow melt and reduced demand for energy for heating. Prices vary yearly between years. Figure 8.5 shows average yearly energy price fluctiations for region Molde-NO.

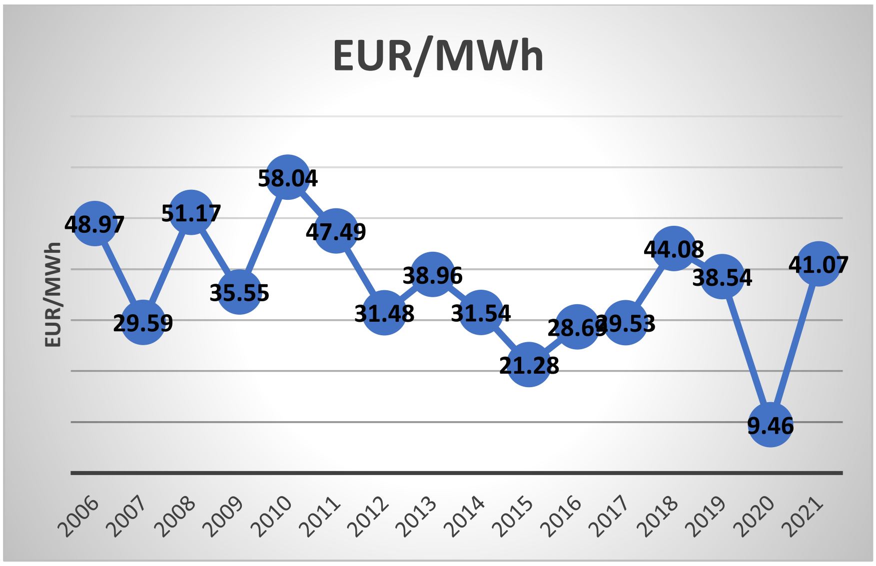


Figure 8. 5: Average yearly Price fluctuation

The average yearly Energy price is 36.59 EUR/MWh. However, 2020 shows exceptionally low price of 9.46 EUR/MWh.

Figure 8.6 shows the total cost of investment and the resulting Benefit Cost Ratio.

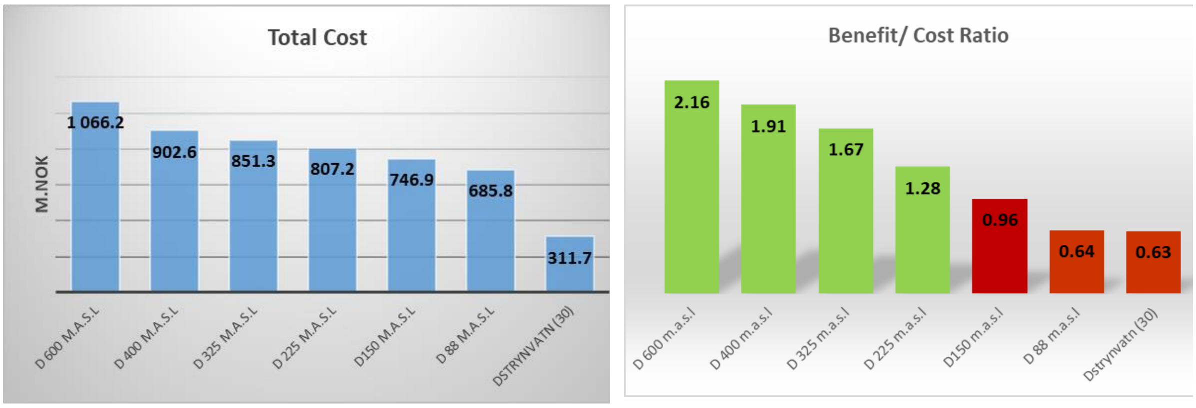


Figure 8. 6: Total investment Cost and Benefit/Cost Ratio

From the cost analysis, diverting water at intakes D600 and D400 m.a.s.l showed better performance in the Benefit Cost ratio. Alternatives D150, D88 and at DStrynvatn are not financially profitable for development.

8.5 Discussion

The steep elevation profiles of upstream tributaries of Oppstrynsvatnet shows high head hence high potential for hydropower. The location of the intake dictates the gross head and the catchment volume available for energy production. As you progress further downstream of the catchment, more water is available for generation. However, the loss in the available head results into a reduced energy production potential. Consequently, diverting water at intake 600 m.a.s.l showed the highest energy potential in comparison to diverting at downstream of Oppstrynsvatnet.

Due to the length of the tunnel system, tunnelling is expected cost the most in project development. The tunnelling costs have been estimated to carry 78.7% of the overall construction costs. Diverting water further upstream increased the length of the tunnel system, hence producing the highest cost. However, the overall high costs are compensated for by the net present values as a result of the revenue from the Energy sales (Figure 8.6). Costs saved due to flood reduction have not been included in the study. The expected Benefit/cost ratio of the project are therefore estimated to be higher than stated in this report.

9. EFFECT OF REGULATION ON NATURAL FLOW

9.1 Changes in the river flows

Regulation will create changes in the downstream river flow. The flood control and hydropower generation from flood diverted water should ensure minimal impact to the salmon in the river flow and reduce the effect of regulation in the downstream river course. The proposed hydropower production is to ensure that all times, the minimum flow (Q95) is maintained in the river. The amount of water diverted to intakes is dependent on the tunnel capacity. Figure 9.1 shows the changes to daily average discharge considering hydropower production (regulation) at different intakes.

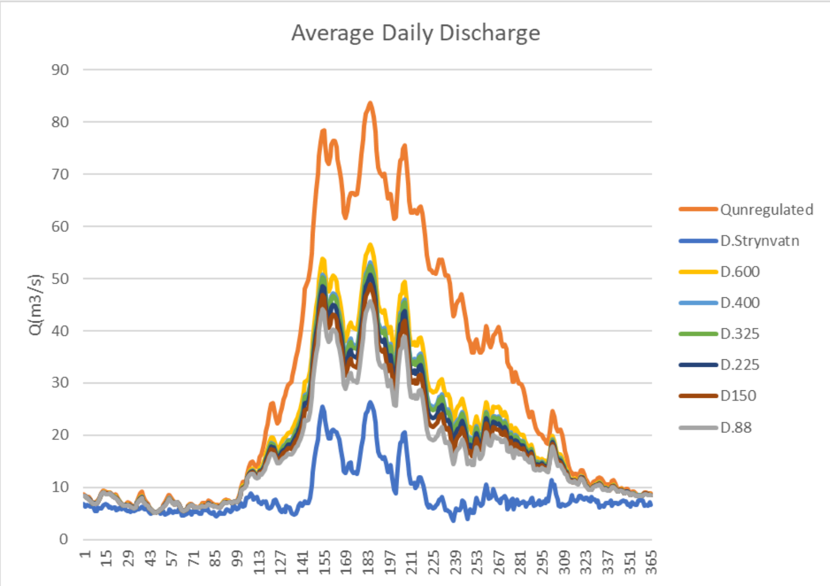


Figure 9. 1: Changes in average daily flows in Stryn due to upstream regulation

As seen in the Figure 9.1, there is a small change in daily average flows in Stryn as a result of diversion of water at intake levels D600, D400, D325, D225, D150, D88 m.a.sl. and Dstrynvatn The maximum impact of flow reduction due to diversion at the outlet of Oppstrynsvatnet (Dstynvatn).

9.2 Changes in the weekly average

Changes in the lowest weekly average are used to assess the likelihood impact of regulation on the salmon population. Diversion of water is done from upstream tributaries flowing into Oppstrynsvatnet lake. Expected changes in minimum and maximum weekly averages in the different tributaries before and after regulation at different intake locations are shown in Figure 9.2.

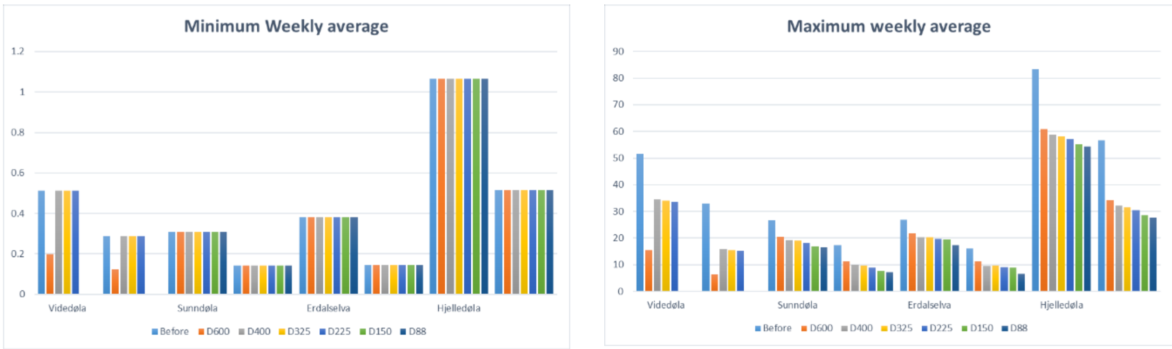


Figure 9. 2: Changes in weekly averages

The maximum impact to lowest weekly average is the upstream tributaries of Videdøla when water is diverted at intake D600 m.a.s.l. As the rivers flows downstream, inflows from subsequently catchments dampen the river flow hence reduce the impact of reduction.

Changes in the lowest weekly average as a result of diversion of flow upstream Oppstrynsvatnet lake in Stryn river are evaluated. Figure 9.3 shows changes in the lowest weekly averages in Stryn in summer and winter.

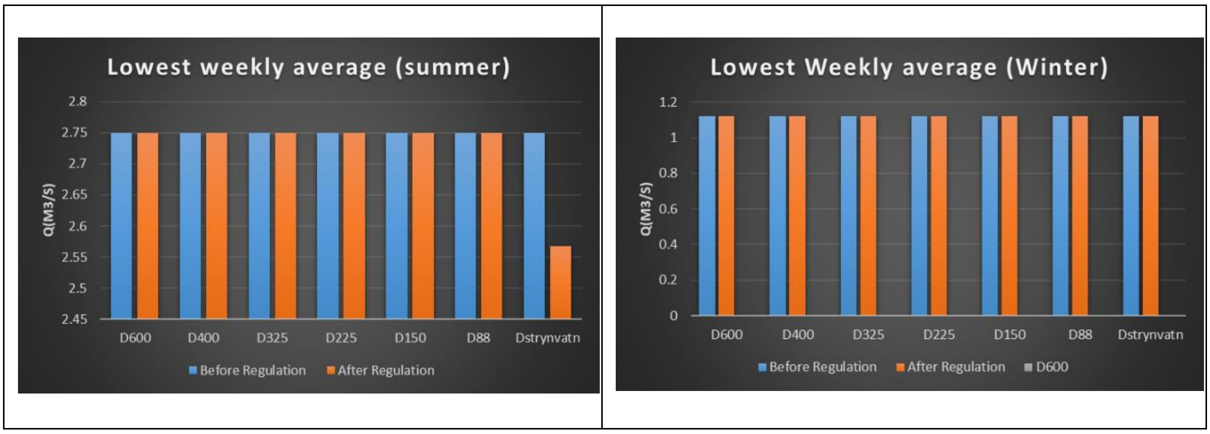


Figure 9. 3: Changes in lowest weekly average considering flow diversion at different intakes

Regulation from intakes 600, 400, 325, 225, 150 and 88 m.a.s.l will have no effect on lowest weekly averages in Stryn river in both summer and winter. However, diversion at outlet of Oppstrynsvatnet (Dstrynvatn) causes a 6.6% decrease in the lowest weekly average in summer. Comparison of the results with guidelines on flow regulation in Salmon rivers in From Table 7, section 3.5 indicates no likelihood bottleneck to the population of salmon as a result of changes in lowest weekly average.

As seen in Figure 9.3, maintaining Q95 in river section ensures that the lowest weekly average before and after regulation remain the unchanged in Stryn.

Changes to the highest weekly average in Stryn.

The effect of regulation has been analysed on the highest weekly average. With flow regulation at intake 600 m.a.s.l, there is 18.6% reduction in the highest weekly average in summer and 23.7% reduction in the winter flow in Stryn as shown in Figure 9.4

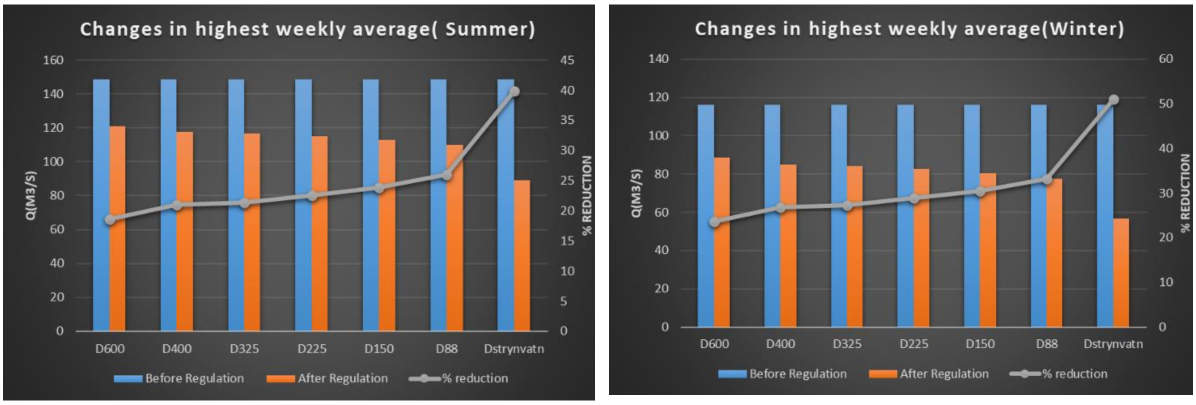


Figure 9. 4: Changes in the highest weekly average

The highest impact to flow is due to regulation at the outlet of Oppstrynsvatnet lake showing a 39.9% reduction and 51% reduction in the highest weekly average in summer and winter flows, respectively.

9.3 Changes in the flood values

Using annual maxima series, the flood values after regulation at different intakes were evaluated. The tunnels and intakes have a fixed capacity, therefore flow exceeding the design capacity is added to Q95 downstream of the river. Figure 9.5 shows changes in a flood of return period 5 years given regulation from the various intakes.

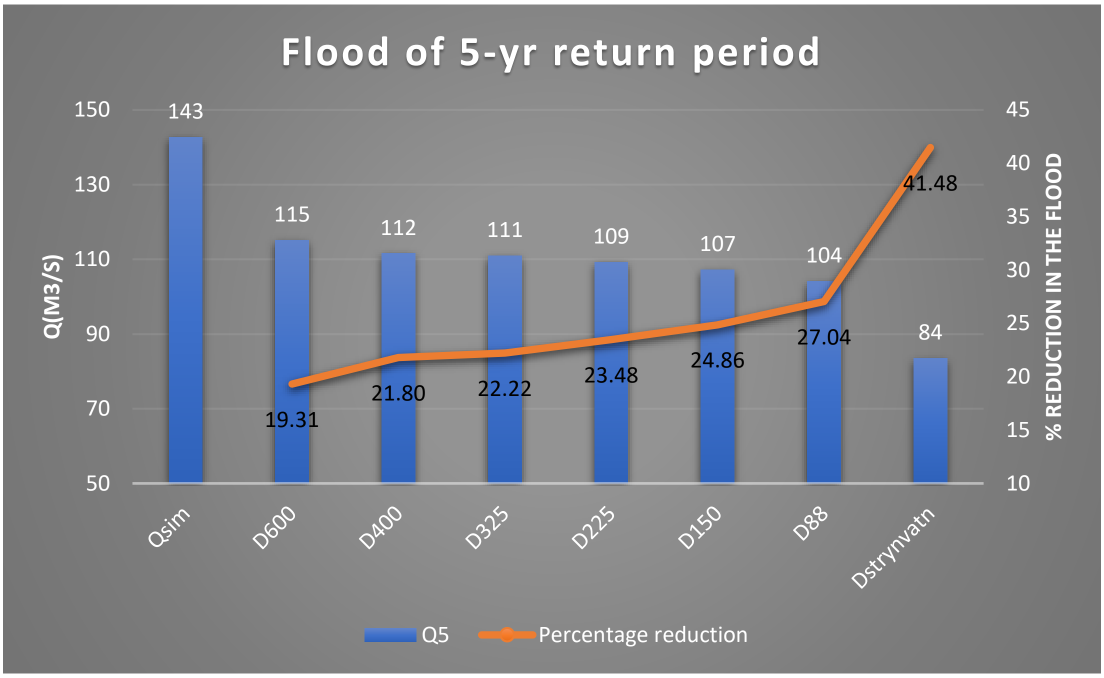


Figure 9. 5: Changes in 5-year return flood due to regulation

By diverting water at 600 m.a.s.l, the 5-year flood is reduced by 19.31%. The highest impact on flood reduction is observed by diverting water at the outlet of Oppstrynsvatnet giving a reduction of 41.48%.

9.4 Optimum alternative

As seen from the diversion scenarios, diversion D600 at elevation of 600 m.a.s.l gives the most optimum solution for hydropower production and highest benefit-cost ratio (Section 8.3 and 8.4). Diverting water at 600 m.a.s.l. as well creates minimum impact due flow regulation on changes in the lowest weekly averages.

9.4.1 Hydropower production

Figure 9.6 shows the available flow for energy production and corresponding energy prices with a tunnel capacity of 26.3m^3/s (twice the average discharge).

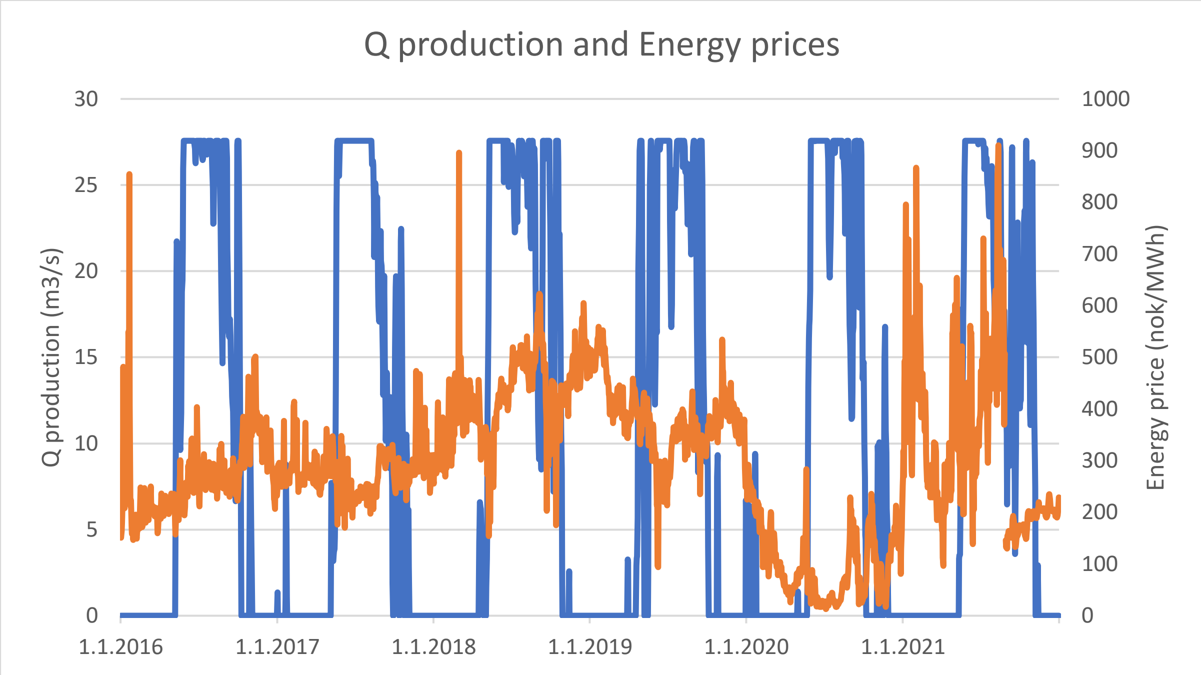


Figure 9. 6: Available Production flow and Energy Prices

Energy production in kWh/day and corresponding revenue form energy sales is shown in the Figure 9.7

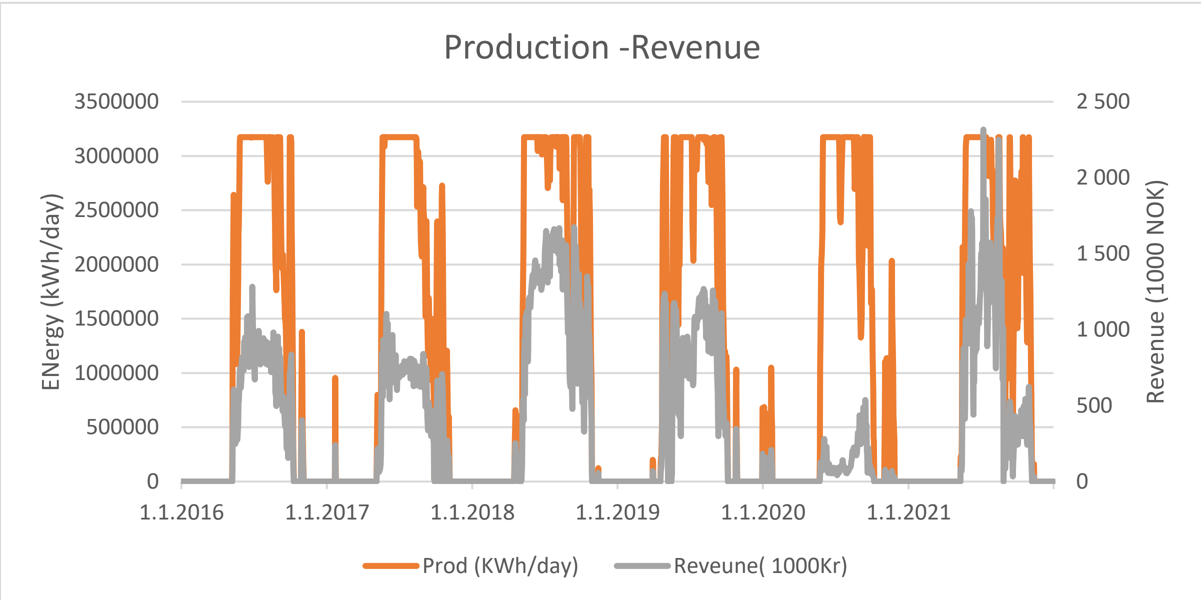


Figure 9. 7: Energy Production and Revenue

9.4.2 Changes in Hydrology due to regulation

Flow changes in the upstream tributaries are assessed. Figure 9.8 shows discharge before and after regulation, in the downstream section of the upstream river tributaries.

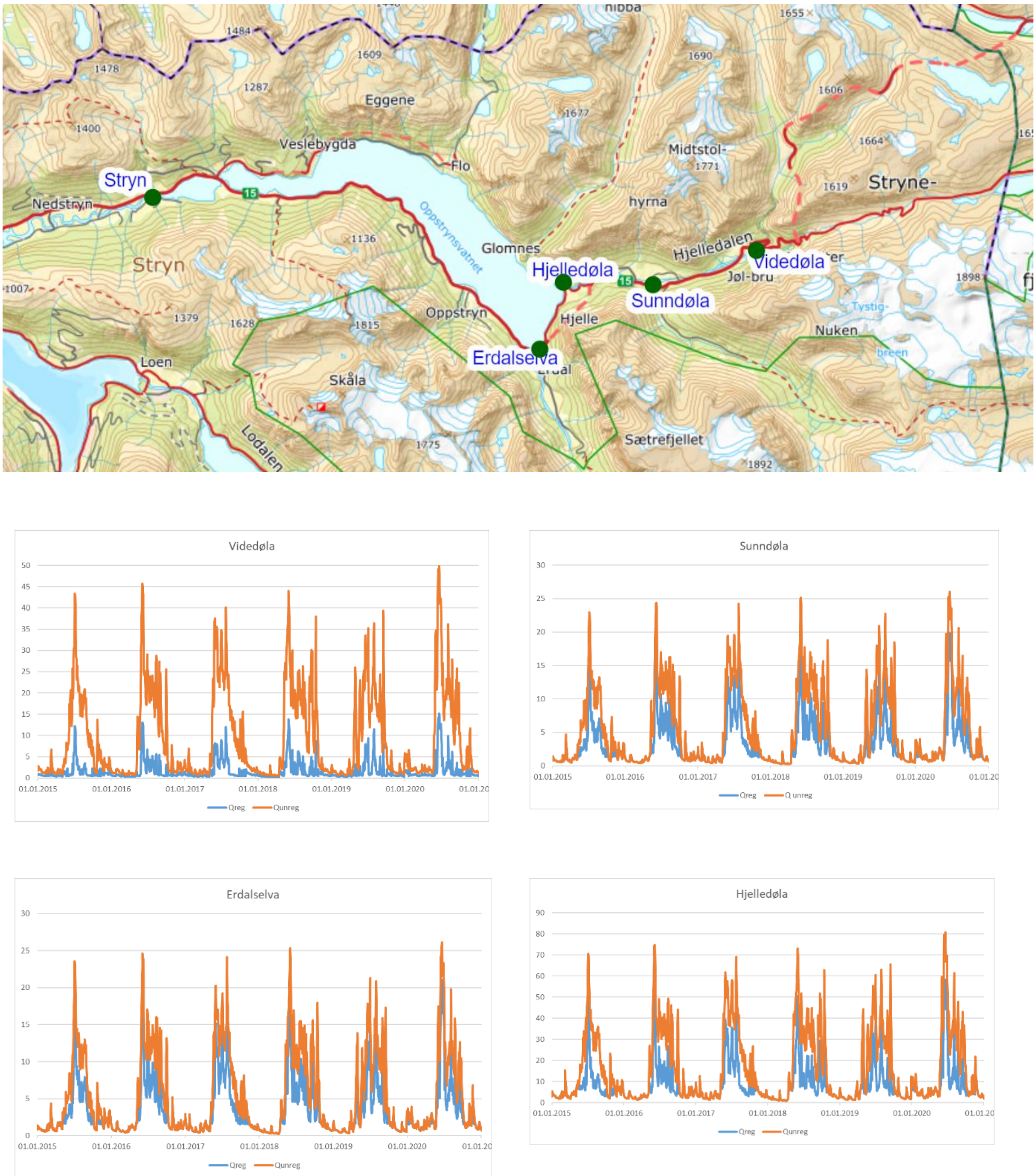
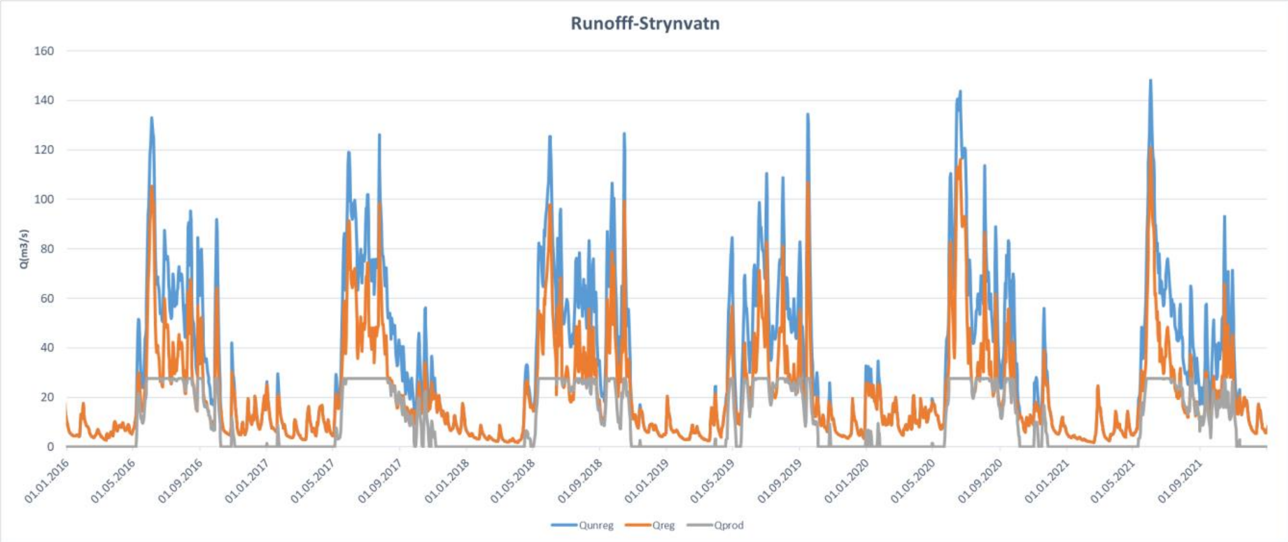


Figure 9. 8: Changes in river flows due to regulation

Changes in the river flows are most observed upstream of Videdøla. As the river flow downstream, changes in hydrology are damped due to inflow from small minor tributaries.

Changes in the runoff in Stryn

Changes in Stryn river discharge as result of regulation by diverting flow at intake D600 are shown in Figure 9.9. The average changes in the daily flows Stryn is shown in the graph below.



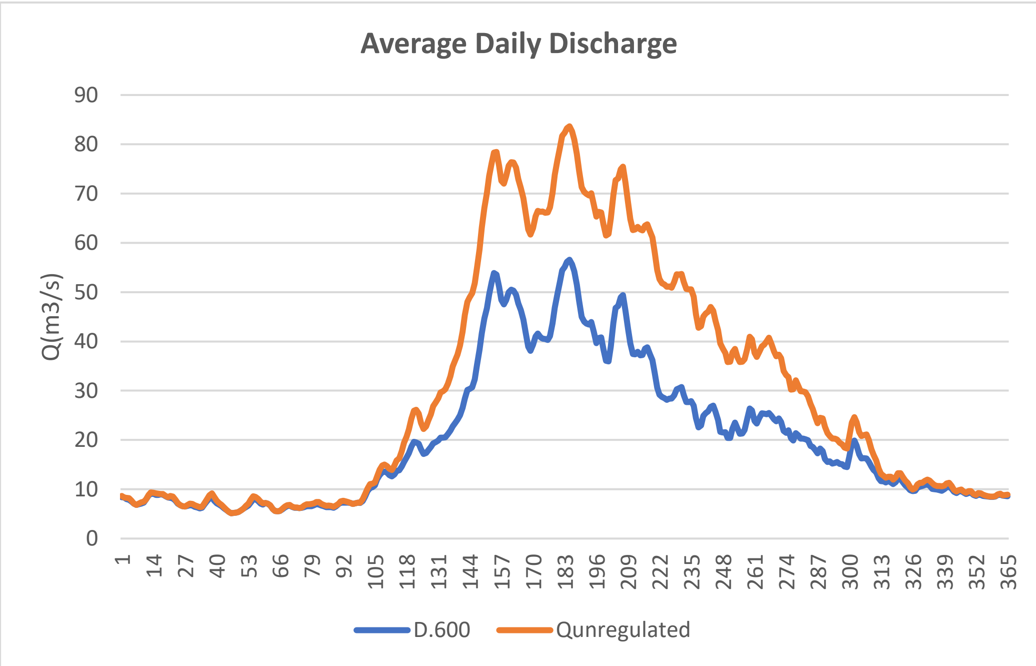


Figure 9. 9: Changes in river flows in Stryn

Regulation has no effect on the minimum flow but reduces the peak flows during spring and summer.

Changes in AMS and flood levels

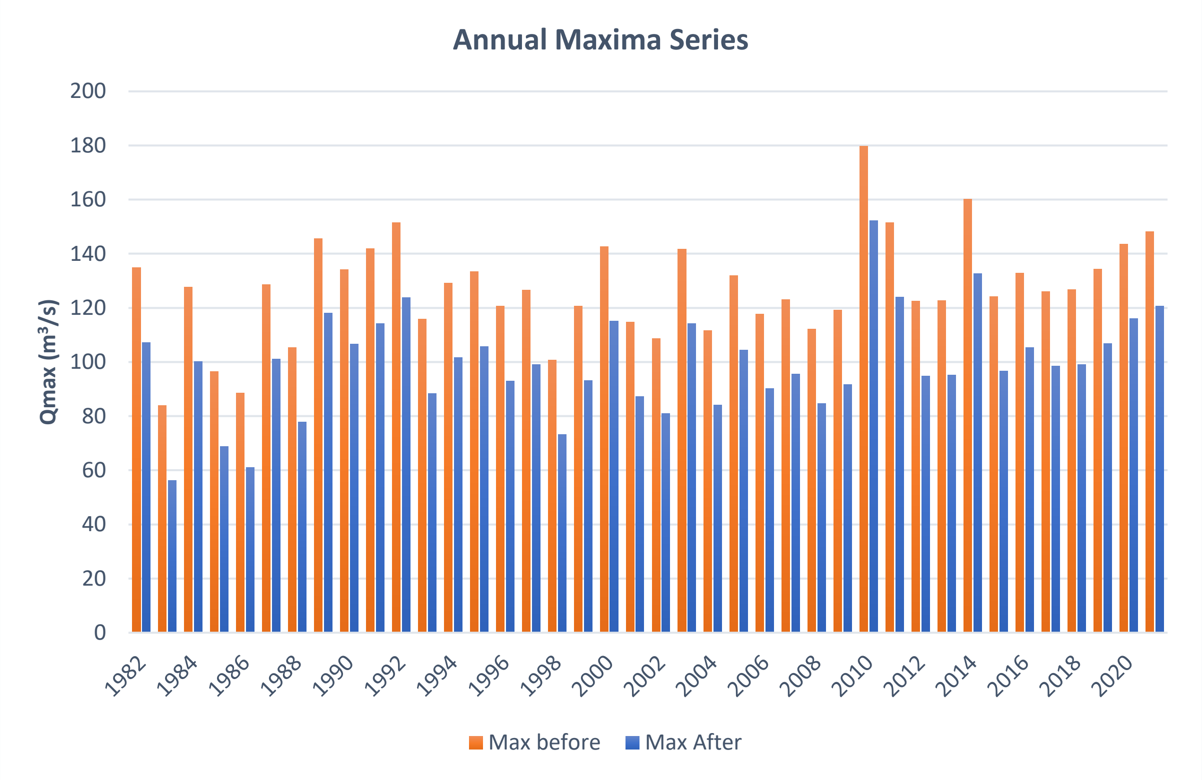
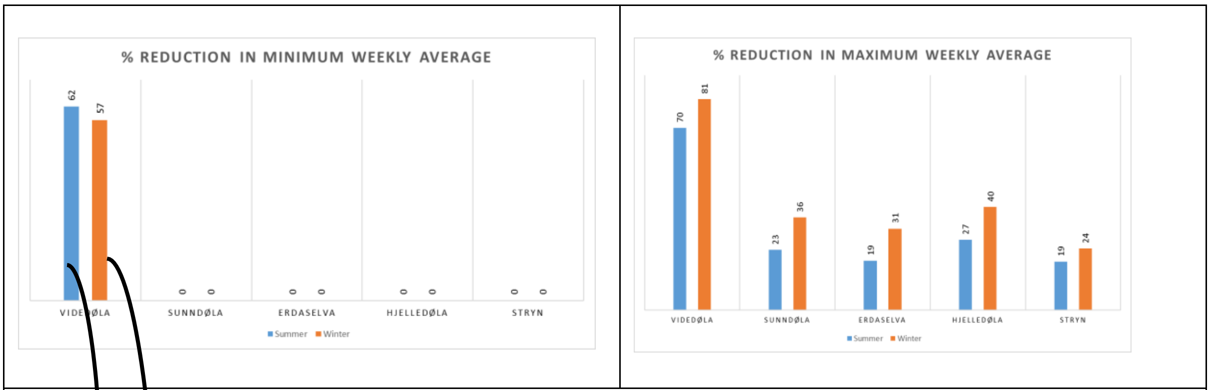


Figure 9. 10: Changes in Annual flood as a result of regulation

Changes in weekly average runoff

Figure 9.11 shows analysis of changes in the weekly average runoff at different tributaries upstream due to flow regulation at intake location 600 m.a.s.l. Changes in the lowest weekly average are assessed just downstream of the intake in Videdøla and further downstream of the river course. Effect of regulation are assessed against guidelines on the bottleneck to impact on population on Salmon section 2.3



Season	Change in lowest weekly average	Impact on population
Summer	Increase	Positive
	Reduction < 20%	No bottleneck
	Reduction 20-40%	Weak bottleneck
	Reduction 41-60%	Moderate bottleneck
	Reduction < 60%	Severe bottleneck
Winter	Increase	Positive
	Reduction < 10%	No bottleneck
	Reduction 10-30%	Weak bottleneck
	Reduction 31-50%	Moderate bottleneck
	Reduction < 50%	Severe bottleneck

Figure 9. 11: Changes in lowest weekly average and indicators on Impact of population

Table: Impact of Flow alteration on Population: Source (Table 7: Forseth & Harby, 2014)

As seen from the Figure 9.11, regulation will cause severe reduction in the lowest weekly average flow upstream of Videdøla. However, there is no change to the lowest weekly averages in downstream river sections of Sunndøla, Erdalselva and Hjelledøla of Stryn catchment. This can be attributed to flow dampening due to increased inflow into the river course from the downstream catchments.

9.4.3 Assessing increased tunnel Capacity

From section 8.3 and 8.4, diverting water at intake locations D600 m.a.s.l. gives the highest energy production of 437.7 GWh/year respectively, and a resulting benefit to cost ratio of 2.16. However, the alternative showed an average flood reduction of 22%.

To increase the flood regulation of the intakes, the tunnel capacities is increased to accommodate a discharge capacity exceeded 10% of the time. The resulting energy production, cost analysis and benefit-cost ratio were recalculated. Table 11 shows changes caused due the new tunnel capacity.

Table 11: Changes caused by increase tunnel capacity (D600)

	Capacity 1	**Capacity 2**	**% Change**	Trend
Tunnel capacity Q_{max} (m^3/s)	26.3	38.4	46.0	↑
Annual Prod (GWh/h)	437.7	506.8	15.8	↑
Annual revenue (MNOK)	125.8	144.9	15.2	↑
PV revenue (50 years)	2416.1	1999.3	17.3	↓
Total investment cost (M.NOK)	1120.6	1241.2	10.8	↑
B/C ratio	2.2	1.6	25.3	↓
Flood reduction (%)	22.0	31.0	40.9	↑

9.5 Discussion

From the results of the study, the most effective solution of flood control is diversion at the outlet of Oppstrynsvatnet to the Nordfjord (alternative DStrynsvatn). By controlling outflow directly from the lake, flow regulation effects in Stryn pose a significant impact on the river flows in Stryn and major impact on the salmon population in the river. Assessment of hydropower production from the alternative resulted into the least energy production. This primarily attributed to available low head between the intake (30 m.a.s.l) and the powerhouse (5 m.a.s.l)..

The best alternative for hydropower production is divert water further upstream at D600. The available head gives the most energy production potential and consequently the highest benefit-cost ratio. Analysis of diverting flood water at the other location showed a decrease in the energy potential and benefit-cost ratio.

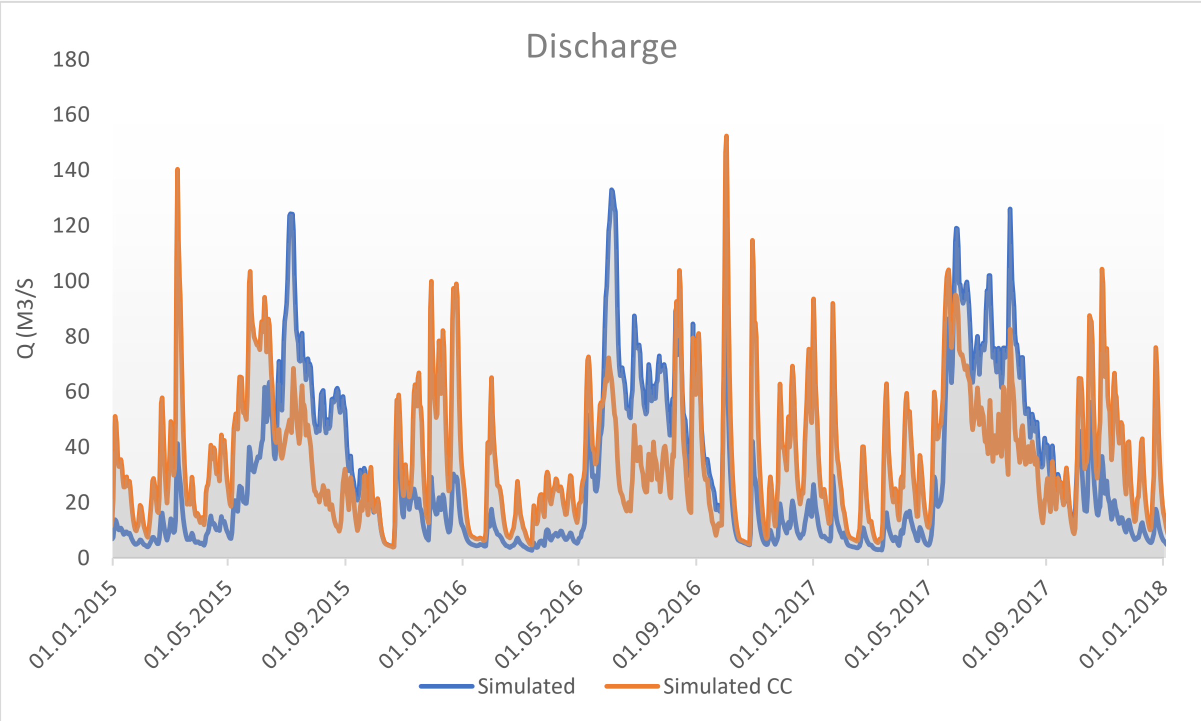
The downside of diverting water at D600 is that it will have the minimal impact of flood reduction. An investigated alternative is to increase the tunnel size. By doing so, more water is diverted hence an increase in potential flood reduction. Similarly, the tunnels have a bigger capacity to divert water hence increased potential for energy production. The downside is that the larger the tunnel, the higher the cost of construction thereby reducing the benefit-cost ratio.

10. CHANGES DUE TO CLIMATE CHANGE

Stryn catchment lies with Sogn and Fjordane. Climate profile of Sogn and Fjordane indicates a 10% increase in precipitation in winter and spring, and 15% increase in autumn and summer and an average temperature increase 4.0° C in autumn, winter and spring, and increase of 3.5° C in summer (Norsk Klimaservicesenter, 2017). The input timeseries for precipitation and temperature was consequently adjusted and the calibrated ENKI model simulated to model the runoff response. Changes in hydrology, hydropower production and flood magnitude were analysed with the results from the model.

10.1 Changes in Hydrology

Figure 10.1 shows changes in the runoff due to climate change and daily average flows in Stryn.



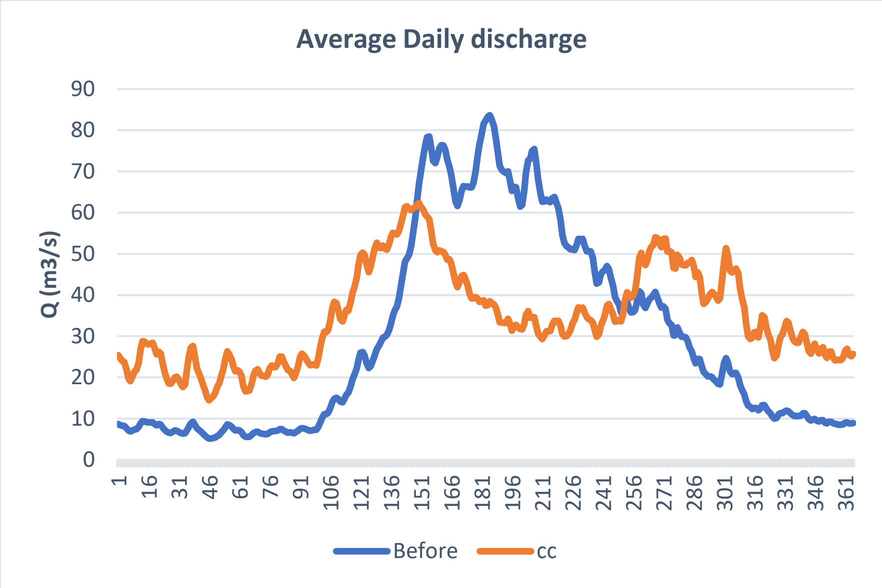


Figure 10. 1: Changes in discharge in Stryn due to climate change.

As seen in Figures 10.1, there is a change in seasonal distribution of runoff. There is an increased winter and spring flows and reduced summer flows in Stryn. The flood peak in summer is reduced and flood peak occurs in earlier spring.

10.2 Changes in hydropower production

Increase in precipitation will lead to more runoff hence more water will be available for hydropower production. Changes in runoff were evaluated against the tunnel capacities for diverting water at intake 600 m.a.s.l. The changes in the potential energy production were analysed. Table 11 shows changes in the energy production given the two proposed tunnel capacities (refer to section 9.4.3).

Table 12: Changes in hydropower production due to Climate change

	Tunnel capacity 1		**Tunnel Capacity 2**	
	Before	**Due to CC**	**Before**	**Due to CC**
GWh/yr	427.09	513.04	504.21	546.78
Percentage increase	20.1		8.4	

The increase in runoff will increase the annual energy production for tunnel capacity 1 by 20.1% and tunnel capacity 2 by 8.4% . The limitation to hydropower production is mainly dependent on the tunnel sizes. Comparison of daily production for two years is shown in the Figure 10.2.

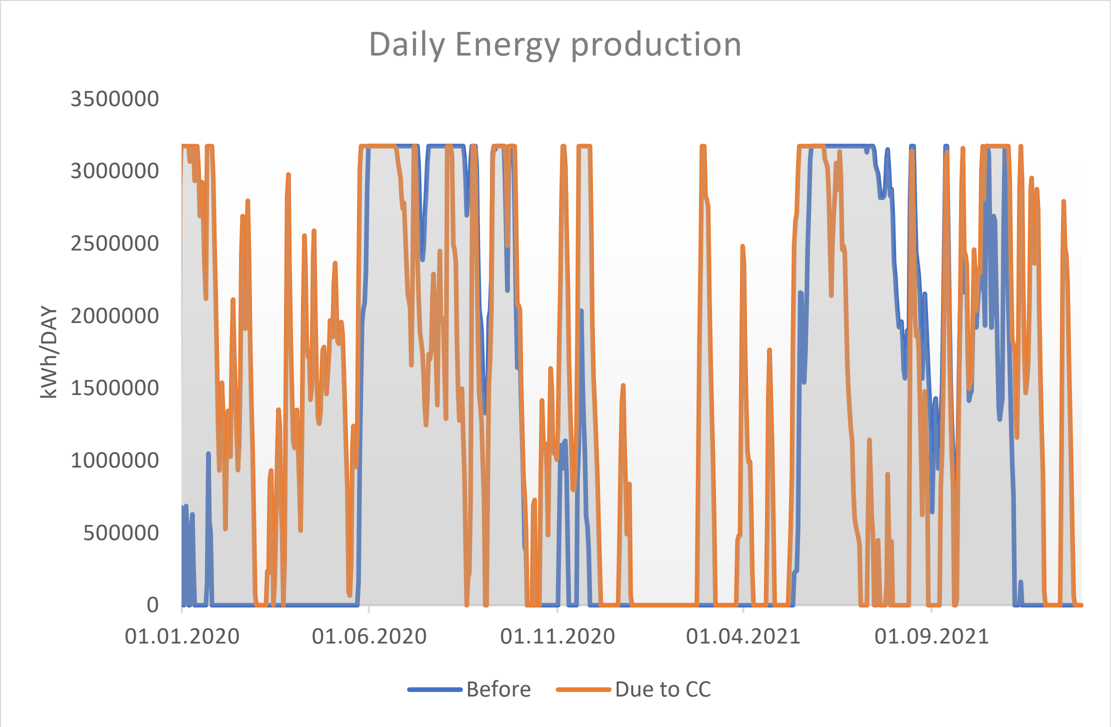


Figure 10. 2: Changes in Hydropower production as result of climate change

There is an increase in the energy production during winter and a decrease in the summer period. This is attributed to the increased runoff in winter and reduced runoff in summer due to a lower runoff from snowmelt as a result of reduced snow accumulation.

10.3 Changes in Expected flood magnitude

Figure 10.3 shows changes in annual maximum series for 39 simulated years.

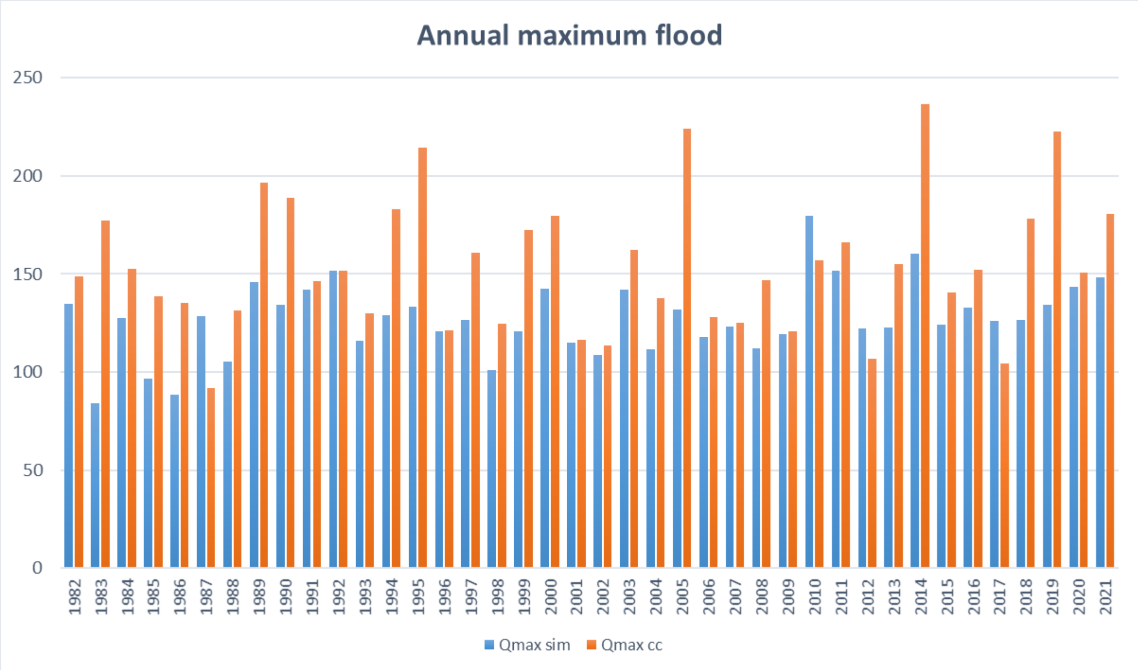


Figure 10. 3: Changes in annual flood due to climate change

Table 13: Changes in flood due to climate change

Flood	Mean flood (m^3/s)	Q200 (m^3/s)
Qobs	132	227
Qsim	127	197
Q sim CC	154	280

There is general increase in the maximum annual flood. The maximum simulated flood peak due to climate change effects is 235.5 m^3/s. The estimated Q200 flood is 280 m^3/s which is higher than the 260 m^3/s reported by NGI, (2018) considering a climate surcharge of 20%.

The tunnel capacities were evaluated against the expected flood levels and potential flood reduction evaluated . Flow regulation with tunnel capacity 1 reduces the flood peaks by 18% while capacity 2 reduces the flood peaks by 24.6%.

10.4 Discussion

There is an increase in runoff in winter and early spring as result of changes caused by climate change. This is attributed to increase in air temperatures. As the temperature increases, more precipitation falls as rain creating direct runoff hence an increase in the winter flows.. As more precipitation falls as rain, there is less snow accumulation during winter. Consequently, the reduced snow accumulation in winter results into reduced snowmelt during spring and summer hence low flood peak as result of the melt. The flood peak also occurs much earlier due to increase in the temperature which heats and melts the snowpack earlier.

The high peak runoff in late spring and summer experienced will be reduced due to reduced snow accumulation and consequently reduced snow melt in spring and summer. The runoff also indicates that floods will be experienced in late winter and early spring as opposed to the summer floods. The changes in the hydrology are in agreement with results from study by (Saelthun et al., 1990).

Climate change therefore shows an average increase of 22.6% in the mean yearly flood. This is agreement with the projected percentages changes in mean annual flood by Lawrence & Hisdal, (2011). According to a study by Lawrence & Hisdal, (2011), Stryn lies within a region of projected change in the mean annual flood of between 21-30% (Figure 2.3). With the increased discharges in the river, there is a reduction in flood reduction by proposed bypass tunnels.

11. CONCULSION AND RECOMMENDATIONS

The main objective of the research is to evaluate the feasibility use of hydropower production as means of flood regulation in Stryn - a national salmon river.

Use of distributed model provides a clearer understanding of the spatial catchment responses. Catchment data, such as land use, vegetation and forest cover, topography affect runoff generation process can be easily modelled in distributed model. However more computer power is required to process vast number of details and information.

Upstream tributaries in Stryn catchment have a steep gradient hence high potential for energy production. Flow diversion at intake 600 m.a.s.l showed the highest energy potential and most economically profitable option. However, due to the reduced catchment area from upstream intakes, the average flood reduction potential is reduced. Increase in tunnel capacities can increase flood reduction potential at an added cost.

By maintaining Q95 in bypass section of rivers, the effect of reduction in the lowest weekly averages is negligible in Stryn. This is mainly attributed to dampening effects of downstream catchment flowing into the bypassed section. From the study, a trade-off between hydropower production, flood reduction and effects on the regulation of river flows should be optimised.

Climate change will have a positive impact on the hydropower production with increased precipitation with increased runoff especially during winter. However, an increase in flood is expected in Stryn.

It is beyond the scope of study to assess the effect of regulation on physical changes in the river due to regulation. Such changes include changes in water covered areas, water temperatures and water velocity which affect the habitant conditions can result into bottlenecks on the population of salmon. A more detailed analysis of the above changes on the effect of salmon population is recommended for further studies.

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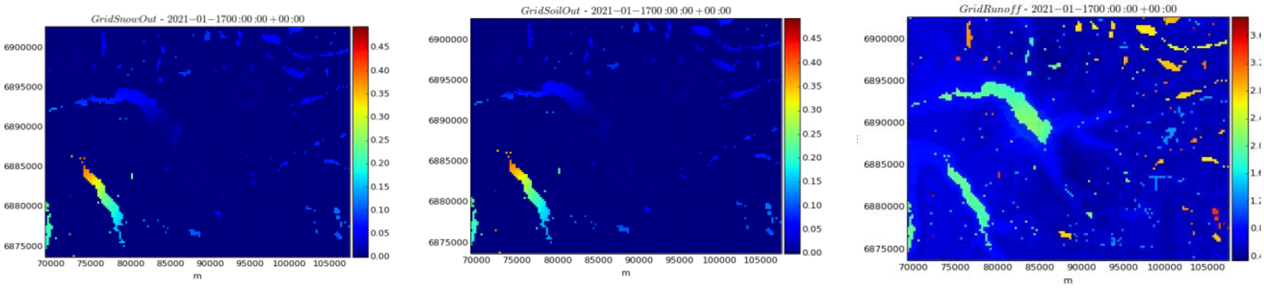
APPENDICES

ENKI Model responses

Month **Grid SnowOut** **Grid Soilout** **Grid Runoff**

Jan



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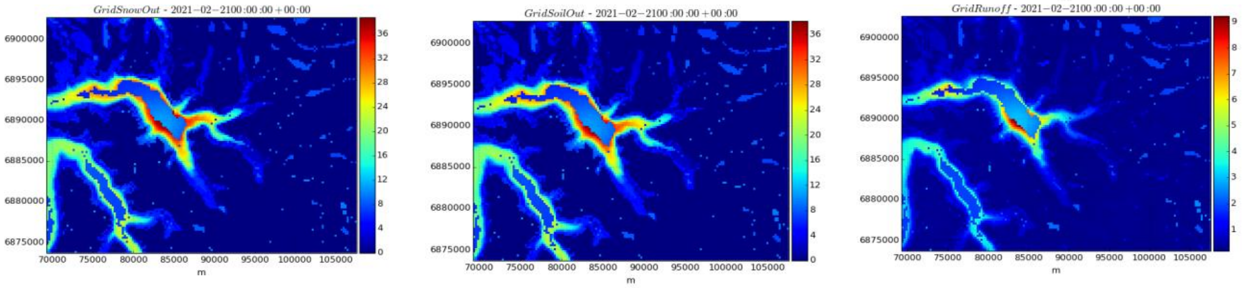

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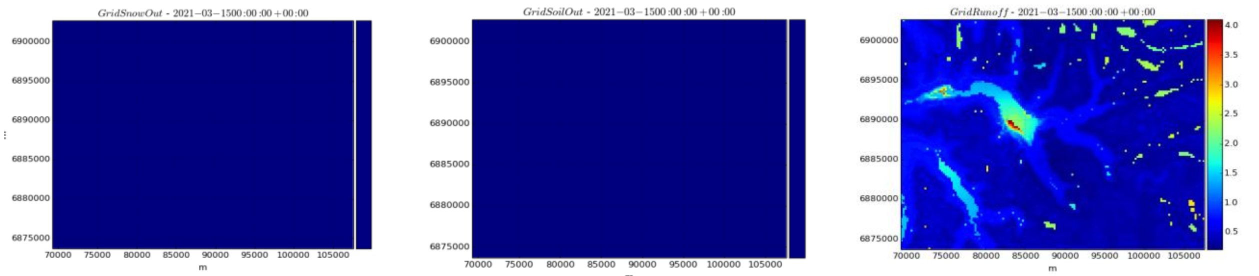

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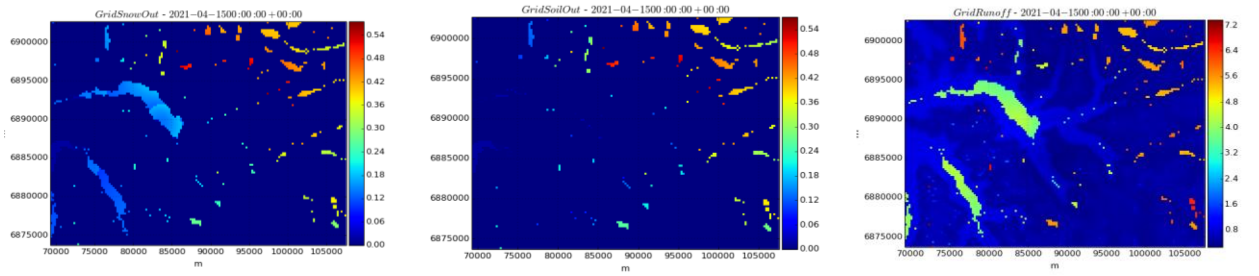

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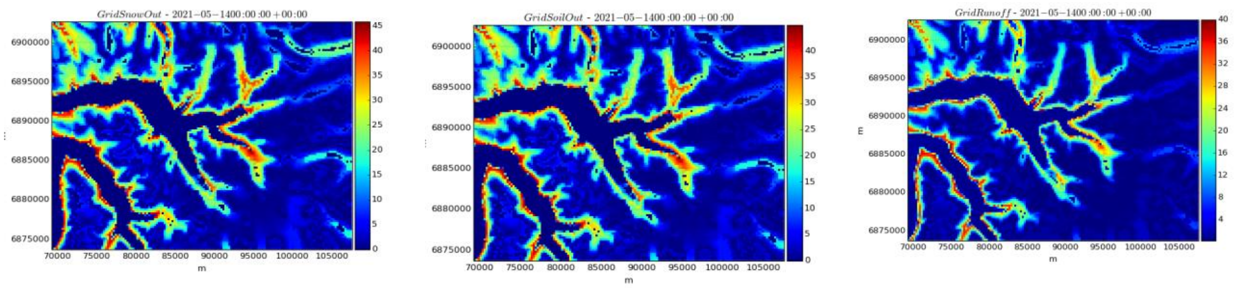
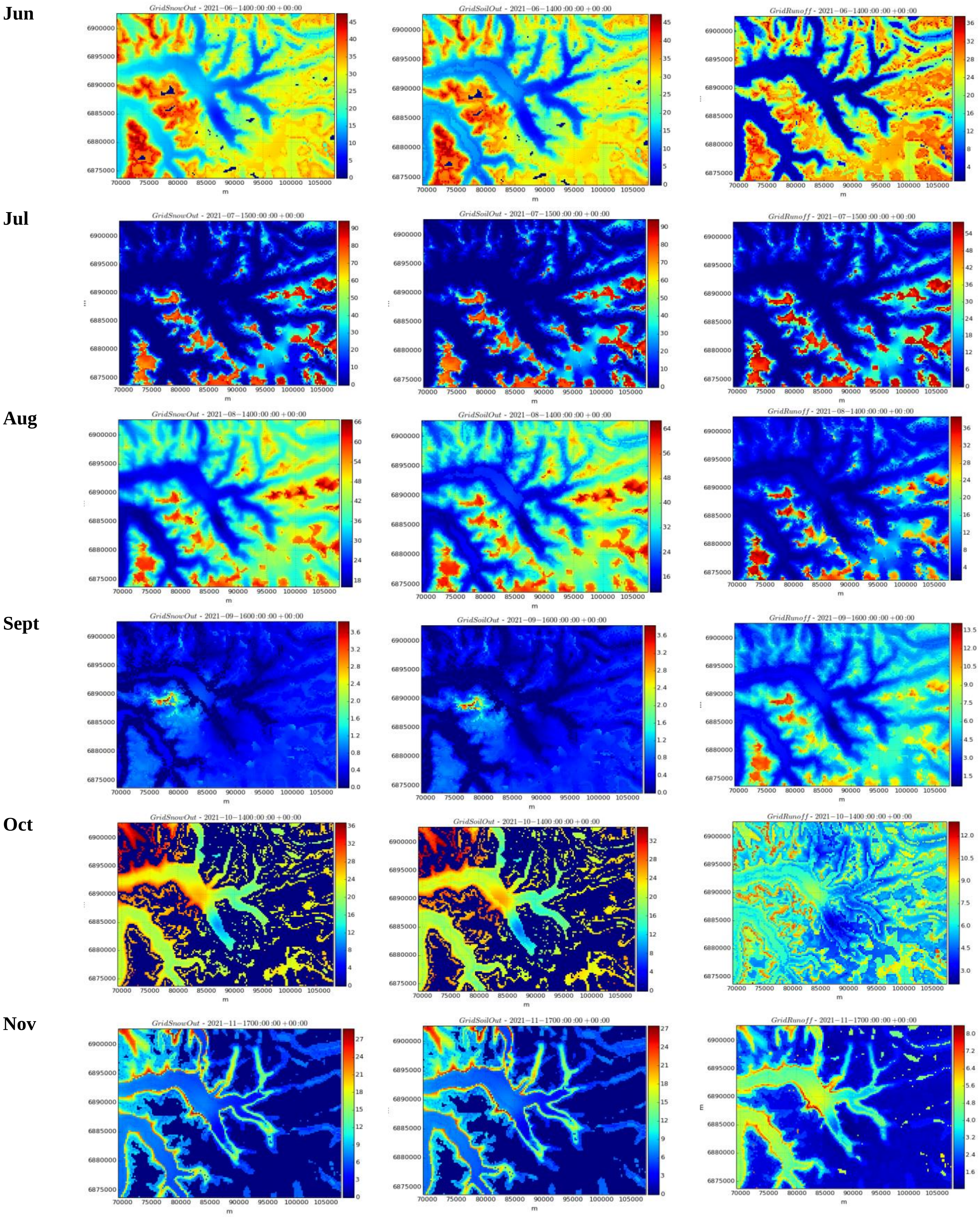
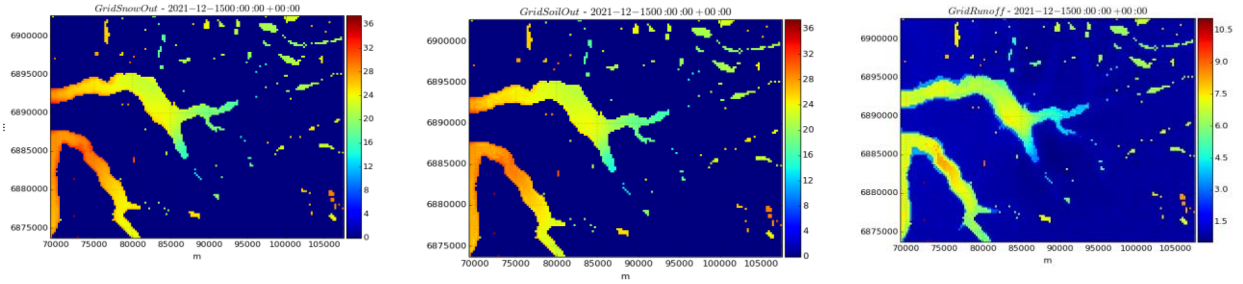



Jun
GridSnowOut - 2021−06−1400:00:00+00:00
GridSoilOut - 2021−06−1400:00:00+00:00
GridRunoff - 2021−06−1400:00:00+00:00
Jul
GridSnowOut - 2021−07−1500:00:00+00:00
GridSoilOut - 2021−07−1500:00:00+00:00
GridRunoff - 2021−07−1500:00:00+00:00
Aug
GridSnowOut - 2021−08−1400:00:00+00:00
GridSoilOut - 2021−08−1400:00:00+00:00
GridRunoff - 2021−08−1400:00:00+00:00
Sept
GridSnowOut - 2021−09−1600:00:00+00:00
GridSoilOut - 2021−09−1600:00:00+00:00
GridRunoff - 2021−09−1600:00:00+00:00
Oct
GridSnowOut - 2021−10−1400:00:00+00:00
GridSoilOut - 2021−10−1400:00:00+00:00
GridRunoff - 2021−10−1400:00:00+00:00
Nov
GridSnowOut - 2021−11−1700:00:00+00:00
GridSoilOut - 2021−11−1700:00:00+00:00
GridRunoff - 2021−11−1700:00:00+00:00
m

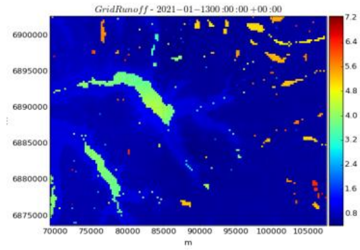
B

Dec



Runoff in Stryn (2021)

Jan



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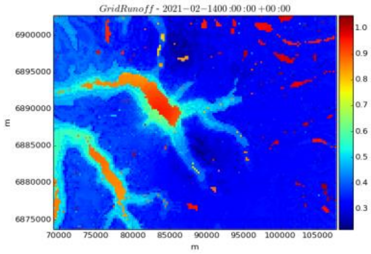

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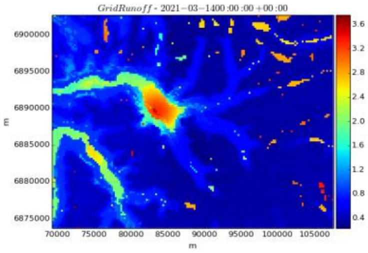

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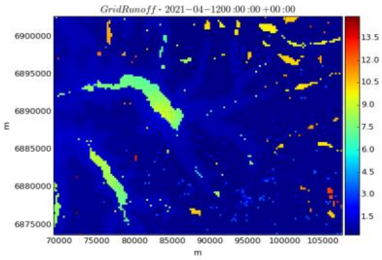

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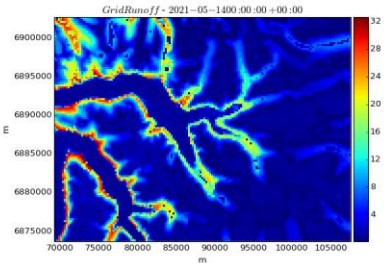

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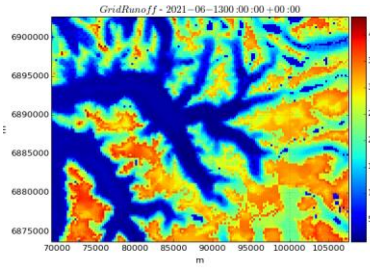
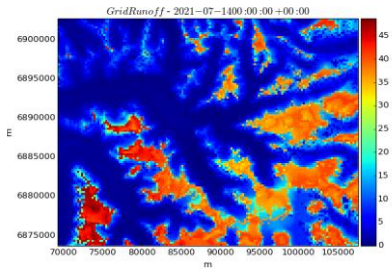


Jul



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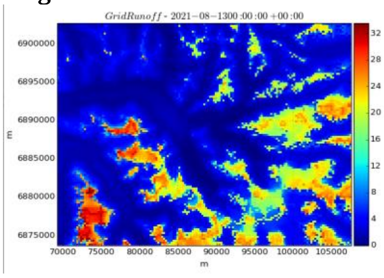
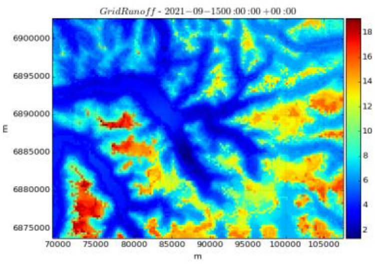


Sept



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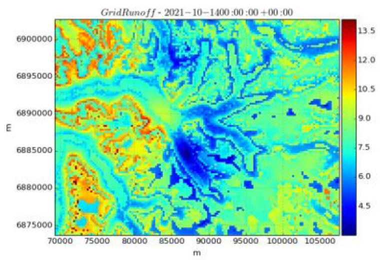

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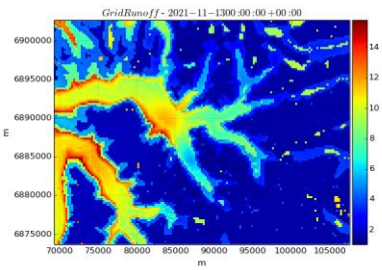

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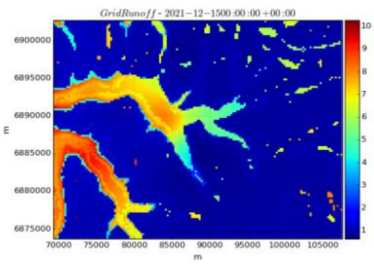
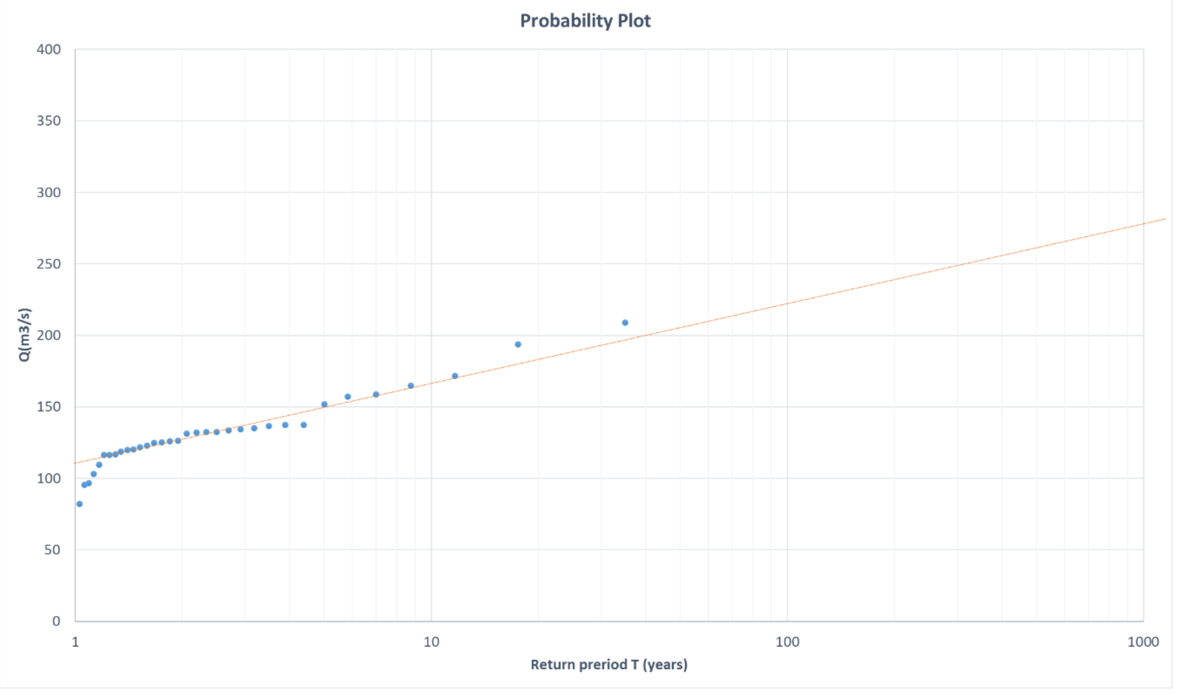
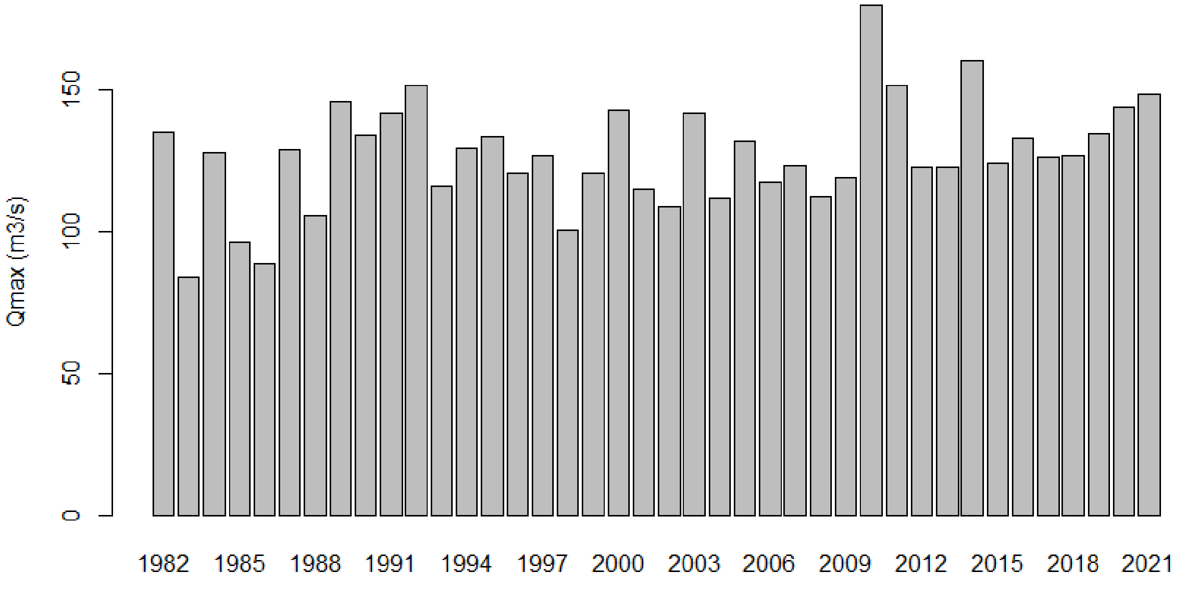


Probability Plot For flood analysis



AMS (Simulated)



Cost analysis

Intake: Waterway optimisation and tunnelling

Diversion	Intake	Powerhouse	Q prod mean(m3/s)	Tunnel Length(km)	Qmax
D 600 m.a.s.l	600	5	20.22	38.76	26.30
D 400 m.a.s.l	400	5	23.81	30.08	31.12
D 325 m.a.s.l	325	5	24.28	28.53	31.72
D 225 m.a.s.l	225	5	25.65	25.64	33.52
D150 m.a.s.l	150	5	27.15	23.13	35.49
D88 m.a.s.l	88	5	29.50	19.96	38.60
DStrynsvatn	30	5	42.74	73.17	59.22

Tunnel Diameter (m)

Tunnel Diameter	Skjerdingsdøla 2-Grasdola	Grasdøla-Videdøla	Videdøla-Sunndøla	Sunndøla-Erdaselva	Erdaselva _ outlet
D 600	2	2.5	3.5	4	5.75
D400	2.5		4	5	6.25
D325	3		3.75	4.75	6.25
D225	3		4	4.5	6.75
D150	5			5.5	6.5
D88	5			5.75	6.75
Dstrynvatn	8				

Tunnel Costs

Tunnel cost	Skjerdingsdøla 2- Grasdøla	Grasdøla - Videdøla	Videdøla-Sunndøla	Sunndøla-Erdalselva	Erdalselva _ outlet	Sum (M.NOK)
D 600	16.3	40.7	140.4	175.0	466.0	838.4
D400	18.1		96.0	176.0	425.4	715.5
D325	17.8		82.2	163.8	412.9	676.7
D225	6.2		74.8	145.2	425.5	651.7
D150	76.8			125.7	407.2	609.8
D88	26.4			115.8	387.9	530.1
DStrynsvatnet	232.3					232.3

Head losses in the tunnel system

Diversion	Head loss (m)
D 600	10.96
D400	8.52
D325	8.9

D225	6.22
D150	8.38
D88	7.31
DStrynsvatn	3.73

Intake Costs

Diversion	Civil work cost (M.NOK)	Gate Cost (M.NOK)	Total cost (M.NOK)
D 600	14.17	8.13	22.30
D400	7.23	9.47	16.70
D325	7.26	9.33	16.59
D225	7.35	9.96	17.31
D150	6.08	10.46	16.53
D88	6.24	11.03	17.27
DStrynsvatn	5.10	6.90	12.00

Electro technical costs

Waterway	Q Design	Capacity (MW)	Generator	Transformer	Control System	Auxillary System	Total cost (M.NOK)
D 600 m.a.s.l	26.30	135.47	64.04	19.34	9.92	15.65	108.95
D 400 m.a.s.l	31.12	106.08	55.21	15.83	9.00	13.72	93.76
D 325 m.a.s.l	31.72	87.00	48.95	13.46	8.32	12.33	83.05
D 225 m.a.s.l	33.52	63.17	40.30	10.35	7.33	10.37	68.35
D150 m.a.s.l	35.49	42.68	31.76	7.51	6.27	8.40	53.94
D 88 m.a.s.l	38.60	25.67	23.33	4.95	5.13	6.38	39.79
DStrynsvatn	59.22	11.02	13.96	2.47	3.67	4.05	24.16

Hydromechanical Costs

Waterway	Q (m3/s)	H(m)	P (MW)	Turbine type	Turbine Cost (MNOK)	Inlet Gate	Trash rack	Lifting Equipment	Total cost
D 600 m.a.s.l	26.30	583.5	135.47	Pelton	78.21	2.47	0.27	0.086	**81.04**
D 400 m.a.s.l	31.12	386.1	106.08	Pelton	56.19	2.47	0.42	0.086	**59.16**
D 325 m.a.s.l	31.72	310.7	87.00	Francis	53.86	2.47	0.42	0.086	**56.83**
D 225 m.a.s.l	33.52	213.5	63.17	Francis	47.54	2.33	0.65	0.086	**50.61**
D150 m.a.s.l	35.49	136.2	42.68	Francis	42.73	2.42	0.52	0.086	**45.76**
D 88 m.a.s.l	38.60	75.3	25.67	Kaplan	72.46	2.33	0.65	0.086	**75.53**
DStrynsvatn	59.22	21.1	11.02	Kaplan	26.79	0.26	1.84	0.086	**28.98**

Powerhouse Costs

Waterway	Qmax (m3/s)	Net Head H (m)	Cost (M.NOK)
D 600 m.a.s.l	26.30	583.21	13.07
D 400 m.a.s.l	31.12	386.34	16.98
D 325 m.a.s.l	31.72	310.81	17.47
D 225 m.a.s.l	33.52	210.41	18.91
D150 m.a.s.l	35.49	136.62	20.49

D 88 m.a.s.l	38.60	75.44	22.97
DStrynsvatn	59.22	21.29	14.28

Access roads

Waterway	Distance from nearest road (m)	Cost (MNOK)
D 600 m.a.s.l	1845.06	2.35
D 400 m.a.s.l	390.21	0.50
D 325 m.a.s.l	452.71	0.58
D 225 m.a.s.l	207.76	0.26
D150 m.a.s.l	347.31	0.44
D 88 m.a.s.l	160.17	0.20
DStrynsvatn		0

Total Cost Summary

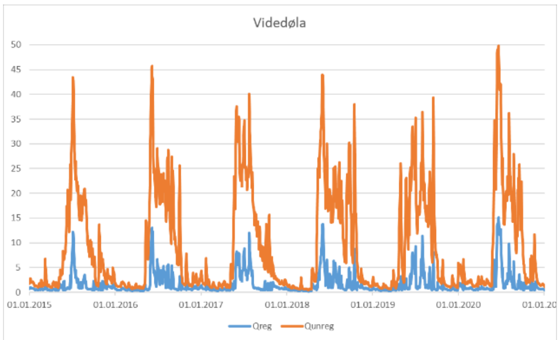
Intake	Tunnel cost	Intake Cost	Road	Electro technical	Hydromechanical	Powerhouse	Total Cost(M.NOK)
D 600 m.a.s.l	838.4	22.3	2.4	109.0	81.0	13.1	1066.2
D 400 m.a.s.l	715.5	16.7	0.5	93.8	59.2	17.0	902.6
D 325 m.a.s.l	676.7	16.6	0.6	83.1	56.8	17.5	851.3
D 225 m.a.s.l	651.7	17.3	0.3	68.4	50.6	18.9	807.2
D150 m.a.s.l	609.8	16.5	0.4	53.9	45.8	20.5	746.9
D 88 m.a.s.l	530.1	17.3	0.2	39.8	75.5	23.0	685.8
DStrynsvatn	232.3	12.0	0.0	24.2	29.0	14.3	311.7

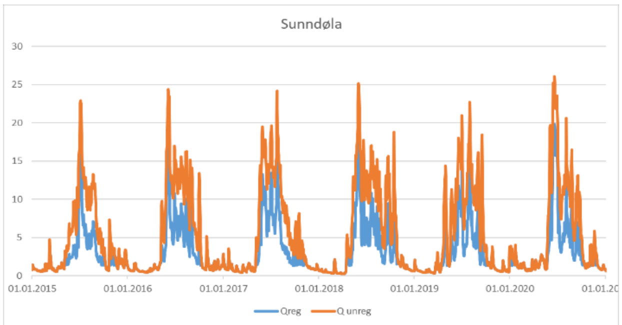
Economic Analysis

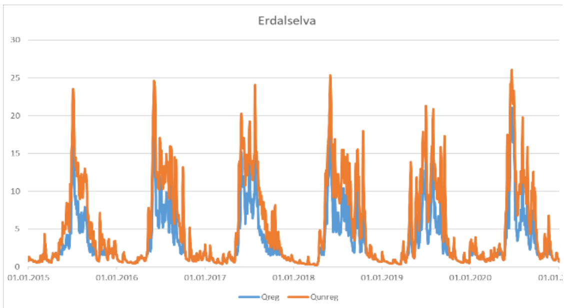
Intake	Construction Cost M.NOK	Production GWh/ year	Annual Revenue	PV of Cost + O&M	Present Value of Revenue	Benefit/ Cost Ratio	Profit MNOK
D 600 m.a.s.l	1066.2	437.7	175.1	1119.5	2416.1	2.16	1296.7
D 400 m.a.s.l	902.6	328.5	131.4	947.7	1813.6	1.91	865.9
D 325 m.a.s.l	851.3	270.8	108.3	893.8	1495.0	1.67	601.2
D 225 m.a.s.l	807.2	196.8	78.7	847.5	1086.5	1.28	239.0
D150 m.a.s.l	746.9	136.2	54.5	784.3	751.6	0.96	-32.6
D 88 m.a.s.l	685.8	83.9	33.6	720.1	463.4	0.64	-256.8
DStrynsvatn	311.7	37.4	14.9	327.3	206.3	0.63	-121.0

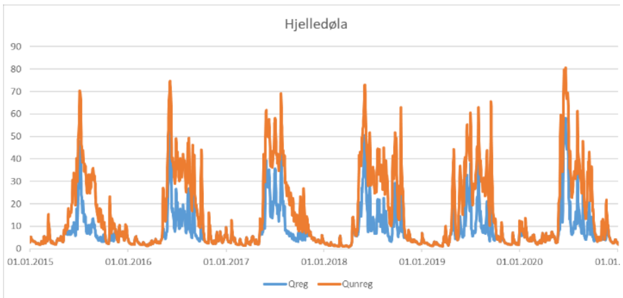
Diversion at 600 m.a.s.l

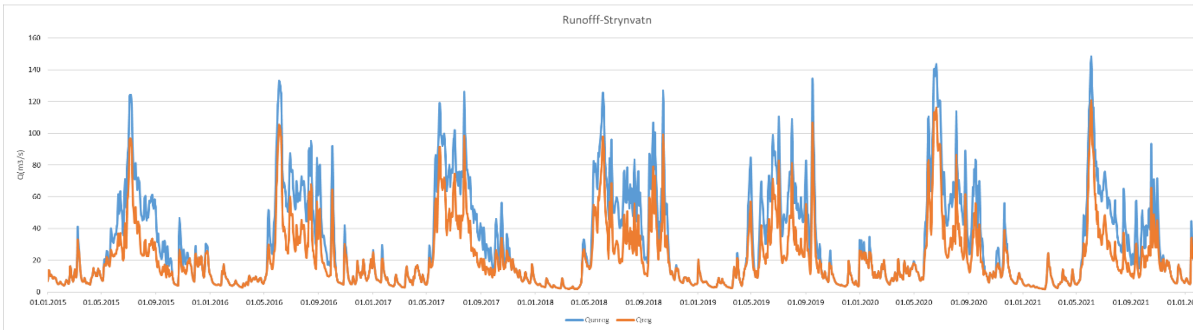
Changes in river flows











Increased tunnel capacity