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Report

Increasing balance power capacity in Norwegian hydroelectric power stations

A preliminary study of specific cases in Southern Norway

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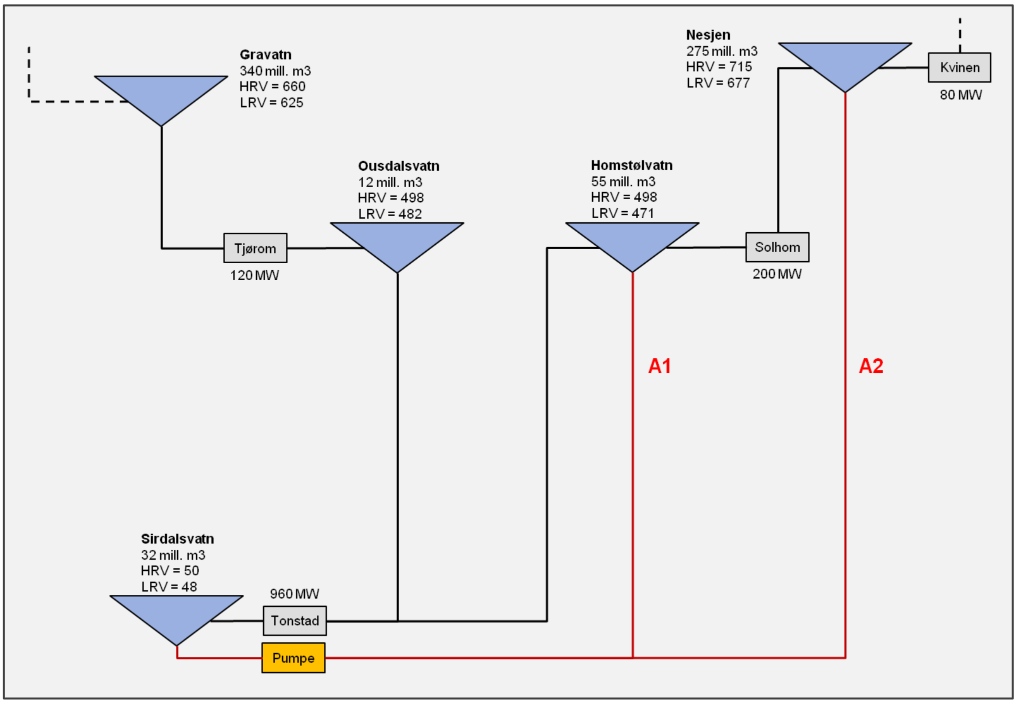

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ABSTRACT

This report describes the results of a preliminary study relating to increasing the power output of hydroelectric power plants at existing reservoirs in Southern Norway subject to the constraints of current regulations regarding highest and lowest regulated water levels (HRWL and LRWL). The main scenario involves twelve new power stations with a combined power output of 11,200 MW. It is envisaged that these power stations would be constructed with new tunnels to an upstream reservoir and to the downstream outflow into a reservoir, a fjord or the sea. Five of the power plants are pumped storage power stations with a combined output of 5,200 MW, while the remainder are hydro storage hydroelectric power stations with a combined output of 6,000 MW, all but one of which discharge into a fjord or the sea. None of the selected power stations will experience more rapid water level variations than 14 cm per hour in the affected upstream and downstream reservoirs. The strictest restrictions on water level variation are associated with downstream reservoirs. In most cases it will take 2-4 weeks of constant power generation to empty an upstream reservoir. It is assumed that the operation of the existing power station will remain unchanged. The most serious environmental challenges affecting reservoirs resulting from increased power generation installation are connected with the risk of increased erosion, changes in circulation, changes in water temperature, reduced ice cover and increased danger of unstable ice. All these physical changes can have an impact on ecosystems. Many of the selected reservoirs are already strongly affected by water level regulation. In reservoirs which receive pumped water from lower reservoirs or neighbouring water systems, environmental impacts can be considerable because transferred water can result in major changes in water chemistry and temperature, and a range of organisms may be transferred from the lower reservoir to the upper one. Knowledge of the possible effects of such water transfer is incomplete. The environmental challenges connected with balance power will vary from project to project and will depend on the type of operational pattern and restrictions implemented. Our ability to develop and use knowledge of environmental effects will determine what sort of local impacts balance power projects may have. Each of the power station installations studied will require connection through a separate 420 kV line to appropriate points in the central supply grid if power exchange with other countries is to take place by way of the central transmission grid.

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1 Introduction

1.1 Increasing balance power capacity in Southern Norway

Many countries are in the process of increasing the proportion of renewable energy in their electrical supply, and for European countries this will generally result in an increase in wind and solar power generation. Since it is not possible to store energy generated by wind and solar power plants, there will be an increased need to balance consumption and generation. Hydroelectric power generation systems can store energy through the storage of water in a reservoir, and it is also possible to pump water from a lower reservoir to a higher one, thereby storing energy for later consumption. This type of compensation for the difference between production and consumption is known as "balance power". Norwegian hydroelectric reservoirs have considerable storage capacity and there is great international and national interest in Norway's ability to supply balance power services over various time scales to the European market. The potential and challenges have not been studied to any great extent. This report describes a preliminary study of the technical potential of balance power in Norway, and includes a brief treatment of environmental impacts and grid connection.

The balance power capacity of Norwegian hydroelectric power stations can be increased by increasing the absorption capacity and turbine/generator output in some power stations, and by installing (reversible) pump turbines to pump water between two reservoirs. This should preferably be achieved by constructing new tunnels parallel to existing ones and by building new power stations in association with existing facilities.

The balance power capacity of hydroelectric power stations depends on how much power can be supplied during periods of shortage and how much power can be absorbed in periods of overproduction. The power capacity depends on the level of power which can be supplied or absorbed in a given period.

Power can be absorbed if a power station can pump water up to a higher reservoir. In many power stations the capacity of the downstream reservoir will limit the amount of power which can be supplied. Pumping at times of the day when the power demand is lowest (e.g. at night) will reduce the capacity restriction effect of the downstream reservoir. Such pumping will also increase the capacity of the upstream reservoir and the periods of power generation can be extended by pumping water back during the part of the day in which the power demand is lowest, to be used at the time when the demand is highest.

Increased exploitation of reservoirs for generating balance power is planned to take place in compliance with existing regulations governing highest and lowest regulated water levels (HRWL and LRWL). Rapid changes in water level in reservoirs resulting from increased power generation (drawing down) can harm species inhabiting the reservoirs, as well as the reservoirs themselves. Pumping can result in detrimental spreading of species from one water system to another. For the purposes of this report, the construction of new reservoirs with the aim of balance power generation is disregarded.

1.2 Other studies

The Norwegian Water Resources and Energy Directorate (NVE) has studied the potential for increasing the power output of 89 existing hydroelectric power stations with an output of more than 50 MW [1]. These are mainly power stations which discharge into the sea, reservoirs or large lakes. The study did not consider the potential represented by pumping.

The 89 power stations studied by NVE had an average usage time of approximately 3,900 hours. If the usage time for each individual power station can be reduced to 2,000 hours by upgrading its power output, the total power output of these power stations can be increased from 17,000 MW to 33,500 MW. This is an increase of 16,500 MW. A reduction of usage time to 2,000 hours was selected to illustrate the potential for improvement. In some power stations the increase in power output could be significantly more than that corresponding to a usage time of 2,000 hours.

EC Group and THEMA Consulting Group have carried out a study for Energi Norge [2] in which the following project hypothesis is studied: *It is possible to establish at least 10,000 MW of profitable power output in Norway to contribute to the balancing of more than 100,000 MW of new and difficult to regulate power generation in Europe by 2030, reducing greenhouse gas emissions from equivalent thermal power generation and providing climatic benefits.* The study concludes that this is possible, but that there are a number of important barriers which will make it difficult to achieve. CEDREN and SINTEF Energy Research have contributed to the above-mentioned study in the form of the results presented in this report. The combined output of the twelve power stations in **Table 3.1** is 11,200 MW. These are used in Energi Norge's study as an example of how it is possible to establish 10,000 MW of new capacity using existing regulated reservoirs in compliance with current regulations regarding highest and lowest regulated water levels.

Several energy companies have commenced their own studies of the potential for increasing hydro storage and pumped storage capacity, but these have not yet been completed or published.

In Germany a government-appointed committee has studied [3, 4] how extensive exchange with the Norwegian hydroelectric generation system may make Germany's energy supplies 100 per cent renewable by 2050. Among a number of alternatives, the report shows that exchange with Norway will also be by far the cheapest option if this goal is to be met.

1.3 Summary of cases

We have selected 19 specific cases in Southern Norway in order to analyse the potential for increasing power output for the purpose of balance power generation. The analysis has been carried out using a simple calculation model. The selected cases are listed below and described in Chapter 2. All the cases are new power stations and with the exception of B7 are located adjacent to existing plants. It is envisaged that the new power stations would be constructed with new tunnels to an upstream reservoir and to the downstream outflow into a reservoir, a fjord or the sea.

The power stations are designated "pumped storage power stations" or "hydro storage power stations". The first category has reversible pump turbines, pumping water between two reservoirs, while hydro storage power stations are not fitted with such pump turbines. With one exception (G2), all the hydro storage power stations discharge into a fjord or the sea. The case designation includes the name of the power station with which the new plant is associated (e.g. Tonstad), or in some cases the name of the downstream reservoir or fjord. The name of either an upstream or downstream reservoir or fjord is added in parentheses.

A Tonstad

- A1 Tonstad pumped storage power station (Homstølvatn – Sirdalsvatn)
- A2 Tonstad pumped storage power station (Nesjen – Sirdalsvatn)

B Blåsjø – Svartevatn – Otra reservoirs

- B1 Bossvatn pumped storage power station (Blåsjø – Bossvatn)
- B2 Bossvatn pumped storage power station (Svartevatn – Bossvatn)
- B3 Holen pumped storage power station (Urarvatn – Bossvatn)
- B4 Vatnedalsvatn pumped storage power station (Urarvatn – Vatnedalsvatn)
- B5 Kvilldal pumped storage power station (Sandsavatn – Suldalsvatn)
- B6 Kvilldal pumped storage power station (Blåsjø – Suldalsvatn)
- B7 Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden/sea)

C Møsvatn – Tinnsjø – Kallhovd/Mår

- C1 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)
- C2 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø) + Tinnsjø pumped storage power station (Kallhovd – Tinnsjø)
- C3 Tinnsjø pumped storage power station (Kallhovd – Tinnsjø) + Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)

C1 and C2 involve the same power station, Tinnsjø (Møsvatn – Tinnsjø). The difference between C1 and C2 is that C2 also includes drawdown from Kallhovd to Tinnsjø via the power station at C3, Tinnsjø (Kallhovd – Tinnsjø).

D Lysebotn

- D1 Lysebotn hydro storage power station (Lyngsvatn – Lysefjorden/sea)

E Mauranger – Oksla – Tysso

- E1 Mauranger hydro storage power station (Juklavatn – Hardangerfjorden/sea)
- E2 Oksla hydro storage power station (Ringedalsvatn – Hardangerfjorden/sea)
- E3 Tysso pumped storage power station (Langevatn – Ringedalsvatn)

F Sima

- F1 Sy-Sima hydro storage power station (Sysenvatn – Hardangerfjorden/sea)

G Aurland – Tyin

- G1 Aurland/Vangen hydro storage power station (Viddalsvatn – Aurlandsfjorden/sea)
- G2 Tyin hydro storage power station (Tyin – Årdalsvatnet)

1.4 Calculation model

Large units have been used as a basis when considering power output. An alternative solution may be to use several small units, depending on local conditions and comprehensive assessments. Very simple water channel and tunnel routes have been determined directly from the map in NVE's Atlas of Hydroelectric Power Stations [5] (cf. for example **Figure 2.1**).

A simple Excel calculation model was used which is described below in connection with Case A2 (cf. **Table 2.1**).

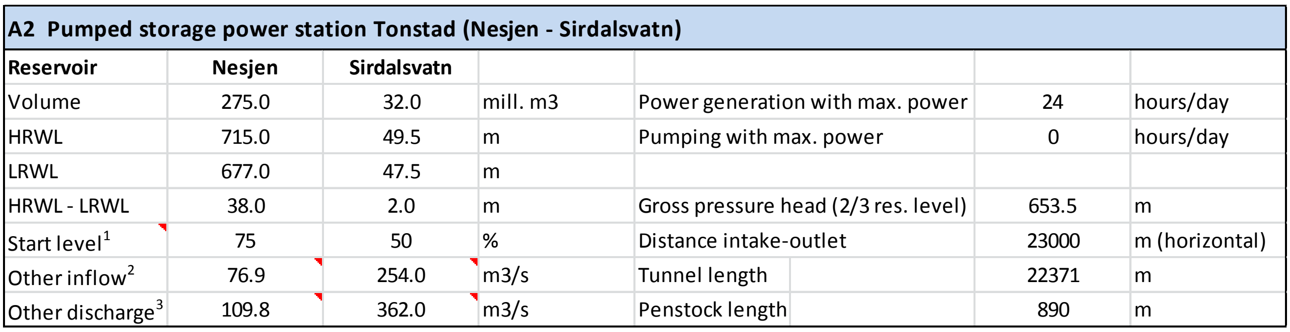
When analysing water level variations resulting from a change in power output, the new power generation capacity is added to the existing maximum output (nominal output) in power stations which use the associated reservoirs both upstream and downstream.

It is assumed that maximum power generation (nominal output) will occur simultaneously in both the existing and new units. In practice it will be natural to select a strategy for power generation and pumping which makes optimal use of the reservoirs within the relevant regulation and market regime. This was not done here, since maximum power generation is assumed to occur simultaneously in all units.

The reservoirs were modelled assuming vertical side surfaces as in an upright cylinder.

In pumped storage power stations, the same installed output in MW is assumed for power generation and pumping. The flow rate (in m³/s) during pumping is set to 80% of the rate during power generation. This means that pumping a given volume of water will take 20% longer than power generation based on the same water volume.

The upper part of the Excel spread sheet contains the following information:



A2 Pumped storage power station Tonstad (Nesjen - Sirdalsvatn)

Reservoir	**Nesjen**	**Sirdalsvatn**				
Volume	275.0	32.0	mill. m3	Power generation with max. power	24	hours/day
HRWL	715.0	49.5	m	Pumping with max. power	0	hours/day
LRWL	677.0	47.5	m			
HRWL - LRWL	38.0	2.0	m	Gross pressure head (2/3 res. level)	653.5	m
Start level[1]	75	50	%	Distance intake-outlet	23000	m (horizontal)
Other inflow[2]	76.9	254.0	m3/s	Tunnel length	22371	m
Other discharge[3]	109.8	362.0	m3/s	Penstock length	890	m

This illustration shows data for the upper (Nesjen) and lower (Sirdalsvatn) reservoirs, including any inflow[2] and discharge[3] resulting from maximum generation in the other power stations associated with the reservoirs, which in this case are:

[2] Inflow to Nesjen (76.9 m³/s) results from:
- 80 MW in the Kvinen power station

[2] Other inflow to Sirdalsvatn (254.0 m³/s) results from:
- 960 MW in the Tonstad power station

[3] Other discharge from Nesjen (109.8 m³/s) results from:
- 200 MW in the Solhom power station

[3] Discharge from Sirdalsvatn (362.0 m³/s) results from:
- 150 MW in the Åna-Sira power station

The length of the approach/discharge tunnel and penstock is calculated on the basis of the gross pressure head, the horizontal distance between the intake and the outlet and a 45 degree inclination of the penstock (cf. **Figure 1.1**). The horizontal distance between the intake and discharge is measured using the distance measuring function in NVE's Atlas of hydroelectric power stations [5]. The gross pressure head is calculated for a 2/3 filled reservoir, i.e. 2×(HRWL-LRWL)/3.

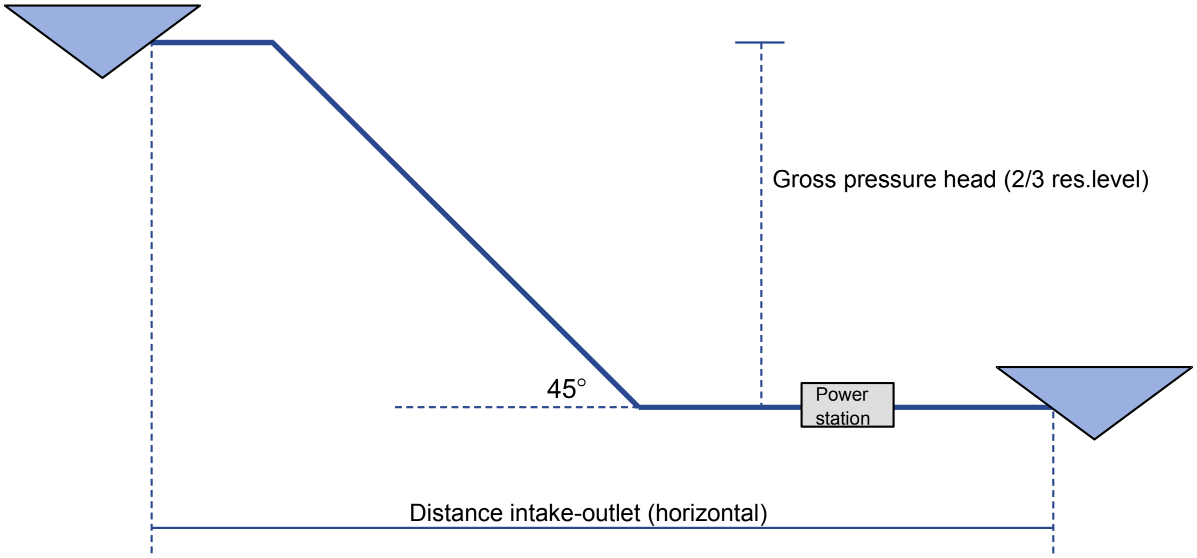


Figure 1.1: Model of tunnel and penstock

The central part of the spread sheet shows calculations for water level variation as a function of the maximum power generated (MW):

Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1000	11	2.6	7.7	18.0	11.1	2	2.5
1100	12	2.8	8.4	19.5	10.2	2	2.0
1200	13	3.0	9.0	21.0	9.5	2	1.7
1300	13	3.2	9.7	22.5	8.9	3	1.4
1400	14	3.4	10.3	24.1	8.3	3	1.3
1500	15	3.7	11.0	25.6	7.8	4	1.1
1600	16	3.9	11.6	27.1	7.4	4	1.0
2000	20	4.7	14.2	33.2	6.0	6	0.7

The values in the cells "Power generation at max. power" (hours/day), "Pumping at max. power" (hours/day) and "Start level" (%) are used to calculate "Water level reduction" (metres per 1-3-7 days), as well as the time for "Emptying of upper reservoir" (days) and "Filling of lower reservoir" (days).

The lowest part of the spread sheet shows calculations of the volume of the tunnel, penstock and power station hall as a function of designed power output given in the column "Max. power generated" (MW):

Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1000	182	91	61	2.038	0.054	0.090	2.181
1100	200	100	67	2.241	0.059	0.097	2.397
1200	219	109	73	2.445	0.065	0.104	2.614
1300	237	118	79	2.649	0.070	0.110	2.830
1400	255	128	85	2.853	0.076	0.117	3.046
1500	273	137	91	3.056	0.081	0.124	3.261
1600	291	146	97	3.260	0.086	0.130	3.477
2000	364	182	121	4.075	0.108	0.156	4.339

The water level decrease (cm/hour) in the upper reservoir and the water level increase (cm/hour) in the lower reservoir in the model used are only provided for periods of power generation. Seepage and any pumping in or out of the reservoirs simultaneously with power generation are disregarded. Seepage is assumed to be small compared with the drawing down of the reservoirs.

The reduction of reservoir level (m) and the time taken to empty the reservoirs to the LRWL and fill them to the HRWL, in addition to the size of the power generation (MW), are also given in terms of the duration of the power generation (hours/day), and the duration of pumping in the period (hours/day), as well as the reservoir levels (%) when power generation commences.

The water level reduction (m) per day and the time taken to empty the upper and fill the lower reservoir are calculated for those combinations of duration of power generation/pumping and start level in the upper/lower reservoirs as shown in **Table 1.1** and **Table 1.2**. The results of such a calculation for Case A2 are shown in **Table 2.2** and **Table 2.3**. The calculation is carried out in each case for the power production selected for Scenario 1 (**Table 3.1**) and Scenario 2 (**Table 3.2**).

Table 1.1: Water level reduction and emptying time for upper reservoir

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100		
		75		
		50		
18	0	75		
	6			
12	0			
	6			
	12			

Table 1.2: Filling time for lower reservoir

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	
		50	
		75	
18	0	50	
	6		
12	0		
	6		
	12		

The relationship between generated power and absorption capacity (water flow through turbine, tunnel and penstock) is calculated using the following formula:

$$P = \rho \cdot Q \cdot g \cdot H \cdot \eta_{tot} \qquad (1.1)$$

where:

P = *usable power (W)*
ρ = *density of water (1000 kg/m³)*
Q = *water flow/absorption capacity (m³/s)*
g = *acceleration due to gravity (9.81 m/s²)*
H = *gross pressure head (m)*
η_{tot} = *total efficiency (water channel, turbine and generator: here set to 0.86)*

When the total degree of efficiency is set to 0.86, the expression for P becomes:

$$P(kW) = 8.4 \cdot Q(m^3/s) \cdot H(m) \qquad (1.2)$$

The cross-sectional areas of the tunnel and penstock are set to give a water velocity of 2 m/s and 3 m/s, respectively.

The blasting volume of the power station halls themselves is calculated by means of the following formula from NVE's *Kostnadsgrunnlag for vannkraftanlegg* (Cost calculation for hydroelectric power stations) [6]:

$$V = 78 \cdot H^{0.5} \cdot Q^{0.7} \cdot n^{0.1} \qquad (1.3)$$

where:

V = *blasted volume (m³)*
H = *net pressure head (m)*
Q = *maximum total water flow (m³/s)*
n = *number of generators (generator size is here set to 200 MW)*

2 Analysis of the selected cases

2.1 Tonstad

Two cases were analysed in connection with Tonstad power station, as follows:

A1 Tonstad pumped storage power station (Homstølvatn – Sirdalsvatn)
A2 Tonstad pumped storage power station (Nesjen – Sirdalsvatn)

The new tunnels in Cases A1 and A2 are drawn in red on the map excerpt in **Figure 2.1**, which is from NVE’s Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

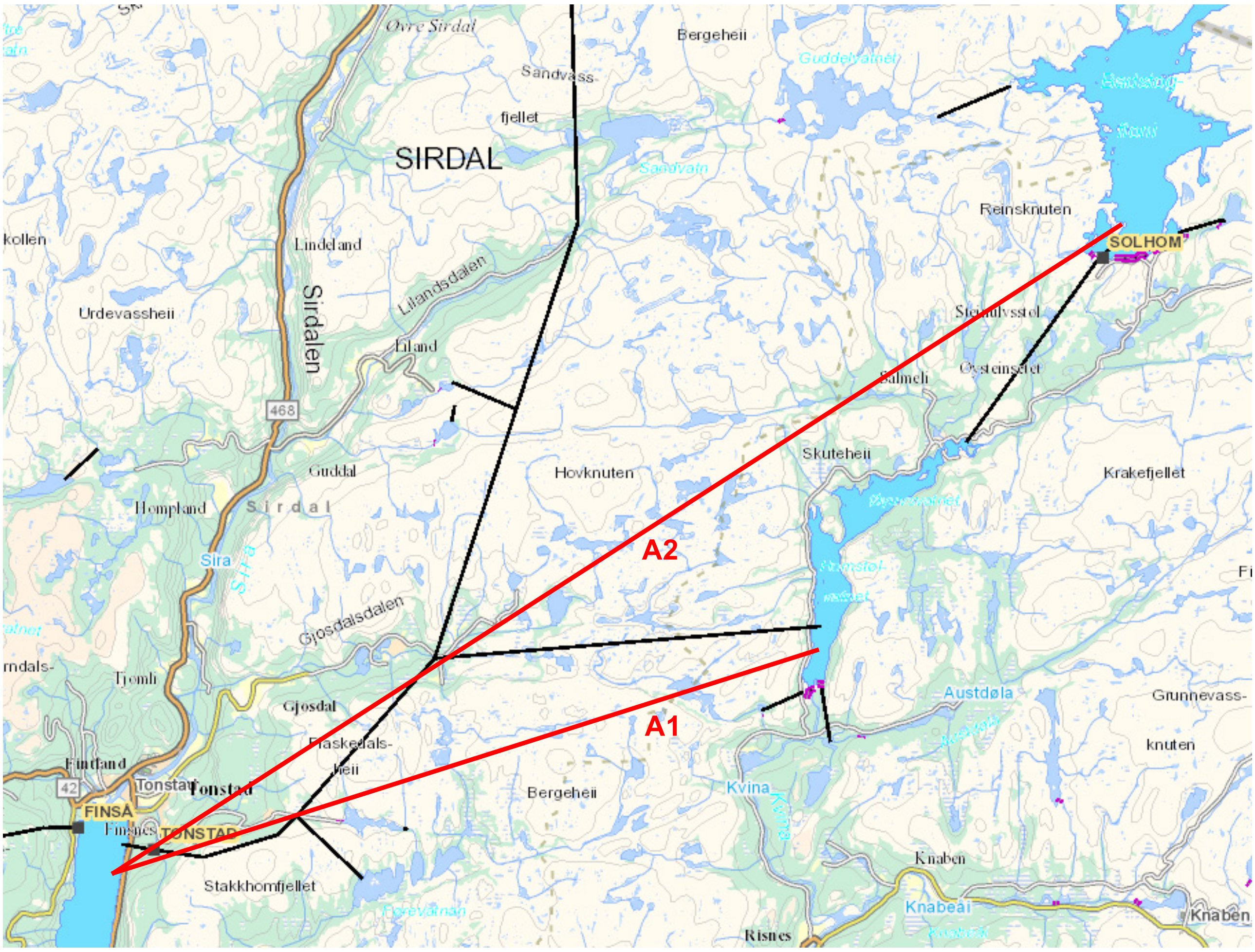


Figure 2.1: The Tonstad Case

The new pumped storage power station, new tunnels and associated reservoirs in Case A1-A2 are shown in **Figure 2.2**.

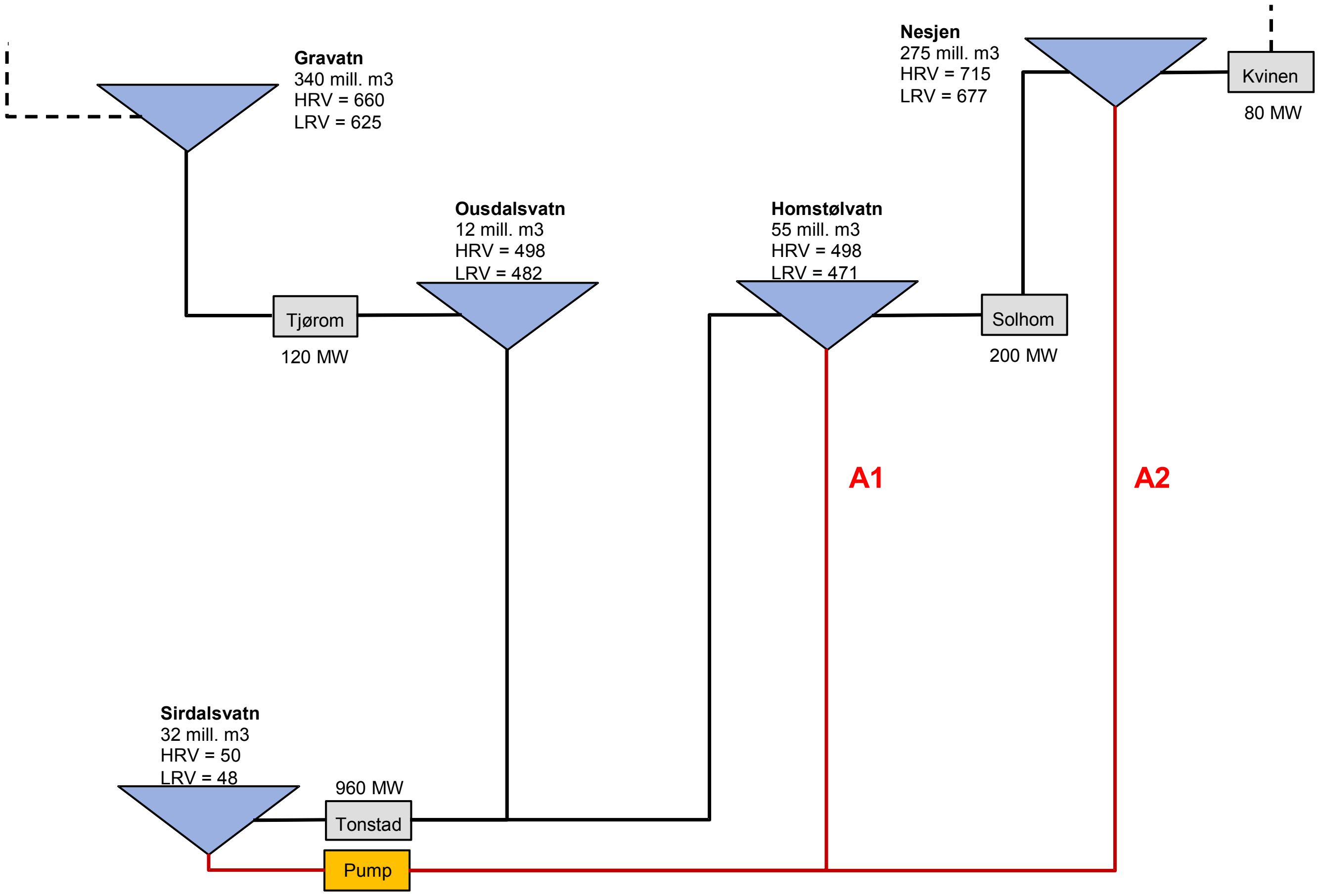


Figure 2.2: The Tonstad Case

A1 Tonstad pumped storage power station (Homstølvatn – Sirdalsvatn)

Table 2.1: Case A1 Tonstad pumped storage power station (Homstølvatn – Sirdalsvatn)

A1 Tonstad pumped storage power station (Homstølvatn - Sirdalsvatn)							
Reservoir	**Homstølvatn**	**Sirdalsvatn**					
Volume	55.0	32.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	498.0	49.5	m	Pumping with max. power		0	hours/day
LRWL	471.0	47.5	m				
HRWL - LRWL	27.0	2.0	m	Gross pressure head (2/3 res. level)		440.2	m
Start level[1]	75	50	%	Distance intake-outlet		12500	m (horizontal)
Other inflow[2]	109.8	254.0	m3/s	Tunnel length		12077	m
Other discharge[3]	144.2	362.0	m3/s	Penstock length		599	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
100	11	2.6	7.8	18.2	7.8	-2	-2.3
200	16	3.8	11.3	26.3	5.4	-1	-3.4
300	20	4.9	14.7	34.3	4.1	-1	-6.9
400	25	6.0	18.1	42.3	3.3	0	1005.7
500	30	7.2	21.6	50.4	2.8	1	6.8
600	35	8.3	25.0	58.4	2.4	1	3.4
700	40	9.5	28.5	66.4	2.1	2	2.3
800	44	10.6	31.9	74.5	1.9	2	1.7
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
100	27	14	9	0.163	0.005	0.015	0.184
200	54	27	18	0.327	0.011	0.027	0.364
300	81	41	27	0.490	0.016	0.037	0.543
400	108	54	36	0.653	0.022	0.047	0.721
500	135	68	45	0.817	0.027	0.056	0.899
600	162	81	54	0.980	0.032	0.064	1.077
700	189	95	63	1.143	0.038	0.073	1.254
800	216	108	72	1.306	0.043	0.081	1.431

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Homstølvatn (109.8 m^3/s) results from:

- 200 MW in the Solhom power station

[2] Other inflow to Sirdalsvatn (254.0 m^3/s) results from:

- 960 MW in the Tonstad power station

[3] Other discharge from Homstølvatn (144.2 m^3/s) results from:

- 960 MW in the Tonstad power station (254 m^3/s from Tonstad power station with 144.2 m^3/s from Homstølvatn and 109.8 m^3/s from Ousdalsvatn)

[2] Discharge from Sirdalsvatn (362.0 m^3/s) results from:

- 150 MW in the Åna-Sira power station

The model in **Table 2.1** does not take into account the connection between Ousdalsvatn and Homstølsvatn. In the model pumping takes place only to Homstølsvatn in case A1.

Table 2.1 shows the water level decrease in Homstølsvatn (upper reservoir) and water level increase in Sirdalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Tonstad pumped storage power station, when the design power output is 100 – 800 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.2 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Homstølsvatn when the power generation in Tonstad pumped storage power station is 400 MW. The number of hours/day of power generation and pumping and the start level (%) in Homstølsvatn are varied. **Table 2.3** shows the filling time (days) to HRWL for Sirdalsvatn under corresponding conditions.

Tabell 2.2: Water level reduction and emptying time for Homstølsvatn when Tonstad pumped storage power station is generating 400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	6.0	4.5
		75		3.3
		50		2.2
18	0	75	4.5	4.5
	6		3.3	6.1
12	0		3.0	6.7
	6		1.8	11.2
	12		0.6	33.5

Tabell 2.3: Filling time for Sirdalsvatn when Tonstad pumped storage power station is generating 400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling[1] (days)
24	0	25	-
		50	-
		75	-
18	0	50	-
	6		-
12	0		-
	6		-
	12		-

[1] With the selected inflow from Tonstad (254 m^3/s) and discharge to Åna-Sira (362.0 m^3/s) there is little (~ 0 cm/hour) decrease in water level in Sirdalsvatn as consequence of 400 MW generation in Tonstad pumped storage power station (108 m^3/s). The filling time up to HRWL is therefore omitted in the table.

A2 Tonstad pumped storage power station (Nesjen – Sirdalsvatn)

Tabell 2.2: Case A2 Tonstad pumped storage power station (Nesjen – Sirdalsvatn).

A2 Pumped storage power station Tonstad (Nesjen - Sirdalsvatn)							
Reservoir	**Nesjen**	**Sirdalsvatn**					
Volume	275.0	32.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	715.0	49.5	m	Pumping with max. power		0	hours/day
LRWL	677.0	47.5	m				
HRWL - LRWL	38.0	2.0	m	Gross pressure head (2/3 res. level)		653.5	m
Start level[1]	75	50	%	Distance intake-outlet		23000	m (horizontal)
Other inflow[2]	76.9	254.0	m3/s	Tunnel length		22371	m
Other discharge[3]	109.8	362.0	m3/s	Penstock length		890	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1000	11	2.6	7.7	18.0	11.1	2	2.5
1100	12	2.8	8.4	19.5	10.2	2	2.0
1200	13	3.0	9.0	21.0	9.5	2	1.7
1300	13	3.2	9.7	22.5	8.9	3	1.4
1400	14	3.4	10.3	24.1	8.3	3	1.3
1500	15	3.7	11.0	25.6	7.8	4	1.1
1600	16	3.9	11.6	27.1	7.4	4	1.0
2000	20	4.7	14.2	33.2	6.0	6	0.7
Max. power generated [MW]	Max. absorp-tion capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1000	182	91	61	2.038	0.054	0.090	2.181
1100	200	100	67	2.241	0.059	0.097	2.397
1200	219	109	73	2.445	0.065	0.104	2.614
1300	237	118	79	2.649	0.070	0.110	2.830
1400	255	128	85	2.853	0.076	0.117	3.046
1500	273	137	91	3.056	0.081	0.124	3.261
1600	291	146	97	3.260	0.086	0.130	3.477
2000	364	182	121	4.075	0.108	0.156	4.339

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Nesjen (76.9 m³/s) results from:

- 80 MW in the Kvinen power station

[2] Other inflow to Sirdalsvatn (254.0 m³/s) results from:

- 960 MW in the Tonstad power station

[3] Other discharge from Nesjen (109.8 m³/s) results from:

- 200 MW in the Solhom power station

[2] Discharge from Sirdalsvatn (362.0 m³/s) results from:

- 150 MW in the Åna-Sira power station

Power generation of 960 MW in Tonstad power station will result in a reduction in water level in Ousdalsvatn and Homstølvatn when Tjørom power station and Solhom power station generate 120 MW and

200 MW, respectively. The water level would be unchanged in the case of 660 MW generation in Tonstad power station.

Table 2.4 shows the water level decrease in Nesjen (upper reservoir) and water level increase in Sirdalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Tonstad pumped storage power station, when the design power output is 1,000 – 2,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.5 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Nesjen when the power generation in Tonstad pumped storage power station is 1,400 MW. The number of hours/day of power generation and pumping and the start level (%) in Nesjen are varied. **Table 2.6** shows the filling time (days) to HRWL for Sirdalsvatn under corresponding conditions.

Table 2.5: Water level reduction and emptying time for Nesjen when Tonstad pumped storage power station is generating 1,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	3.4	11.1
		75		8.3
		50		5.5
18	0	75	2.6	11.1
	6		1.9	15.1
12	0		1.7	16.6
	6		1.0	27.6
	12		0.3	82.9

Table 2.6: Filling time for Sirdalsvatn when Tonstad pumped storage power station is generating 1,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	1.9
		50	1.3
		75	0.6
18	0	50	1.7
	6		2.3
12	0		2.5
	6		4.2
	12		12.6

2.2 Blåsjø – Svartevatn – Otramagasinene

Nine cases were analysed in connection with Blåsjø – Svartevatn – Otramagasinene, as follows:

- B1 Bossvatn pumped storage power station (Blåsjø – Bossvatn)
- B2 Bossvatn pumped storage power station (Svartevatn – Bossvatn)
- B3 Holen pumped storage power station (Urarvatn – Bossvatn)
- B4 Vatnedalsvatn pumped storage power station (Urarvatn – Vatnedalsvatn)
- B5 Kvilldal pumped storage power station (Sandsavatn – Suldalsvatn)
- B6 Kvilldal pumped storage power station (Blåsjø – Suldalsvatn)
  - a. 1,400 MW Jøsenfjorden hydro storage power station
  - b. 2,400 MW Jøsenfjorden hydro storage power station
- B7 Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden)
  - a. 1,400 MW Kvilldal pumped storage power station
  - b. 2,400 MW Kvilldal pumped storage power station

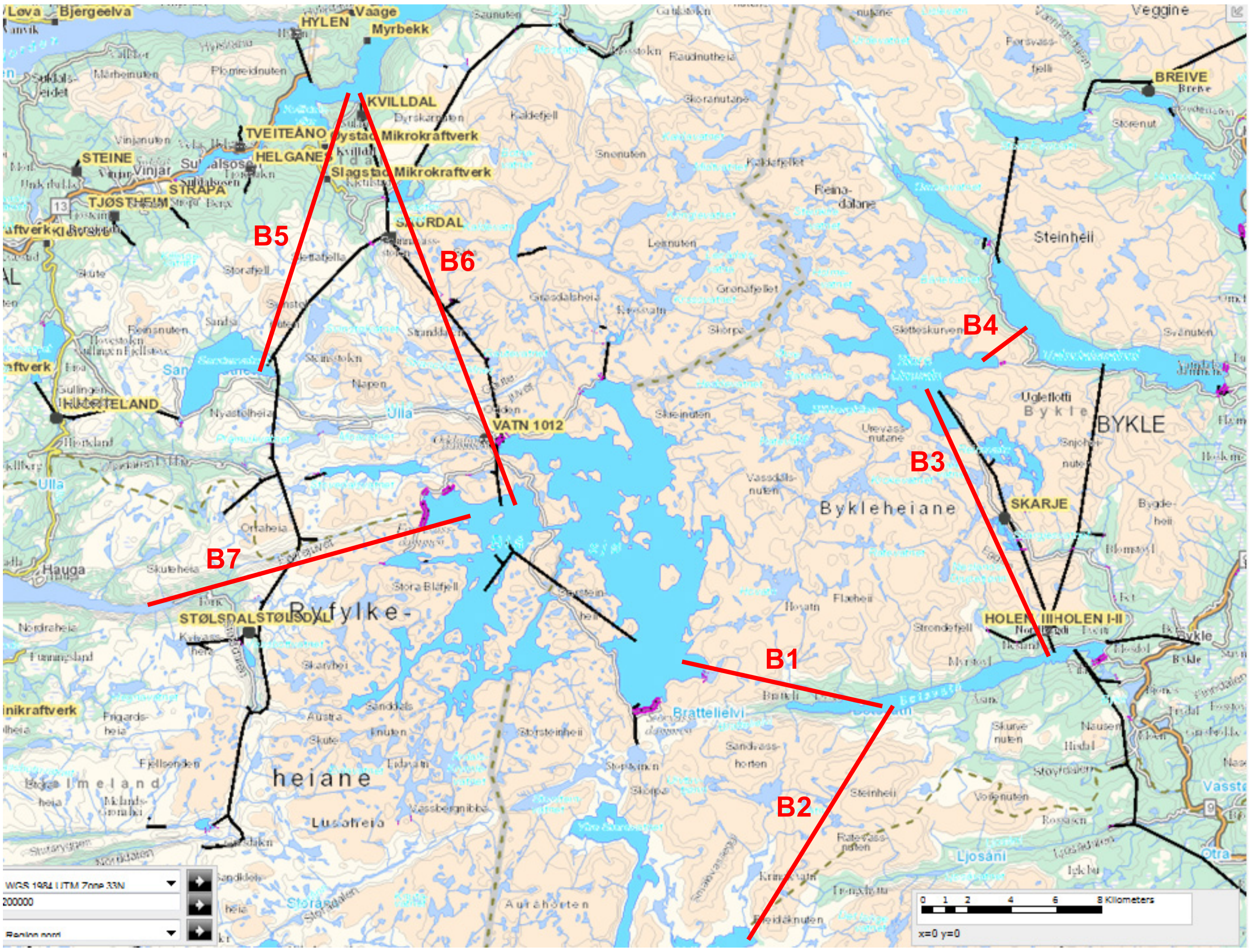


Figure 2.3: Case Blåsjø – Svartevatn – Otramagasinene.

The new tunnels in case B1 – B7 are drawn in red on the map excerpt in **Figure 2.3**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

The new hydro storage and pumped storage power stations, new tunnels and associated reservoirs in cases B1-B6 are illustrated in **Figure 2.4**.

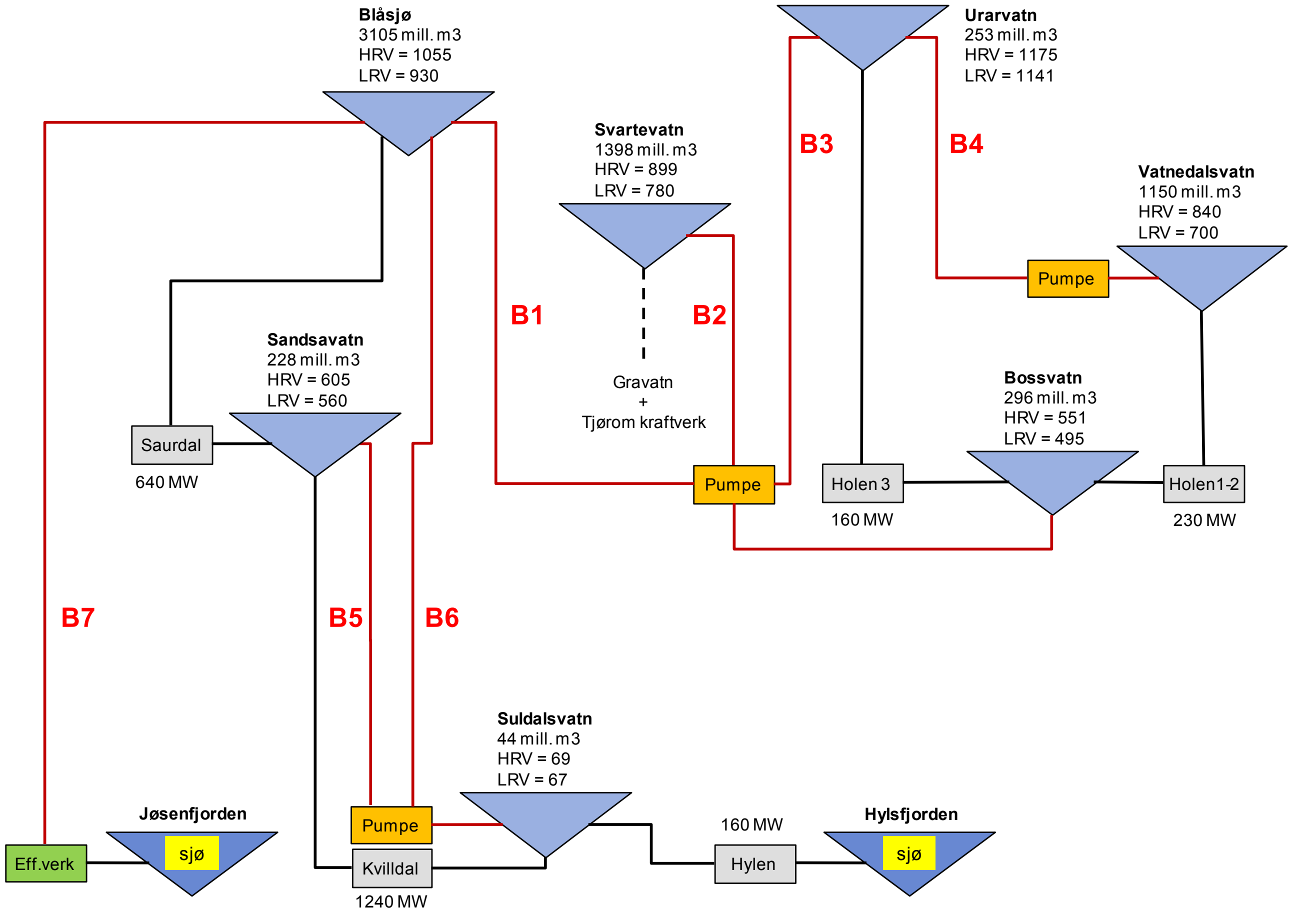


Figure 2.4: Case Blåsjø – Svartevatn – Otramagasinene.

Pumping in Kvilldal pumped storage power station from Suldalsvatn to Blåsjø in case B6 must be carried out in two steps because of the large difference in elevation (gross pressure head of 945 m).

The decrease in water level in Blåsjø in case B1, B6 and B7 includes discharge to Sandsavatn due to 640 MW power generation in Saurdal power station. Case B6 and B7 could also realised with zero generation in Saurdal power station as discharge there, which corresponds to 640 MW, would result in more power if the water was used in Kvilldal pumped storage power station (B6) and Jøsenfjorden hydro storage power station (B7) due to larger head.

B1 Bossvatn pumped storage power station (Blåsjø – Bossvatn)

Table 2.7: Case B1 Bossvatn pumped storage power station (Blåsjø – Bossvatn).

B1 Bossvatn pumped storage power station (Blåsjø - Bossvatn)							
Reservoir	**Blåsjø**	**Bossvatn**					
Volume	3105.0	296.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1055.0	551.0	m	Pumping with max. power		0	hours/day
LRWL	930.0	495.0	m				
HRWL - LRWL	125.0	56.0	m	Gross pressure head (2/3 res. level)		481.0	m
Start level[1]	75	50	%	Distance intake-outlet		8000	m (horizontal)
Other inflow[2]		307.0	m3/s	Tunnel length		7565	m
Other discharge[3]	757.3	131.0	m3/s	Penstock length		615	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	12	2.9	8.7	20.2	32.4	17	6.8
400	12	3.0	8.9	20.8	31.5	19	6.2
500	13	3.1	9.2	21.5	30.6	20	5.7
600	13	3.2	9.5	22.1	29.8	22	5.3
700	13	3.2	9.7	22.7	29.0	24	4.9
800	14	3.3	10.0	23.3	28.2	25	4.6
900	14	3.4	10.2	23.9	27.5	27	4.3
1000	15	3.5	10.5	24.5	26.8	29	4.0
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	74	37	25	0.281	0.015	0.036	0.332
400	99	50	33	0.374	0.020	0.046	0.441
500	124	62	41	0.468	0.025	0.055	0.548
600	149	74	50	0.562	0.030	0.063	0.655
700	173	87	58	0.655	0.036	0.072	0.762
800	198	99	66	0.749	0.041	0.080	0.869
900	223	111	74	0.843	0.046	0.087	0.976
1000	248	124	83	0.936	0.051	0.095	1.082

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Bossvatn (307.0 m^3/s) results from:

- 230 MW in the Holen power station 1-2
- 160 MW in the Holen power station 3
- 1,000 MW in the Holen power station (Urarvatn)
- 0 MW in the Holen power station (Svartevatn)

[3] Other discharge from Blåsjø (757.3 m^3/s) results from:

- 640 MW i Saurdal power station
- 2,400 MW i Jøsenfjorden power station
- 2,400 MW i Kvilldal power station (Blåsjø)

[3] Discharge from Bossvatn (131.0 m^3/s) results from:

- 330 MW in Brokke power station

Table 2.7 shows the water level decrease in Blåsjø (upper reservoir) and water level increase in Bossvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Bossvatn pumped storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.8 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Blåsjø when the power generation in Bossvatn pumped storage power station is 700 MW. The number of hours/day of power generation and pumping and the start level (%) in Blåsjø are varied. **Table 2.9** shows the filling time (days) to HRWL for Bossvatn under corresponding conditions.

Table 2.3: Water level reduction and emptying time for Blåsjø when Bossvatn pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	3.2	38.6
		75		29.0
		50		19.3
18	0	75	2.4	38.6
	6		1.8	52.7
12	0		1.6	57.9
	6		1.0	96.5
	12		0.3	289.6

Table 2.4: Filling time for Bossvatn when Bossvatn pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	7.4
		50	4.9
		75	2.5
18	0	50	6.5
	6		8.9
12	0		9.8
	6		16.3
	12		49.0

B2 Bossvatn pumped storage power station (Svartevatn – Bossvatn)

Table 2.10: Case B2 Bossvatn pumped storage power station (Svartevatn – Bossvatn).

B2 Bossvatn pumped storage power station (Svartevatn - Bossvatn)							
Reservoir	**Svartevatn**	**Bossvatn**					
Volume	1398.0	296.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	899.0	551.0	m	Pumping with max. power		0	hours/day
LRWL	780.0	495.0	m				
HRWL - LRWL	119.0	56.0	m	Gross pressure head (2/3 res. level)		327.0	m
Start level[1]	75	50	%	Distance intake-outlet		11000	m (horizontal)
Other inflow[2]		307.0	m3/s	Tunnel length		10715	m
Other discharge[3]	100.0	131.0	m3/s	Penstock length		403	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	6	1.5	4.6	10.8	58.0	19	6.0
400	8	1.8	5.4	12.6	49.4	22	5.3
500	9	2.1	6.2	14.5	43.0	24	4.8
600	10	2.3	7.0	16.4	38.1	27	4.3
700	11	2.6	7.8	18.3	34.2	29	4.0
800	12	2.9	8.6	20.1	31.0	32	3.7
900	13	3.1	9.4	22.0	28.4	34	3.4
1000	14	3.4	10.2	23.9	26.2	37	3.2
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	109	55	36	0.585	0.015	0.039	0.639
400	146	73	49	0.780	0.020	0.049	0.849
500	182	91	61	0.975	0.024	0.059	1.059
600	218	109	73	1.170	0.029	0.068	1.268
700	255	127	85	1.365	0.034	0.077	1.477
800	291	146	97	1.560	0.039	0.086	1.686
900	328	164	109	1.755	0.044	0.095	1.894
1000	364	182	121	1.950	0.049	0.103	2.102

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Bossvatn (307.0 m^3/s) results from:

- 230 MW in the Holen power station 1-2
- 160 MW in the Holen power station 3
- 1,000 MW in the Holen power station (Urarvatn)
- 0 MW in the Holen power station (Blåsjø)

[3] Other discharge from Svartevatn (100.0 m^3/s) results from:

- 200 MW in Duge power station

[3] Discharge from Bossvatn (131.0 m^3/s) results from:

- 330 MW in Brokke power station

Table 2.10 shows the water level decrease in Svartevatn (upper reservoir) and water level increase in Bossvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Bossvatn pumped storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.11 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Svartevatn when the power generation in Bossvatn pumped storage power station is 700 MW. The number of hours/day of power generation and pumping and the start level (%) in Svartevatn are varied. **Table 2.12** shows the filling time (days) to HRWL for Bossvatn under corresponding conditions.

Table 2.5: Water level reduction and emptying time for Svartevatn when Bossvatn pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	2.6	45.6
		75		34.2
		50		22.8
18	0	75	2.0	45.6
	6		1.4	62.2
12	0		1.3	68.4
	6		0.8	114.0
	12		0.3	342.0

Table 2.6: Filling time for Bossvatn when Bossvatn pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	6.0
		50	4.0
		75	2.0
18	0	50	5.3
	6		7.2
12	0		8.0
	6		13.3
	12		39.8

B3 Holen pumped storage power station (Urarvatn – Bossvatn)

Table 2.7: Case B3 Holen pumped storage power station (Urarvatn – Bossvatn).

B3 Pumped storage power station Holen (Urarvatn - Bossvatn)							
Reservoir	**Urarvatn**	**Bossvatn**					
Volume	253.0	296.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1175.0	551.0	m	Pumping with max. power		0	hours/day
LRWL	1141.0	495.0	m				
HRWL - LRWL	34.0	56.0	m	Gross pressure head (2/3 res. level)		631.3	m
Start level[1]	75	50	%	Distance intake-outlet		13000	m (horizontal)
Other inflow[2]	0.0	118.0	m3/s	Tunnel length		12354	m
Other discharge[3]	28.0	131.0	m3/s	Penstock length		914	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
400	5	1.2	3.6	8.4	21.2	4	27.4
500	6	1.4	4.3	9.9	18.0	6	21.1
600	7	1.6	4.9	11.5	15.6	7	17.1
700	8	1.9	5.6	13.0	13.7	8	14.4
800	9	2.1	6.2	14.5	12.3	9	12.4
1000	10	2.5	7.5	17.6	10.1	12	9.8
1200	12	3.0	8.9	20.7	8.6	15	8.0
1400	14	3.4	10.2	23.7	7.5	17	6.8
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
400	75	38	25	0.466	0.023	0.043	0.532
500	94	47	31	0.582	0.029	0.052	0.663
600	113	57	38	0.699	0.034	0.060	0.793
700	132	66	44	0.815	0.040	0.068	0.923
800	151	75	50	0.932	0.046	0.075	1.053
1000	189	94	63	1.165	0.057	0.090	1.312
1200	226	113	75	1.398	0.069	0.104	1.571
1400	264	132	88	1.631	0.080	0.118	1.829

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow (0.0 m^3/s) to Urarvatn:

- 0 MW pumping in Vatnedalsvatn power station

[2] Other inflow to Bossvatn (118.0 m^3/s) results from:

- 230 MW in Holen power station 1-2
- 160 MW in Holen power station 3
- 0 MW in Holen power station (Svartevatn)
- 0 MW in Holen power station (Blåsjø)

[3] Other discharge from Urarvatn (28.0 m^3/s) results from:

- 0 MW in Vatnedalsvatn power station
- 160 MW in Holen 3

[3] Discharge from Bossvatn (131.0 m^3/s) results from:

- 330 MW in Brokke power station

Table 2.13 shows the water level decrease in Urarvatn (upper reservoir) and water level increase in Bossvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Holen pumped storage power station, when the design power output is 400 – 1,400 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.14 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Urarvatn when the power generation in Holen pumped storage power station is 700 MW. The number of hours/day of power generation and pumping and the start level (%) in Urarvatn are varied. **Table 2.15** shows the filling time (days) to HRWL for Bossvatn under corresponding conditions.

Table 2.14: Water level reduction and emptying time for Urarvatn when Holen pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	1.9	18.3
		75		13.7
		50		9.2
18	0	75	1.4	18.3
	6		1.0	25.0
12	0		0.9	27.5
	6		0.6	45.8
	12		0.2	137.3

Table 2.8: Filling time for Bossvatn when Holen pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	21.6
		50	14.4
		75	7.2
18	0	50	19.2
	6		26.2
12	0		28.8
	6		48.0
	12		143.9

B4 Vatnedalsvatn pumped storage power station (Urarvatn – Vatnedalsvatn)

Table 2.9: Case B4 Vatnedalsvatn pumped storage power station (Urarvatn – Vatnedalsvatn).

B4 Vatnedalsvatn pumped storage power station (Urarvatn - Vatnedalsvatn)							
Reservoir	**Urarvatn**	**Vatnedalsvatn**					
Volume	253.0	1150.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1175.0	840.0	m	Pumping with max. power		0	hours/day
LRWL	1141.0	700.0	m				
HRWL - LRWL	34.0	140.0	m	Gross pressure head (2/3 res. level)		370.3	m
Start level[1]	75	50	%	Distance intake-outlet		4700	m (horizontal)
Other inflow[2]			m3/s	Tunnel length		4259	m
Other discharge[3]	217.0	90.0	m3/s	Penstock length		624	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
100	12	2.9	8.7	20.2	8.8	-3	-115.0
200	14	3.3	9.8	22.9	7.8	-1	-258.9
300	15	3.6	10.9	25.5	7.0	0	1033.7
400	17	4.0	12.0	28.1	6.4	2	172.5
500	18	4.4	13.2	30.7	5.8	3	94.1
600	20	4.8	14.3	33.3	5.4	5	64.7
700	21	5.1	15.4	35.9	5.0	6	49.3
800	23	5.5	16.5	38.5	4.6	7	39.8
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
100	32	16	11	0.068	0.007	0.016	0.091
200	64	32	21	0.137	0.013	0.028	0.178
300	96	48	32	0.205	0.020	0.038	0.264
400	129	64	43	0.274	0.027	0.048	0.349
500	161	80	54	0.342	0.033	0.058	0.433
600	193	96	64	0.411	0.040	0.067	0.517
700	225	113	75	0.479	0.047	0.075	0.601
800	257	129	86	0.548	0.053	0.084	0.685

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Urarvatn og Vatnedalsvatn: 0.0 m^3/s

[3] Other discharge from Urarvatn (217.0 m^3/s) results from:

- 160 MW in Holen power station 3
- 1,000 MW in Holen power station (Urarvatn)

[3] Discharge from Vatnedalsvatn power station (90.0 m^3/s) results from:

- 230 MW in Holen power station 1-2

Table 2.16 shows the water level decrease in Urarvatn (upper reservoir) and water level increase in Vatnedalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Vatnedalsvatn pumped storage power station, when the design power output is 100 – 800 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.17 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Urarvatn when the power generation in Vatnedalsvatn pumped storage power station is 400 MW. The number of hours/day of power generation and pumping and the start level (%) in Urarvatn are varied. **Table 2.18** shows the filling time (days) to HRWL for Vatnedalsvatn under corresponding conditions.

Tabell 2.10: Water level reduction and emptying time for Urarvatn when Vatnedalsvatn pumped storage power station is generating 400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	4.0	8.5
		75		6.4
		50		4.2
18	0	75	3.0	8.5
	6		2.2	11.6
12	0		2.0	12.7
	6		1.2	21.2
	12		0.4	63.5

Tabell 2.11: Filling time for Bossvatn when Vatnedalsvatn pumped storage power station is generating 400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	258.7
		50	172.5
		75	86.2
18	0	50	230.0
	6		313.6
12	0		345.0
	6		574.9
	12		1724.8

B5 Kvilldal pumped storage power station (Sandsavatn – Suldalsvatn)

Table 2.12: Case B5 Kvilldal pumped storage power station (Sandsavatn – Suldalsvatn).

B5 Kvilldal pumped storage power station (Sandsavatn - Suldalsvatn)							
Reservoir	**Sandsavatn**	**Suldalsvatn**					
Volume	228.0	44.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	605.0	69.0	m	Pumping with max. power		0	hours/day
LRWL	560.0	67.0	m				
HRWL - LRWL	45.0	2.0	m	Gross pressure head (2/3 res. level)		521.7	m
Start level[1]	75	50	%	Distance intake-outlet		3900	m (horizontal)
Other inflow[2]	173.3	656.9	m3/s	Tunnel length		3407	m
Other discharge[3]	263.0	269.0	m3/s	Penstock length		697	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	11	2.7	8.1	18.9	12.5	7	0.6
400	13	3.1	9.3	21.6	10.9	8	0.5
500	14	3.5	10.4	24.3	9.7	8	0.5
600	16	3.9	11.6	27.1	8.7	9	0.5
700	18	4.3	12.8	29.8	7.9	9	0.5
800	19	4.6	13.9	32.5	7.3	9	0.4
900	21	5.0	15.1	35.2	6.7	10	0.4
1000	23	5.4	16.3	37.9	6.2	10	0.4
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	68	34	23	0.117	0.016	0.036	0.168
400	91	46	30	0.155	0.021	0.045	0.222
500	114	57	38	0.194	0.027	0.054	0.275
600	137	68	46	0.233	0.032	0.062	0.327
700	160	80	53	0.272	0.037	0.070	0.380
800	183	91	61	0.311	0.042	0.078	0.432
900	205	103	68	0.350	0.048	0.086	0.484
1000	228	114	76	0.389	0.053	0.094	0.535

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Sandsavatn (173.3 m^3/s) results from:

- 640 MW in Saurdal power station

[2] Other inflow to Suldalsvatn (656.9 m^3/s) results from:

- 1,240 MW in Kvilldal power station
- 2,400 MW in Kvilldal power station (Blåsjø)
- 160 MW in Suldal power station 1
- 150 MW in Suldal power station 2

[3] Other discharge from Sandsavatn (263.0 m^3/s) results from:

- 1,240 MW in Kvilldal power station

[3] Discharge from Suldalsvatn (269.0 m^3/s) results from:

- 160 MW in Hylen power station

Table 2.19 shows the water level decrease in Sandsavatn (upper reservoir) and water level increase in Suldalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Kvilldal pumped storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.20 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Sandsavatn when the power generation in Kvilldal pumped storage power station is 500 MW. The number of hours/day of power generation and pumping and the start level (%) in Sandsavatn are varied. **Table 2.21** shows the filling time (days) to HRWL for Suldalsvatn under corresponding conditions.

Table 2.13: Water level reduction and emptying time for Sandsavatn when Kvilldal pumped storage power station is generating 500 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	3.5	12.9
		75		9.7
		50		6.5
18	0	75	2.6	12.9
	6		1.9	17.7
12	0		1.7	19.4
	6		1.0	32.4
	12		0.3	97.1

Table 2.14: Filling time for Suldalsvatn when Kvilldal pumped storage power station is generating 500 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	0.8
		50	0.5
		75	0.3
18	0	50	0.7
	6		0.9
12	0		1.0
	6		1.7
	12		5.1

B6a Kvilldal pumped storage power station (Blåsjø – Suldalsvatn)

Table 2.15: Case B6a Kvilldal pumped storage power station (Blåsjø – Suldalsvatn).

B6a Pumped storage power station Kvilldal (Blåsjø - Suldalsvatn), 1 400 MW in hydro storage power station Jøsenfjorden							
Reservoir	**Blåsjø**	**Suldalsvatn**					
Volume	3105.0	44.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1055.0	69.0	m	Pumping with max. power		0	hours/day
LRWL	930.0	67.0	m				
HRWL - LRWL	125.0	2.0	m	Gross pressure head (2/3 res. level)		945.0	m
Start level[1]	75	50	%	Distance intake-outlet		20000	m (horizontal)
Other inflow[2]		354.9	m3/s	Tunnel length		19137	m
Other discharge[3]	337.3	269.0	m3/s	Penstock length		1220	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1000	7	1.6	4.8	11.3	58.2	3	1.2
1200	7	1.7	5.1	11.9	55.2	4	1.1
1400	7	1.8	5.4	12.5	52.5	4	1.0
1600	8	1.9	5.6	13.1	50.0	5	0.9
1800	8	2.0	5.9	13.7	47.8	5	0.8
2000	9	2.0	6.1	14.3	45.7	6	0.8
2200	9	2.1	6.4	15.0	43.9	6	0.7
2400	9	2.2	6.7	15.6	42.1	6	0.7
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1000	126	63	42	1.205	0.051	0.083	1.340
1200	151	76	50	1.446	0.061	0.096	1.604
1400	176	88	59	1.688	0.072	0.109	1.868
1600	202	101	67	1.929	0.082	0.121	2.132
1800	227	113	76	2.170	0.092	0.133	2.395
2000	252	126	84	2.411	0.102	0.145	2.658
2200	277	139	92	2.652	0.113	0.156	2.921
2400	302	151	101	2.893	0.123	0.168	3.183

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Suldalsvatn (354.9 m^3/s) results from:

- 1,240 MW in Kvilldal
- 0 MW in Kvilldal power station (Sandsavatn)
- 160 MW in Suldal power station 1
- 150 MW in Suldal power station 2

[3] Other discharge from Blåsjø (337.3 m^3/s) results from:

- 640 MW in Saurdal power station
- 1,400 MW in power station in Jøsenfjorden
- 0 MW in Holen power station

[3] Discharge from Suldalsvatn (269.0 m^3/s) results from:

- 160 MW in Hylen power station

Table 2.22 shows the water level decrease in Blåsjø (upper reservoir) and water level increase in Suldalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Kvilldal pumped storage power station, when the design power output is 1,000 – 2,400 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.23 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Blåsjø when the power generation in Kvilldal pumped storage power station is 1,400 MW. The number of hours/day of power generation and pumping and the start level (%) in Blåsjø are varied. **Table 2.24** shows the filling time (days) to HRWL for Suldalsvatn under corresponding conditions.

Table 2.16: Water level reduction and emptying time for Blåsjø when Kvilldal pumped storage power station is generating 1,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	1.8	70.0
		75		52.5
		50		35.0
18	0	75	1.3	70.0
	6		1.0	95.4
12	0		0.9	104.9
	6		0.5	174.9
	12		0.2	524.7

Table 2.17: Filling time for Suldalsvatn when Kvilldal pumped storage power station is generating 1,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	1.5
		50	1.0
		75	0.5
18	0	50	1.3
	6		1.8
12	0		1.9
	6		3.2
	12		9.7

B6b Kvilldal pumped storage power station (Blåsjø – Suldalsvatn)

Table 2.18: Case B6b Kvilldal pumped storage power station (Blåsjø – Suldalsvatn).

B6b Kvilldal pumped storage power station (Blåsjø - Suldalsvatn), 2 400 MW in hydro storage power station Jøsenfjorden							
Reservoir	**Blåsjø**	**Suldalsvatn**					
Volume	3105.0	44.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1055.0	69.0	m	Pumping with max. power		0	hours/day
LRWL	930.0	67.0	m				
HRWL - LRWL	125.0	2.0	m	Gross pressure head (2/3 res. level)		945.0	m
Start level[1]	75	50	%	Distance intake-outlet		20000	m (horizontal)
Other inflow[2]		354.9	m3/s	Tunnel length		19137	m
Other discharge[3]	455.3	269.0	m3/s	Penstock length		1220	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1600	10	2.3	6.9	16.0	41.0	5	0.9
1800	10	2.4	7.1	16.6	39.5	5	0.8
2000	10	2.5	7.4	17.2	38.1	6	0.8
2200	11	2.5	7.6	17.8	36.8	6	0.7
2400	11	2.6	7.9	18.4	35.6	6	0.7
2600	11	2.7	8.2	19.1	34.4	7	0.6
2800	12	2.8	8.4	19.7	33.4	7	0.6
3000	12	2.9	8.7	20.3	32.3	8	0.5
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1600	202	101	67	1.929	0.082	0.121	2.132
1800	227	113	76	2.170	0.092	0.133	2.395
2000	252	126	84	2.411	0.102	0.145	2.658
2200	277	139	92	2.652	0.113	0.156	2.921
2400	302	151	101	2.893	0.123	0.168	3.183
2600	328	164	109	3.134	0.133	0.179	3.446
2800	353	176	118	3.375	0.143	0.190	3.708
3000	378	189	126	3.616	0.154	0.200	3.970

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Suldalsvatn (354.9 m^3/s) results from:

- 1,240 MW in Kvilldal power station
- 0 MW in Kvilldal power station (Sandsavatn)
- 160 MW in Suldal power station 1
- 150 MW in Suldal power station 2

[3] Other discharge from Blåsjø (455.3 m^3/s) results from:

- 640 MW in Saurdal power station
- 2,400 MW in power station in Jøsenfjorden
- 0 MW in Holen power station

[3] Discharge from Suldalsvatn (269.0 m^3/s) results from:

- 160 MW in Hylen power station

Table 2.25 shows the water level decrease in Blåsjø (upper reservoir) and water level increase in Suldalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Kvilldal pumped storage power station, when the design power output is 1,600 – 3,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.26 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Blåsjø when the power generation in Kvilldal pumped storage power station is 2,400 MW. The number of hours/day of power generation and pumping and the start level (%) in Blåsjø are varied. **Table 2.27** shows the filling time (days) to HRWL for Suldalsvatn under corresponding conditions.

Table 2.19: Water level reduction and emptying time for Blåsjø when Kvilldal pumped storage power station is generating 2,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	2.6	47.4
		75		35.6
		50		23.7
18	0	75	2.0	47.4
	6		1.4	64.7
12	0		1.3	71.1
	6		0.8	118.6
	12		0.3	355.7

Table 2.20: Filling time for Suldalsvatn when Kvilldal pumped storage power station is generating 2,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	1.0
		50	0.7
		75	0.3
18	0	50	0.9
	6		1.2
12	0		1.3
	6		2.2
	12		6.6

B7a Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden)

Table 2.21: Case B7a Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden).

B7a Hydro storage power station Jøsenfjorden (Blåsjø - Jøsenfjorden), 1 400 MW in pumped storage power station Kvilldal							
Reservoir	**Blåsjø**	(sjø)					
Volume	3105.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	1055.0	0.0	m	Pumping with max. power			hours/day
LRWL	930.0	0.0	m				
HRWL - LRWL	125.0	0.0	m	Gross pressure head (2/3 res. level)		1013.3	m
Start level[1]	75		%	Distance intake-outlet		15000	m (horizontal)
Other inflow[2]			m3/s	Tunnel length		14070	m
Other discharge[3]	349.3		m3/s	Penstock length		1315	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1000	7	1.6	4.9	11.4	57.7		
1200	7	1.7	5.1	11.9	55.0		
1400	7	1.8	5.4	12.5	52.5		
1600	8	1.9	5.6	13.1	50.2		
1800	8	2.0	5.9	13.7	48.1		
2000	8	2.0	6.1	14.2	46.1		
2200	9	2.1	6.3	14.8	44.3		
2400	9	2.2	6.6	15.4	42.7		
Max. power generated [MW]	Max. absorp-tion capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1000	117	59	39	0.826	0.052	0.082	0.960
1200	141	70	47	0.992	0.062	0.095	1.148
1400	164	82	55	1.157	0.072	0.107	1.337
1600	188	94	63	1.322	0.082	0.119	1.524
1800	211	106	70	1.488	0.093	0.131	1.712
2000	235	117	78	1.653	0.103	0.143	1.899
2200	258	129	86	1.818	0.113	0.154	2.086
2400	282	141	94	1.984	0.124	0.165	2.272

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[3] Other discharge from Blåsjø (349.3 m^3/s) results from:

- 640 MW in Saurdal power station
- 1,400 MW in Kvilldal power station
- 0 MW in Holen power station (Blåsjø)

Table 2.28 shows the water level decrease in Blåsjø (upper reservoir) in the event of maximum power generation for 24 hours/day in Jøsenfjorden hydro storage power station, when the design power output is 1,000 – 2,400 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Blåsjø is 75 %.

Table 2.29 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Blåsjø when the power generation in Jøsenfjorden hydro storage power station is 1,400 MW. The number of hours/day of power generation and the start level (%) in Blåsjø are varied.

Table 2.22: Water level reduction and emptying time for Blåsjø when Jøsenfjorden hydro storage power station is generating 1,400 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	1.8	69.9
	75		52.5
	50		35.0
18	75	1.3	69.9
12		0.9	104.9

B7b Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden)

Table 2.23: Case B7b Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden).

B7b Jøsenfjorden hydro storage power station (Blåsjø - Jøsenfjorden), 2 400 MW in Kvilldal pumped storage power station							
Reservoir	**Blåsjø**	(sjø)					
Volume	3105.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	1055.0	0.0	m	Pumping with max. power			hours/day
LRWL	930.0	0.0	m				
HRWL - LRWL	125.0	0.0	m	Gross pressure head (2/3 res. level)		1013.3	m
Start level[1]	75		%	Distance intake-outlet		15000	m (horizontal)
Other inflow[2]			m3/s	Tunnel length		14070	m
Other discharge[3]	475.3		m3/s	Penstock length		1315	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
2000	10	2.5	7.4	17.3	37.9		
2200	11	2.6	7.7	17.9	36.7		
2400	11	2.6	7.9	18.4	35.6		
2600	11	2.7	8.1	19.0	34.5		
2800	12	2.8	8.4	19.6	33.5		
3000	12	2.9	8.6	20.2	32.6		
3200	12	3.0	8.9	20.7	31.7		
3400	13	3.0	9.1	21.3	30.8		
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
2000	235	117	78	1.653	0.103	0.143	1.899
2200	258	129	86	1.818	0.113	0.154	2.086
2400	282	141	94	1.984	0.124	0.165	2.272
2600	305	153	102	2.149	0.134	0.176	2.459
2800	329	164	110	2.314	0.144	0.187	2.645
3000	352	176	117	2.479	0.155	0.197	2.831
3200	376	188	125	2.645	0.165	0.208	3.018
3400	399	200	133	2.810	0.175	0.218	3.203

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[3] Other discharge from Blåsjø (475.3 m^3/s) results from:

- 640 MW in Saurdal power station
- 2,400 MW in Kvilldal power station
- 0 MW in Holen power station (Blåsjø)

Table 2.30 shows the water level decrease in Blåsjø (upper reservoir) in the event of maximum power generation for 24 hours/day in Jøsenfjorden hydro storage power station, when the design power output is 2,000 – 3,400 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Blåsjø is 75 %.

Table 2.31 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Blåsjø when the power generation in Jøsenfjorden hydro storage power station is 2,400 MW. The number of hours/day of power generation and the start level (%) in Blåsjø are varied.

Table 2.24: Water level reduction and emptying time for Blåsjø when Jøsenfjorden hydro storage power station is generating 2,400 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	2.6	47.5
	75		35.6
	50		23.7
18	75	2.0	47.5
12		1.3	71.2

2.3 Møsvatn – Tinnsjø – Kallhovd/Mår

Three cases were analysed in connection with Møsvatn – Tinnsjø – Kallhovd/Mår, as follows:

- C1 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)
- C2 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø) + Tinnsjø pumped storage power station (Kallhovd – Tinnsjø)
- C3 Tinnsjø pumped storage power station (Kallhovd – Tinnsjø) + Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)

C1 and C2 apply to the same power station, Tinnsjø (Møsvatn – Tinnsjø). The difference in C1 and C2 is that C2 also includes discharge from Kallhovd to Tinnsjø from the power station in C3, Tinnsjø (Kallhovd – Tinnsjø).

The new tunnels in case C1 – C3 are drawn in red on the map excerpt in **Figure 2.5**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

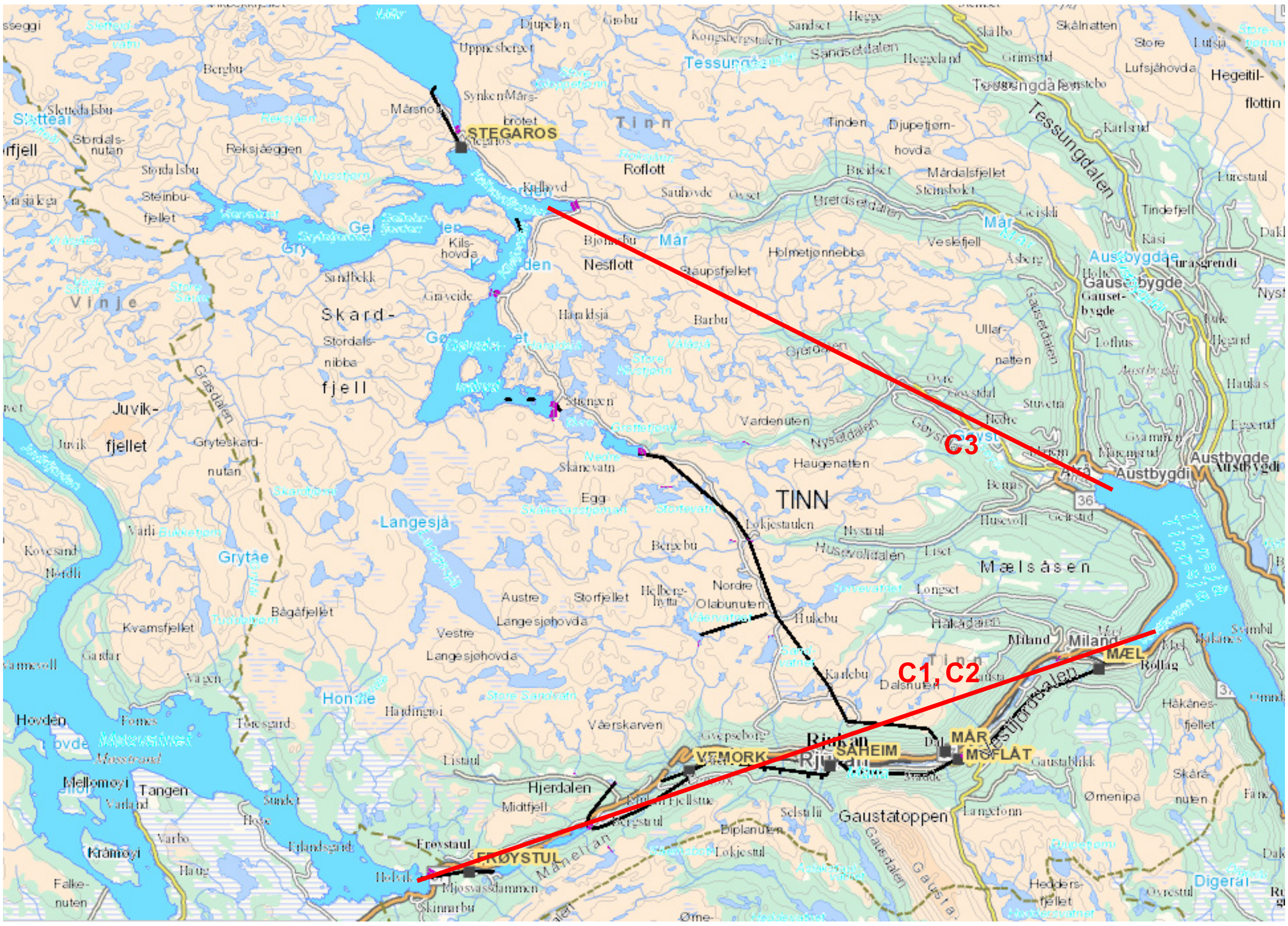


Figure 2.3: Møsvatn – Tinnsjø – Kallhovd/Mår.

The new pumped storage power stations, tunnels and associated reservoirs in cases C1– C3 are illustrated in **Figure 2.6**.

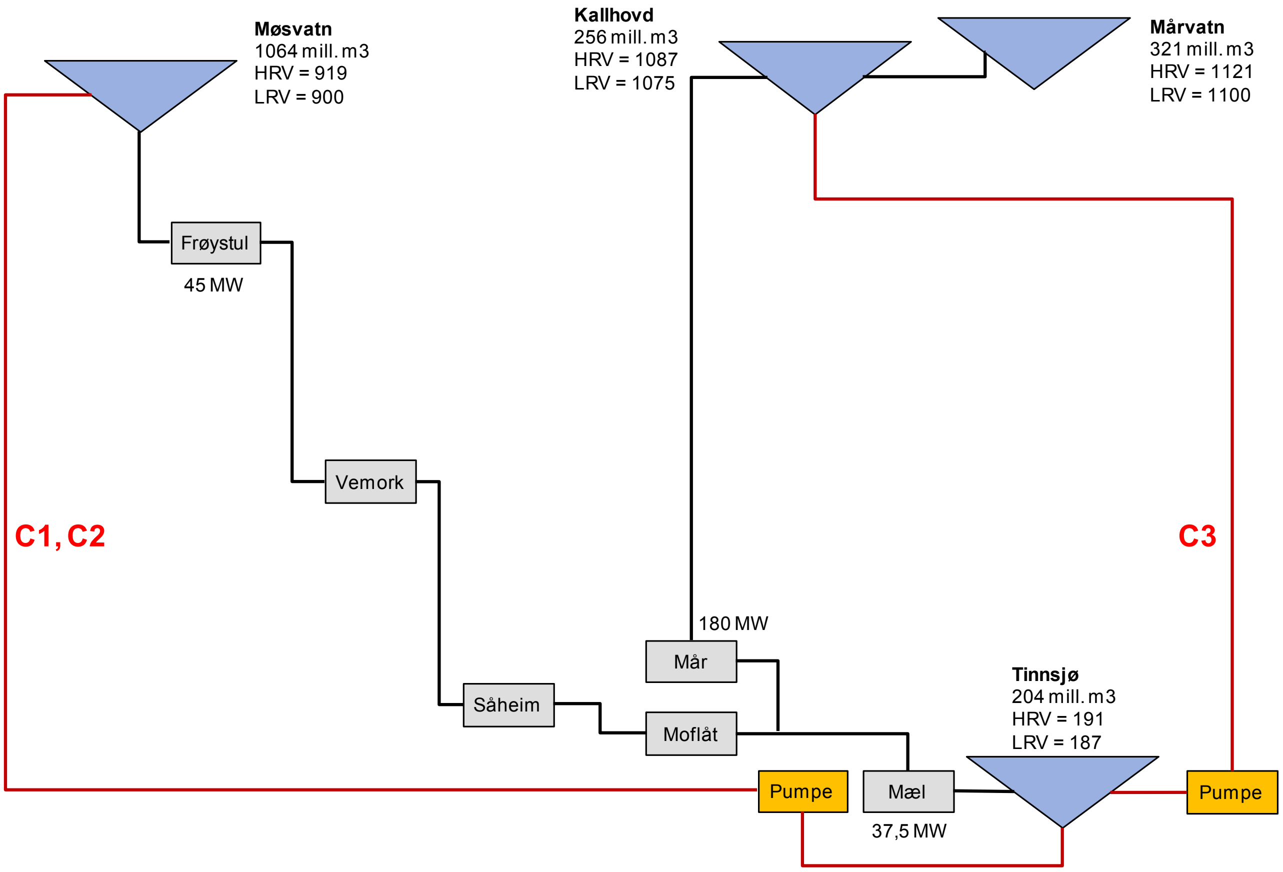


Figure 2.4: Møsvatn – Tinnsjø – Kallhovd/Mår.

C1 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)

Table 2.25: Case C1 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø).

C1 Pumped storage power station Tinnsjø (Møsvatn - Tinnsjø)							
Reservoir	**Møsvatn**	**Tinnsjø**					
Volume	1064.0	204.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	919.0	191.0	m	Pumping with max. power		0	hours/day
LRWL	900.0	187.0	m				
HRWL - LRWL	19.0	4.0	m	Gross pressure head (2/3 res. level)		723.0	m
Start level[1]	75	50	%	Distance intake-outlet		30000	m (horizontal)
Other inflow[2]		99.7	m3/s	Tunnel length		29287	m
Other discharge[3]	87.1	150.2	m3/s	Penstock length		1008	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
700	1	0.3	0.9	2.2	45.6	0	18.2
800	1	0.3	1.0	2.4	42.2	1	14.5
900	2	0.4	1.1	2.5	39.3	1	12.1
1000	2	0.4	1.2	2.7	36.7	1	10.3
1100	2	0.4	1.2	2.9	34.4	1	9.0
1200	2	0.4	1.3	3.1	32.4	1	8.0
1300	2	0.5	1.4	3.3	30.7	1	7.2
1400	2	0.5	1.5	3.4	29.1	1	6.6
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
700	115	58	38	1.688	0.039	0.066	1.793
800	132	66	44	1.929	0.044	0.073	2.047
900	148	74	49	2.170	0.050	0.081	2.301
1000	165	82	55	2.411	0.055	0.088	2.554
1100	181	91	60	2.652	0.061	0.095	2.808
1200	198	99	66	2.893	0.066	0.102	3.061
1300	214	107	71	3.135	0.072	0.108	3.315
1400	231	115	77	3.376	0.077	0.115	3.568

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Tinnsjø (99.7 m^3/s) results from:

- 37.5 MW in Mæl power station

[3] Other discharge from Møsvatn (87.1 m^3/s) results from:

- 45 MW in Frøystul power station

[3] Dicharge from Tinnsjø (150.2 m^3/s) results from:

- 22.2 MW in Årlifoss power station

Table 2.32 shows the water level decrease in Møsvatn (upper reservoir) and water level increase in Tinnsjø (lower reservoir) in the event of maximum power generation for 24 hours/day in Tinnsjø pumped storage power station, when the design power output is 700 – 1,400 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.33 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Møsvatn when the power generation in Tinnsjø pumped storage power station is 1,000 MW. The number of hours/day of power generation and pumping and the start level (%) in Møsvatn are varied. **Table 2.34** shows the filling time (days) to HRWL for Tinnsjø under corresponding conditions.

Table 2.26: Water level reduction and emptying time for Møsvatn when Tinnsjø pumped storage power station is generating 1,000 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	0.4	48.9
		75		36.7
		50		24.5
18	0	75	0.3	48.9
	6		0.2	66.7
12	0		0.2	73.4
	6		0.1	122.3
	12		0.0	366.9

Table 2.27: Filling time for Tinnsjø when Tinnsjø pumped storage power station is generating 1,000 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	15.5
		50	10.3
		75	5.2
18	0	50	13.8
	6		18.8
12	0		20.7
	6		34.5
	12		103.4

C2 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)

Table 2.28: Case C2 Tinnsjø pumped storage power station (Møsvatn – Tinnsjø).

C2 Tinnsjø pumped storage power station (Møsvatn - Tinnsjø)							
Reservoir	**Møsvatn**	**Tinnsjø**					
Volume	1064.0	204.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	919.0	191.0	m	Pumping with max. power		0	hours/day
LRWL	900.0	187.0	m				
HRWL - LRWL	19.0	4.0	m	Gross pressure head (2/3 res. level)		723.0	m
Start level[1]	75	50	%	Distance intake-outlet		30000	m (horizontal)
Other inflow[2]		419.7	m3/s	Tunnel length		29287	m
Other discharge[3]	87.1	150.2	m3/s	Penstock length		1008	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1400	2	0.5	1.5	3.4	29.1	4	2.4
1600	2	0.5	1.6	3.8	26.3	4	2.2
1800	2	0.6	1.8	4.1	24.1	4	2.1
2000	3	0.6	1.9	4.5	22.2	4	2.0
2200	3	0.7	2.1	4.9	20.6	4	1.9
2400	3	0.7	2.2	5.2	19.2	5	1.8
2600	3	0.8	2.4	5.6	17.9	5	1.7
2800	4	0.8	2.5	5.9	16.8	5	1.6
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1400	231	115	77	3.376	0.077	0.115	3.568
1600	263	132	88	3.858	0.089	0.128	4.074
1800	296	148	99	4.340	0.100	0.140	4.580
2000	329	165	110	4.822	0.111	0.153	5.086
2200	362	181	121	5.305	0.122	0.165	5.591
2400	395	198	132	5.787	0.133	0.177	6.096
2600	428	214	143	6.269	0.144	0.188	6.601
2800	461	231	154	6.751	0.155	0.200	7.106

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Other inflow to Tinnsjø (419.7 m^3/s) results from:

- 37.5 MW in Mæl power station
- 2400 MW in Tinnsjø power station (Kallhovd – Tinnsjø)

[3] Other discharge from Møsvatn (87.1 m^3/s) results from:

- 45 MW in Frøystul power station

[3] Discharge from Tinnsjø (150.2 m^3/s) results from:

- 22.2 MW in Årlifoss power station

Table 2.35 shows the water level decrease in Møsvatn (upper reservoir) and water level increase in Tinnsjø (lower reservoir) in the event of maximum power generation for 24 hours/day in Tinnsjø pumped storage power station, when the design power output is 1,400 – 2,800 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.36 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Møsvatn when the power generation in Tinnsjø pumped storage power station is 2,000 MW. The number of hours/day of power generation and pumping and the start level (%) in Møsvatn are varied. **Table 2.37** shows the filling time (days) to HRWL for Tinnsjø under corresponding conditions.

Table 2.29: Water level reduction and emptying time for Møsvatn when Tinnsjø pumped storage power station is generating 2,000 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	0.6	29.6
		75		22.2
		50		14.8
18	0	75	0.5	29.6
	6		0.4	40.3
12	0		0.3	44.4
	6		0.2	73.9
	12		0.1	221.8

Table 2.30: Filling time for Tinnsjø when Tinnsjø pumped storage power station is generating 2,000 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	3.0
		50	2.0
		75	1.0
18	0	50	2.6
	6		3.6
12	0		3.9
	6		6.6
	12		19.7

C3 Tinnsjø pumped storage power station (Kallhovd – Tinnsjø)

Table 2.31: Case C3 Tinnsjø pumped storage power station (Kallhovd – Tinnsjø).

C3 Tinnsjø pumped storage power station (Kallhovd - Tinnsjø)							
Reservoir	**Kallhovd**	**Tinnsjø**					
Volume	256.0	204.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1087.0	191.0	m	Pumping with max. power		0	hours/day
LRWL	1075.0	187.0	m				
HRWL - LRWL	12.0	4.0	m	Gross pressure head (2/3 res. level)		893.3	m
Start level[1]	75	50	%	Distance intake-outlet		25000	m (horizontal)
Other inflow[2]		428.7	m3/s	Tunnel length		24112	m
Other discharge[3]	87.1	150.2	m3/s	Penstock length		1256	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1800	6	1.3	4.0	9.3	6.8	4	2.3
2000	6	1.4	4.3	10.0	6.3	4	2.2
2200	6	1.5	4.6	10.8	5.8	4	2.1
2400	7	1.6	4.9	11.5	5.5	4	2.0
2600	7	1.8	5.3	12.3	5.1	4	1.9
2800	8	1.9	5.6	13.0	4.8	5	1.8
3000	8	2.0	5.9	13.8	4.6	5	1.7
3200	9	2.1	6.2	14.6	4.3	5	1.7
Max. power generated [MW]	Max. absorp-tion capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1800	240	120	80	2.892	0.100	0.135	3.127
2000	267	133	89	3.213	0.112	0.146	3.471
2200	293	147	98	3.535	0.123	0.158	3.815
2400	320	160	107	3.856	0.134	0.169	4.159
2600	346	173	115	4.177	0.145	0.181	4.503
2800	373	187	124	4.499	0.156	0.192	4.846
3000	400	200	133	4.820	0.167	0.203	5.190
3200	426	213	142	5.141	0.179	0.213	5.533

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Kallhovd (0 m^3/s):

- Hva er bidraget fra Mårvatn? (sikkert mer enn det som 2.4 MW i Stegaros kraftverk gir)

[2] Other inflow to Tinnsjø (428.7 m^3/s) results from:

- 37.5 MW in Mæl power station
- 2,000 MW in Møsvatn power station

[3] Other discharge from Kallhovd (87.1 m^3/s) (25.2 according to NVE-data base) results from:

- 180 MW in Mår power station

[3] Discharge from Tinnsjø (150.2 m^3/s) results from:

- 22.2 MW in Årlifoss power station

Table 2.38 shows the water level decrease in Kallhovd (upper reservoir) and water level increase in Tinnsjø (lower reservoir) in the event of maximum power generation for 24 hours/day in Tinnsjø pumped storage power station, when the design power output is 1,800 – 3,200 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.39 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Kallhovd when the power generation in Tinnsjø pumped storage power station is 2,400 MW. The number of hours/day of power generation and pumping and the start level (%) in Kallhovd are varied. **Table 2.40** shows the filling time (days) to HRWL for Tinnsjø under corresponding conditions.

Table 2.32: Water level reduction and emptying time for Kallhovd when Tinnsjø pumped storage power station is generating 2,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	1.6	7.3
		75		5.5
		50		3.6
18	0	75	1.2	7.3
	6		0.9	9.9
12	0		0.8	10.9
	6		0.5	18.2
	12		0.2	54.6

Table 2.33: Filling time for Tinnsjø when Tinnsjø pumped storage power station is generating 2,400 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	3.0
		50	2.0
		75	1.0
18	0	50	2.6
	6		3.6
12	0		3.9
	6		6.6
	12		19.7

2.4 Lysebotn

The following case is analysed in connection with the existing Lysebotn power station:

D1 Lysebotn hydrostorage power station (Lyngsvatn – Lysefjorden)

The new tunnel in case D1 is drawn in red on the map excerpt in **Figure 2.7**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

Figure 2.5: Case Lysebotn.

Lyse Energi got a license to construct a new power station in Lysebotn as replacement of the old one. The new power station will receive water directly from Lyngsvatn, and the power generation will increase by 160 GWh. This increase in generation is not taken into account in case D1.

The planned replacement implies that the intake will be moved up to the main reservoir Lyngsvatn.

According to NVE's assessment, the replacement will lead to minor disadvantages for the environment and other public interests. The current license with associated stipulations for the existing power station and regulations will also apply for the new power station named above.

The new hydro storage power station, tunnel and associated reservoirs in case D1 are illustrated in **Figure 2.8**.

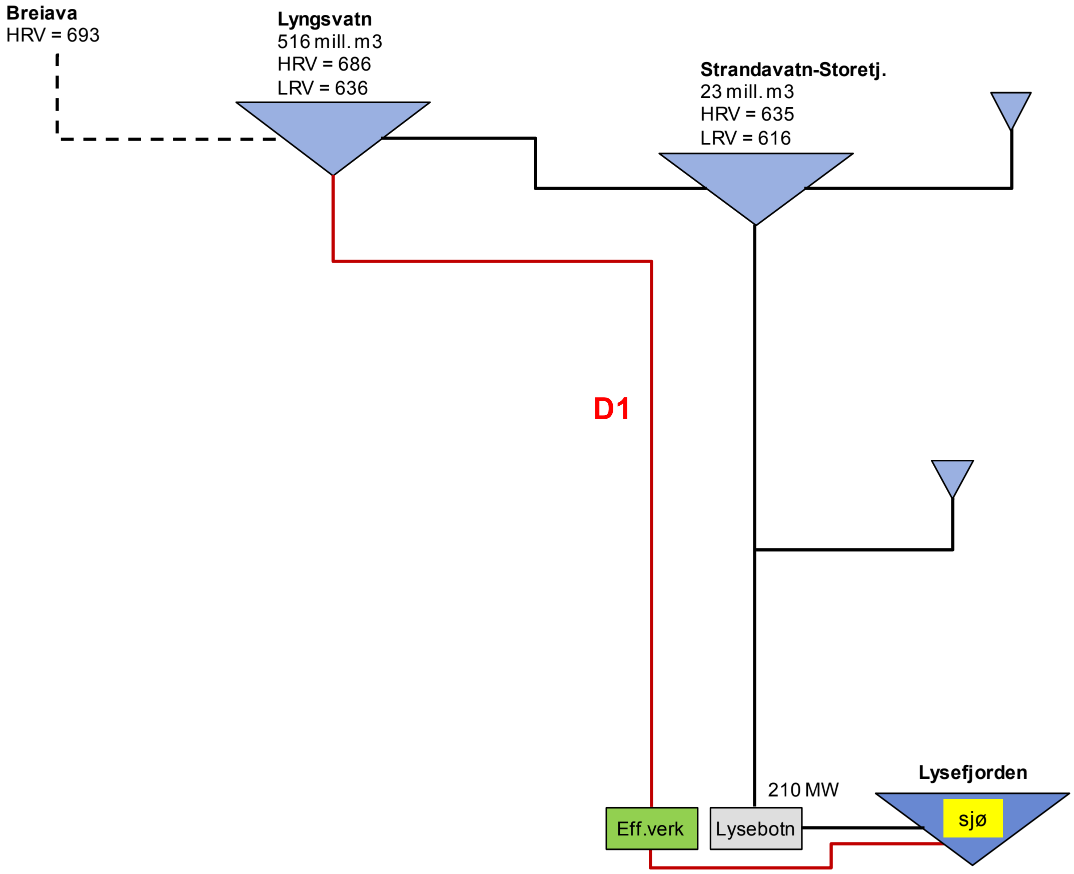


Figure 2.6: Case Lysebotn.

D1 Lysebotn hydro storage power station (Lyngsvatn – Lysefjorden)

Table 2.34: Case D1 Lysebotn hydro storage power station (Lyngsvatn – Lysefjorden).

D1 Hydro storage power station Lysebotn (Lyngsvatn - Lysefjorden)							
Reservoir	**Lyngsvatn**	(sjø)					
Volume	516.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	686.0	0.0	m	Pumping with max. power			hours/day
LRWL	636.0	0.0	m				
HRWL - LRWL	50.0	0.0	m	Gross pressure head (2/3 res. level)		669.3	m
Start level[1]	75		%	Distance intake-outlet		6200	m (horizontal)
Other inflow[2]	29.4		m3/s	Tunnel length		5564	m
Other discharge[3]	42.0		m3/s	Penstock length		899	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
1000	7	1.6	4.8	11.2	23.5		
1200	8	1.9	5.7	13.2	19.8		
1400	9	2.2	6.6	15.3	17.1		
1600	10	2.5	7.5	17.4	15.1		
1800	12	2.8	8.4	19.5	13.5		
2000	13	3.1	9.3	21.6	12.2		
2200	14	3.4	10.1	23.7	11.1		
2400	15	3.7	11.0	25.8	10.2		
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
1000	178	89	59	0.495	0.053	0.089	0.637
1200	213	107	71	0.594	0.064	0.103	0.761
1400	249	125	83	0.693	0.075	0.117	0.884
1600	285	142	95	0.792	0.085	0.130	1.007
1800	320	160	107	0.891	0.096	0.143	1.129
2000	356	178	119	0.990	0.107	0.155	1.251
2200	391	196	130	1.089	0.117	0.167	1.373
2400	427	213	142	1.188	0.128	0.179	1.495

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Lyngsvatn (29.4 m^3/s) results from:

- 14.8 MW in Breiava power station

[3] Other discharge from Lyngsvatn (42.0 m^3/s) results from:

- 210 MW in Lysebotn power station

Table 2.41 shows the water level decrease in Lyngsvatn (upper reservoir) in the event of maximum power generation for 24 hours/day in Lyngsvatn hydro storage power station, when the design power output is 1,000 – 2,400 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Lyngsvatn is 75 %.

Table 2.42 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Lyngsvatn when the power generation in Lyngsvatn hydro storage power station is 1,400 MW. The number of hours/day of power generation and the start level (%) in Lyngsvatn are varied.

Table 2.35: Water level reduction and emptying time for Lyngsvatn when Lyngsvatn hydro storage power station is generating 1,400 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	2.2	22.8
	75		17.1
	50		11.4
18	75	1.6	22.8
12		1.1	34.2

2.5 Mauranger – Oksla – Tysso

Three cases were analysed in connection with Mauranger – Oksla – Tysso, as follows:

E1	Mauranger hydro storage power station (Juklavatn – sjø)
E2	Oksla hydro storage power station (Ringedalsvatn – sjø)
E3	Tysso pumped storage power station (Langevatn – Ringedalsvatn)

The new tunnels in case E1 – E3 are drawn in red on the map excerpt in **Figure 2.9**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

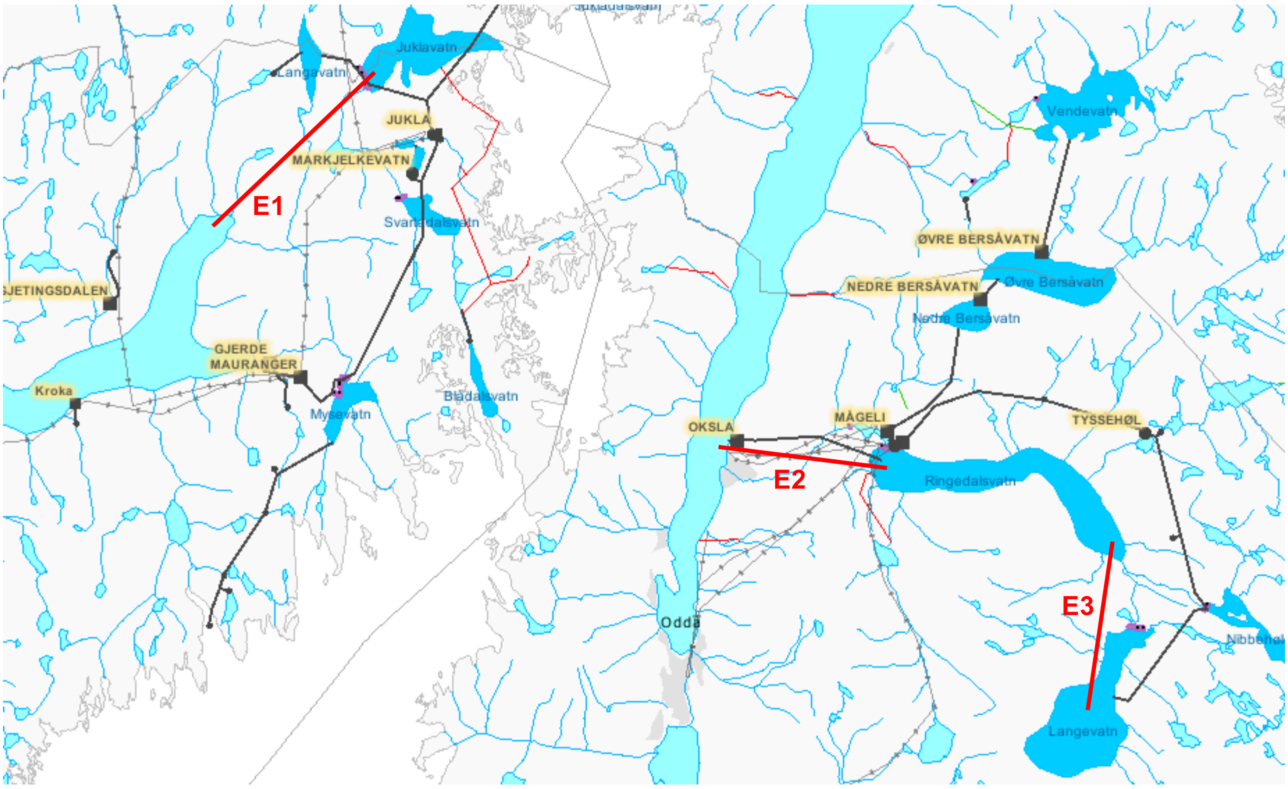


Figure 2.7: Case Mauranger (E1) – Oksla (E2) – Tysso (E3).

The new power stations, tunnels and associated reservoirs in case E1 – E3 are illustrated in **Figure 2.10**.

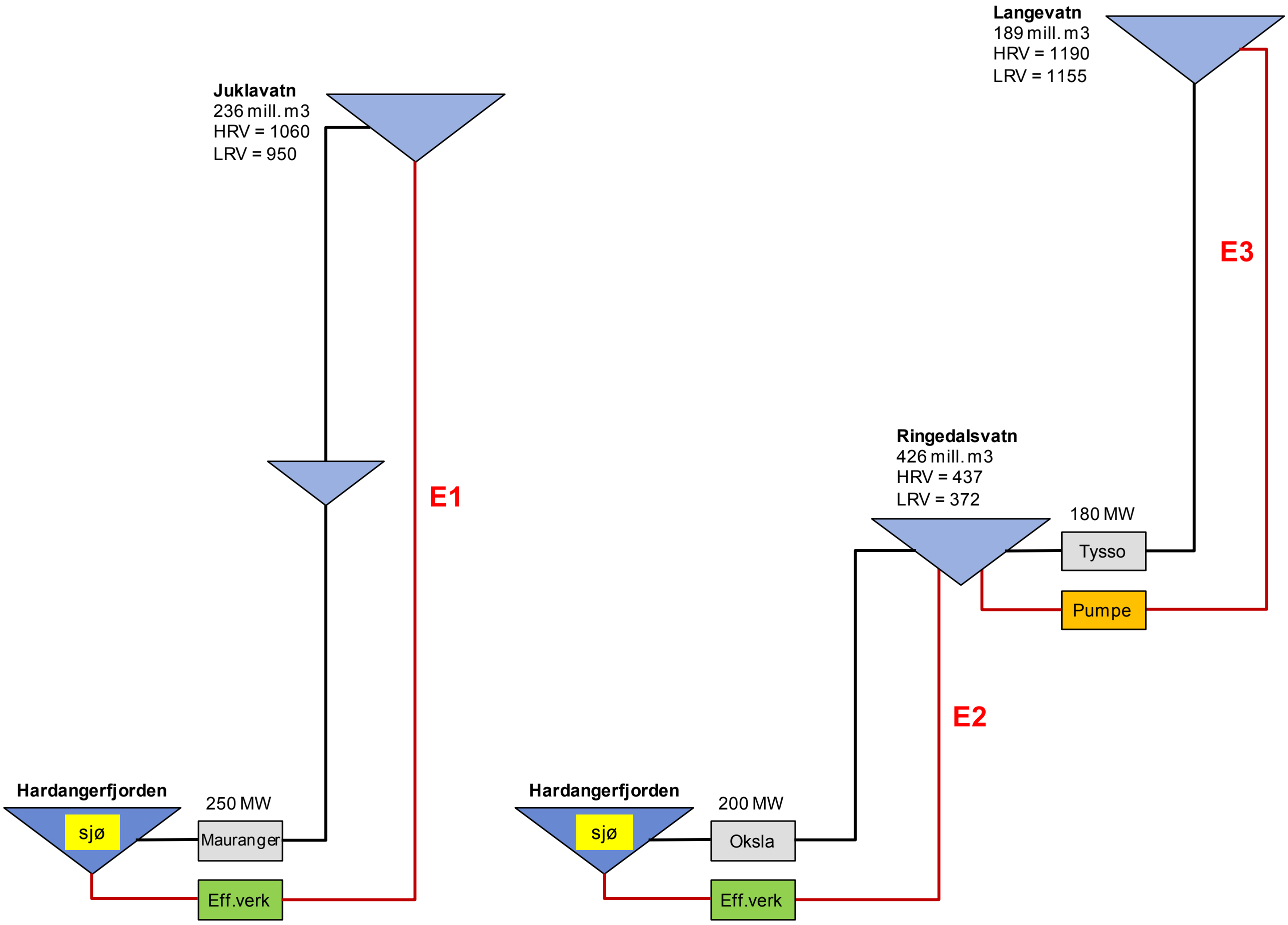


Figure 2.8: Case Mauranger (E1) – Oksla (E2) – Tysso (E3).

E1 Mauranger hydro storage power station (Juklavatn – sjø)

Table 2.36: Case E1 Mauranger hydro storage power station (Juklavatn – sjø).

E1 Mauranger hydro storage power station (Juklavatn - Hardangerfjorden)							
Reservoir	**Juklavatn**	(sjø)					
Volume	236.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	1060.0	0.0	m	Pumping with max. power			hours/day
LRWL	950.0	0.0	m				
HRWL - LRWL	110.0	0.0	m	Gross pressure head (2/3 res. level)		1023.3	m
Start level[1]	75		%	Distance intake-outlet		6200	m (horizontal)
Other inflow[2]			m3/s	Tunnel length		5250	m
Other discharge[3]	36.0		m3/s	Penstock length		1344	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	12	2.9	8.6	20.0	28.9		
400	14	3.3	10.0	23.3	24.8		
500	16	3.8	11.4	26.5	21.8		
600	18	4.3	12.8	29.8	19.4		
700	20	4.7	14.2	33.1	17.4		
800	22	5.2	15.6	36.4	15.9		
900	24	5.7	17.0	39.7	14.6		
1000	26	6.1	18.4	42.9	13.4		
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	35	17	12	0.092	0.016	0.031	0.138
400	47	23	16	0.122	0.021	0.039	0.182
500	58	29	19	0.153	0.026	0.047	0.226
600	70	35	23	0.183	0.031	0.054	0.269
700	81	41	27	0.214	0.036	0.062	0.312
800	93	47	31	0.244	0.042	0.068	0.354
900	105	52	35	0.275	0.047	0.075	0.397
1000	116	58	39	0.305	0.052	0.082	0.439

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[3] Other discharge from Juklavatn (36.0 m^3/s) results from:

- 250 MW in Mauranger power station (via Jukla)

Table 2.43 shows the water level decrease in Juklavatn (upper reservoir) in the event of maximum power generation for 24 hours/day in Mauranger hydro storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Juklavatn is 75 %.

Table 2.44 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Juklavatn when the power generation in Mauranger hydro storage power station is 400 MW. The number of hours/day of power generation and the start level (%) in Juklavatn are varied.

Table 2.37: Water level reduction and emptying time for Juklavatn when Mauranger hydro storage power station is generating 400 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	3.3	33.1
	75		24.8
	50		16.5
18	75	2.5	33.1
12		1.7	49.6

E2 Oksla hydro storage power station (Ringedalsvatn – sjø)

Table 2.38: Case E2 Oksla hydro storage power station (Ringedalsvatn – sjø).

E2 Oksla hydro storage power station (Ringedalsvatn - Hardangerfjorden)							
Reservoir	**Ringedalsvatn**	(sjø)					
Volume	426.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	436.9	0.0	m	Pumping with max. power			hours/day
LRWL	372.0	0.0	m				
HRWL - LRWL	64.9	0.0	m	Gross pressure head (2/3 res. level)		415.3	m
Start level[1]	75		%	Distance intake-outlet		4400	m (horizontal)
Other inflow[2]	30.0		m3/s	Tunnel length		4028	m
Other discharge[3]	52.0		m3/s	Penstock length		526	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	6	1.4	4.3	10.0	34.2		
400	7	1.8	5.4	12.6	27.1		
500	9	2.2	6.5	15.2	22.4		
600	11	2.6	7.7	17.9	19.1		
700	12	2.9	8.8	20.5	16.6		
800	14	3.3	9.9	23.2	14.7		
900	15	3.7	11.1	25.8	13.2		
1000	17	4.1	12.2	28.4	12.0		
Max. power generated [MW]	Max. absorp-tion capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	86	43	29	0.173	0.015	0.037	0.226
400	115	57	38	0.231	0.020	0.047	0.298
500	143	72	48	0.289	0.025	0.056	0.370
600	172	86	57	0.346	0.030	0.065	0.442
700	201	100	67	0.404	0.035	0.074	0.513
800	229	115	76	0.462	0.040	0.082	0.584
900	258	129	86	0.520	0.045	0.090	0.655
1000	287	143	96	0.577	0.050	0.098	0.726

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Ringedalsvatn (30 m^3/s) results from:

- 180 MW in Tysso power station

[3] Other discharge from Ringedalsvatn (22.0 m^3/s) results from:

- 200 MW in Oksla power station

Table 2.45 shows the water level decrease in Ringeldalsvatn (upper reservoir) in the event of maximum power generation for 24 hours/day in Oksla hydro storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Ringeldalsvatn is 75 %.

Table 2.46 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Ringeldalsvatn when the power generation in Oksla hydro storage power station is 700 MW. The number of hours/day of power generation and the start level (%) in Ringeldalsvatn are varied.

Table 2.39: Water level reduction and emptying time for Ringeldalsvatn when Oksla hydro storage power station is generating 700 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	2.9	22.1
	75		16.6
	50		11.1
18	75	2.2	22.1
12		1.5	33.2

E3 Tysso pumped storage power station (Langevatn – Ringedalsvatn)

Table 2.40: Case E3 Tysso pumped storage power station (Langevatn – Ringedalsvatn).

E3 Tysso pumped storage power station (Langevatn - Ringedalsvatn)							
Reservoir	**Langevatn**	**Ringedalsvatn**					
Volume	189.0	426.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1190.0	463.9	m	Pumping with max. power		0	hours/day
LRWL	1155.0	372.0	m				
HRWL - LRWL	35.0	91.9	m	Gross pressure head (2/3 res. level)		745.1	m
Start level[1]	75	50	%	Distance intake-outlet		4000	m (horizontal)
Other inflow[2]		30.0	m3/s	Tunnel length		3217	m
Other discharge[3]	30.0	52.0	m3/s	Penstock length		1107	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	5	1.2	3.7	8.7	21.1	2	95.1
400	6	1.5	4.5	10.5	17.5	3	58.8
500	7	1.8	5.3	12.3	14.9	4	42.6
600	8	2.0	6.0	14.1	13.0	6	33.4
700	9	2.3	6.8	15.9	11.6	7	27.4
800	11	2.5	7.6	17.7	10.4	8	23.3
900	12	2.8	8.3	19.5	9.4	9	20.2
1000	13	3.0	9.1	21.3	8.6	11	17.9
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	48	24	16	0.077	0.018	0.033	0.128
400	64	32	21	0.103	0.024	0.042	0.168
500	80	40	27	0.129	0.029	0.050	0.208
600	96	48	32	0.154	0.035	0.058	0.248
700	112	56	37	0.180	0.041	0.066	0.287
800	128	64	43	0.206	0.047	0.073	0.326
900	144	72	48	0.231	0.053	0.080	0.365
1000	160	80	53	0.257	0.059	0.087	0.403

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Ringdalsvatn (30.0 m^3/s) results from:

- 180 MW in Tysso

[3] Other discharge from Langevatn (30.0 m^3/s) results from:

- 180 MW in Tysso

[3] Discharge from Ringedalsvatn (52.0 m^3/s) results from:

- 200 MW in Oksla

Table 2.47 shows the water level decrease in Langevatn (upper reservoir) and water level increase in Ringedalsvatn (lower reservoir) in the event of maximum power generation for 24 hours/day in Tysso pumped storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start levels in the upper and lower reservoirs are 75 % and 50 %, respectively.

Table 2.48 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Langevatn when the power generation in Tysso pumped storage power station is 700 MW. The number of hours/day of power generation and pumping and the start level (%) in Langevatn are varied. **Table 2.49** shows the filling time (days) to HRWL for Ringedalsvatn under corresponding conditions.

Table 2.41: Water level reduction and emptying time for Langevatn when Tysso pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	0	100	2.3	15.4
		75		11.6
		50		7.7
18	0	75	1.7	15.4
	6		1.2	21.0
12	0		1.1	23.1
	6		0.7	38.6
	12		0.2	115.7

Table 2.42: Filling time for Ringedalsvatn when Tysso pumped storage power station is generating 700 MW

Power generation (hours/day)	Pumping (hours/day)	Start level (%)	Filling (days)
24	0	25	41.2
		50	27.4
		75	13.7
18	0	50	36.6
	6		49.9
12	0		54.9
	6		91.5
	12		274.4

2.6 Sima

The following case was analysed in connection with Sy-Sima kraftverk:

F1 Sy-Sima hydro storage powe station (Sysenvatn – sjø)

The new tunnel in case F1 is drawn in red on the map excerpt in **Figure 2.11**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

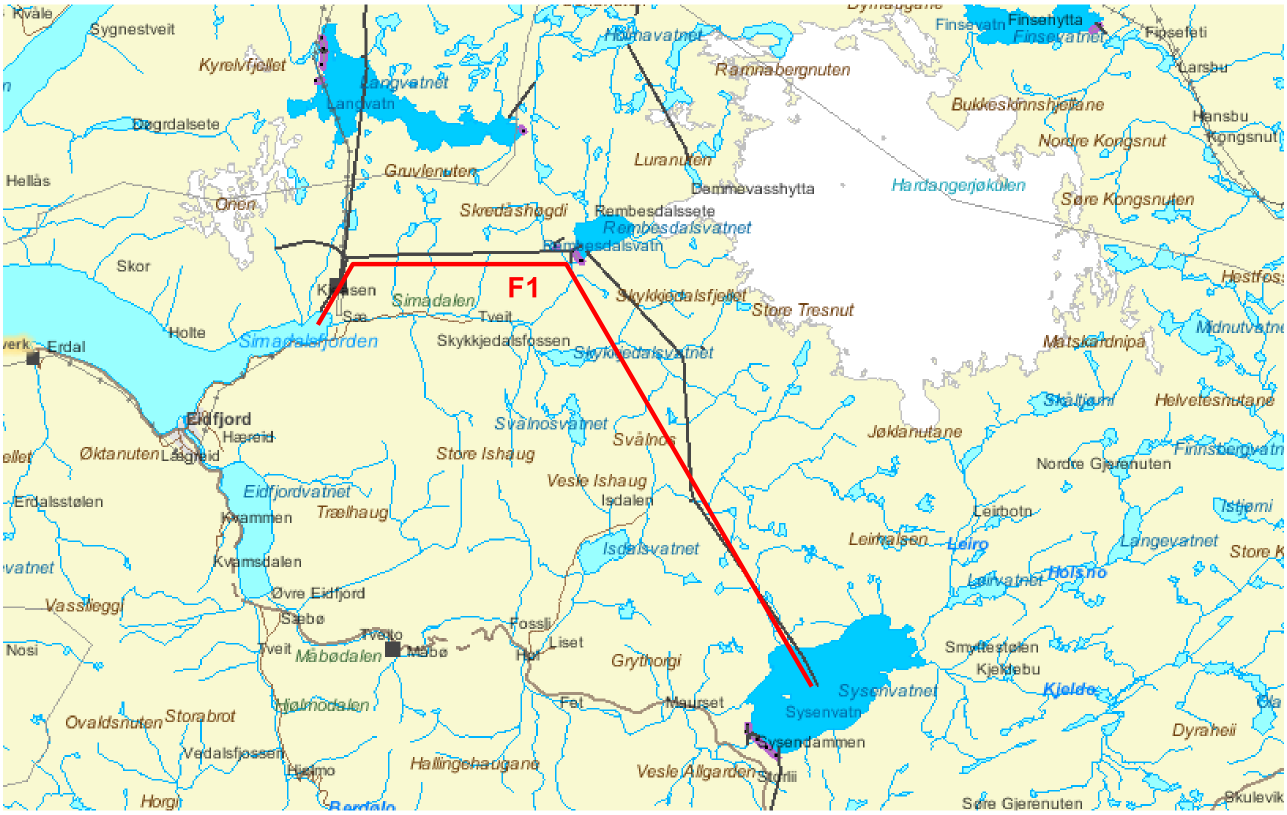


Figure 2.9: Case F1 Sy-Sima.

The new hydro storage power station, tunnel and associated reservoirs in case F1 are illustrated in **Figure 2.12**.

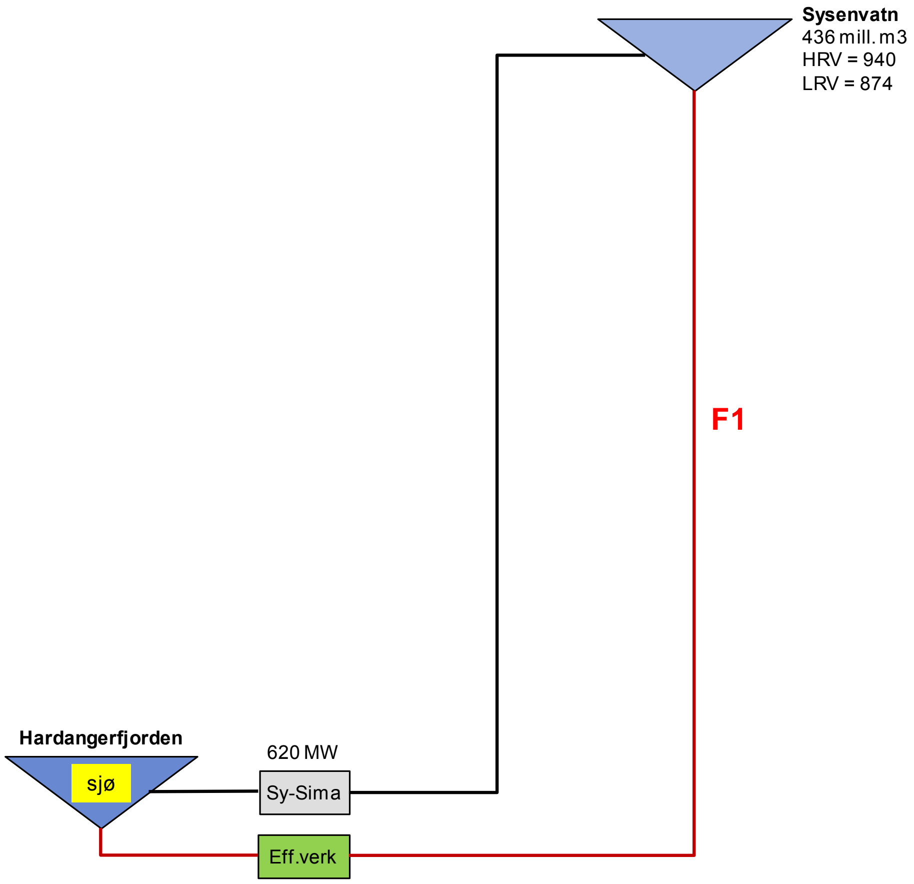


Figure 2.10: Case F1 Sy-Sima.

F1 Sy-Sima hydro storage power station (Sysenvatn – sjø)

Table 2.43: Case F1 Sy-Sima hydro storage power station (Sysenvatn – sjø).

F1 Sy-Sima hydro storage power station (Sysenvatn - Hardangerfjorden)							
Reservoir	**Sysenvatn**	(sjø)					
Volume	436.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	940.0	0.0	m	Pumping with max. power			hours/day
LRWL	874.0	0.0	m				
HRWL - LRWL	66.0	0.0	m	Gross pressure head (2/3 res. level)		918.0	m
Start level[1]	75		%	Distance intake-outlet		22600	m (horizontal)
Other inflow[2]			m3/s	Tunnel length		21726	m
Other discharge[3]	79.4		m3/s	Penstock length		1236	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	6	1.5	4.6	10.8	32.0		
400	7	1.7	5.2	12.0	28.8		
500	8	1.9	5.7	13.2	26.2		
600	9	2.1	6.2	14.4	24.1		
700	9	2.2	6.7	15.6	22.2		
800	10	2.4	7.2	16.8	20.7		
900	11	2.6	7.7	18.0	19.3		
1000	11	2.7	8.2	19.1	18.1		
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	39	19	13	0.423	0.016	0.032	0.471
400	52	26	17	0.563	0.021	0.040	0.625
500	65	32	22	0.704	0.027	0.048	0.779
600	78	39	26	0.845	0.032	0.056	0.933
700	91	45	30	0.986	0.037	0.063	1.086
800	104	52	35	1.127	0.043	0.070	1.240
900	117	58	39	1.268	0.048	0.077	1.393
1000	130	65	43	1.409	0.053	0.084	1.546

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[3] Other discharge from Sysenvatn (79.4 m^3/s) results from:

- 620 MW i Sy-Sima

Table 2.50 shows the water level decrease in Sysenvatn (upper reservoir) in the event of maximum power generation for 24 hours/day in Sy-Sima hydro storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Sysenvatn is 75 %.

Table 2.51 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Sysenvatn when the power generation in Sy-Sima hydro storage power station is 700 MW. The number of hours/day of power generation and the start level (%) in Sysenvatn are varied.

Table 2.44: Water level reduction and emptying time for Sysenvatn when Sy-Sima hydro storage power station is generating 700 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	2.2	29.7
	75		22.2
	50		14.8
18	75	1.7	29.7
12		1.1	44.5

2.7 Aurland - Tyin

Two cases were analysed in connection with Aurland IV (Vangen) and Tyin power stations:

G1 Aurland/Vangen hydro storage power station (Viddalsvatn – sjø)
G2 Tyin hydro storage power station (Tyin – Årdalsvatnet)

The new tunnel in case G1 is drawn in red on the map excerpt in **Figure 2.13**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

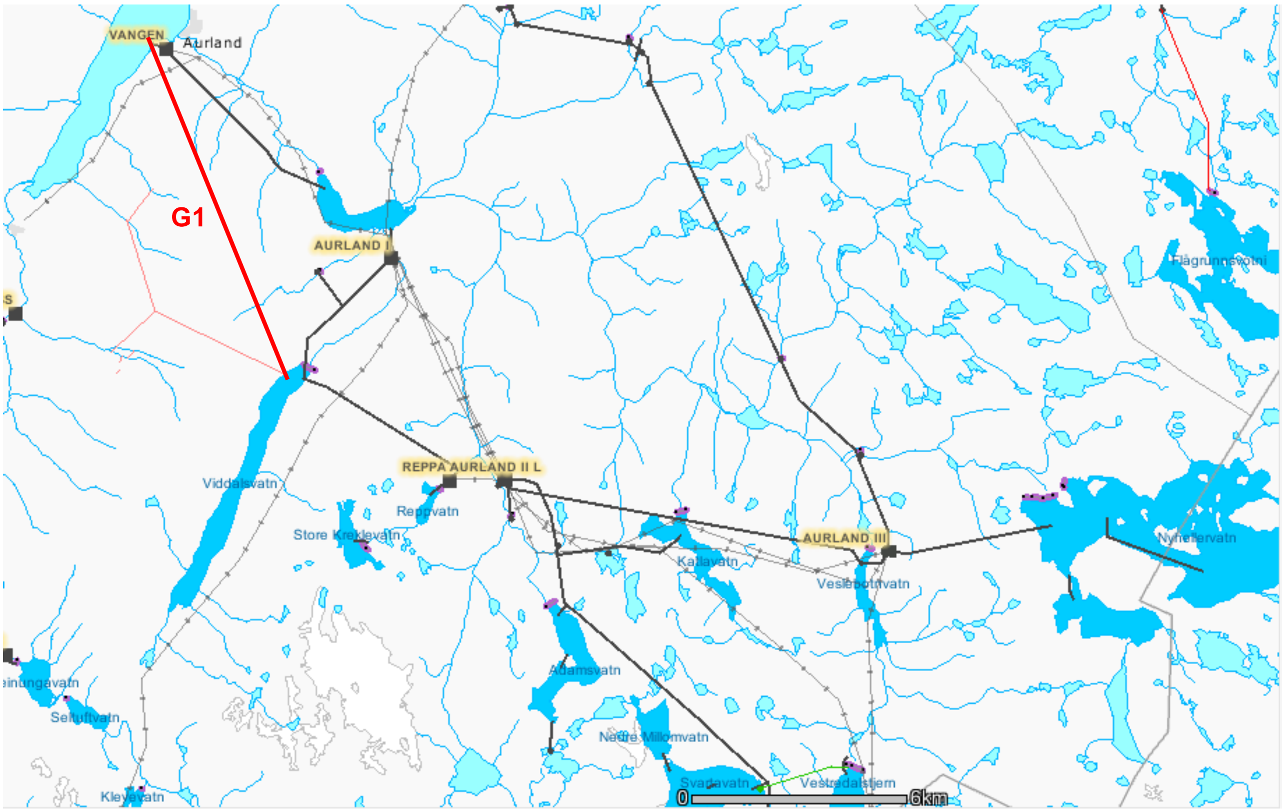


Figure 2.11: Case G1 Aurland/Vangen

The new hydro storage power station, tunnel and associated reservoirs in case G1 are illustrated in **Figure 2.14**.

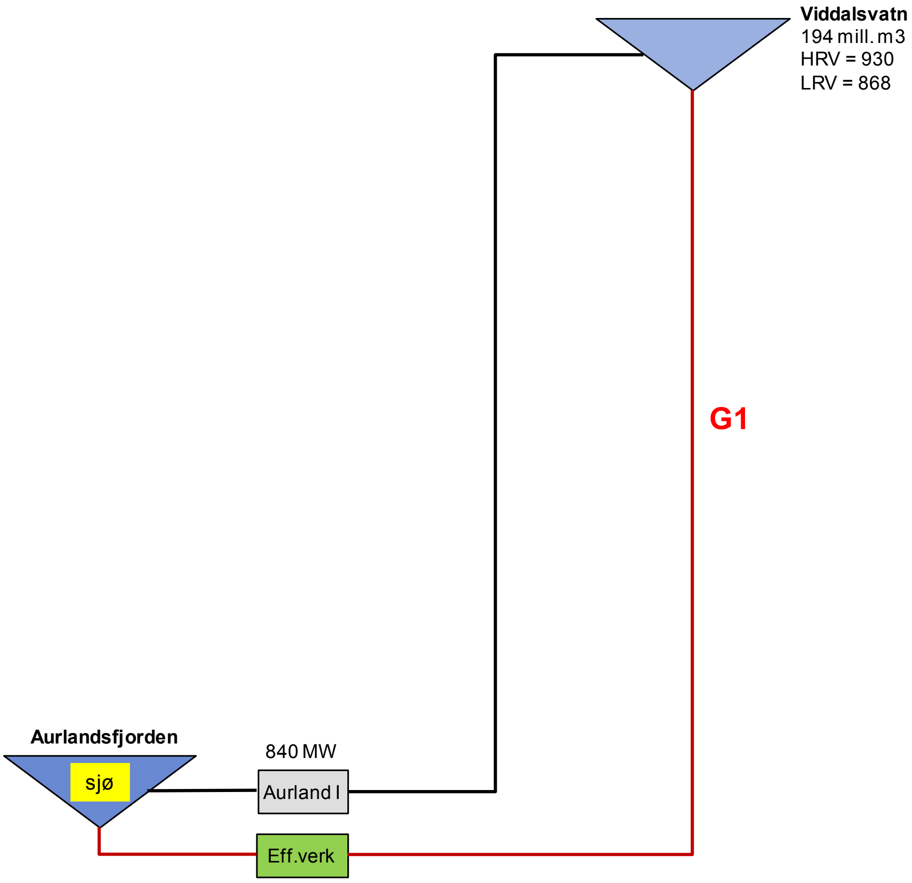


Figure 2.12: Case G1 Aurland/Vangen

G1 Aurland/Vangen hydro storage power station (Viddalsvatn – sjø)

Table 2.45: Case G1 Aurland/Vangen hydro storage power station (Viddalsvatn – sjø).

G1 Aurland/Vangen hydro storage power station (Viddalsvatn - Aurlandsfjorden)							
Reservoir	**Viddalsvatn**	(sjø)					
Volume	194.0		mill. m3	Power generation with max. power		24	hours/day
HRWL	930.0	0.0	m	Pumping with max. power			hours/day
LRWL	868.0	0.0	m				
HRWL - LRWL	62.0	0.0	m	Gross pressure head (2/3 res. level)		909.3	m
Start level[1]	75		%	Distance intake-outlet		10000	m (horizontal)
Other inflow[2]	78.1		m3/s	Tunnel length		9132	m
Other discharge[3]	92.2		m3/s	Penstock length		1228	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	6	1.5	4.4	10.3	31.6		
400	8	1.8	5.5	12.8	25.3		
500	9	2.2	6.6	15.4	21.2		
600	11	2.6	7.7	17.9	18.2		
700	12	2.9	8.8	20.4	15.9		
800	14	3.3	9.8	23.0	14.2		
900	15	3.6	10.9	25.5	12.8		
1000	17	4.0	12.0	28.0	11.6		
Max. power generated [MW]	Max. absorption capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	39	20	13	0.179	0.016	0.032	0.227
400	52	26	17	0.239	0.021	0.040	0.301
500	65	33	22	0.299	0.027	0.048	0.374
600	79	39	26	0.359	0.032	0.056	0.446
700	92	46	31	0.418	0.037	0.063	0.519
800	105	52	35	0.478	0.043	0.070	0.591
900	118	59	39	0.538	0.048	0.077	0.663
1000	131	65	44	0.598	0.054	0.084	0.735

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.

[2] Inflow to Viddalsvatn (78.1 m^3/s) results from:

- 60 MW in Aurland power station IIL
- 70 MW in Aurland power station IIH

[3] Other discharge from Viddalsvatn (92.2 m^3/s) results from:

- 840 MW in Aurland power station I

Table 2.52 shows the water level decrease in Sysenvatn (upper reservoir) in the event of maximum power generation for 24 hours/day in Sy-Sima hydro storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Sysenvatn is 75 %.

Table 2.53 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Sysenvatn when the power generation in Sy-Sima hydro storage power station is 700 MW. The number of hours/day of power generation and the start level (%) in Sysenvatn are varied.

Table 2.46: Water level reduction and emptying time for Viddalsvatn when Aurland hydro storage power station is generating 700 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	2.9	21.2
	75		15.9
	50		10.6
18	75	2.2	21.2
12		1.5	31.9

The new tunnel in case G2 is drawn in red on the map excerpt in **Figure 2.15**, which is from NVE's Atlas of hydroelectric power stations [5]. Existing tunnels are indicated by black lines.

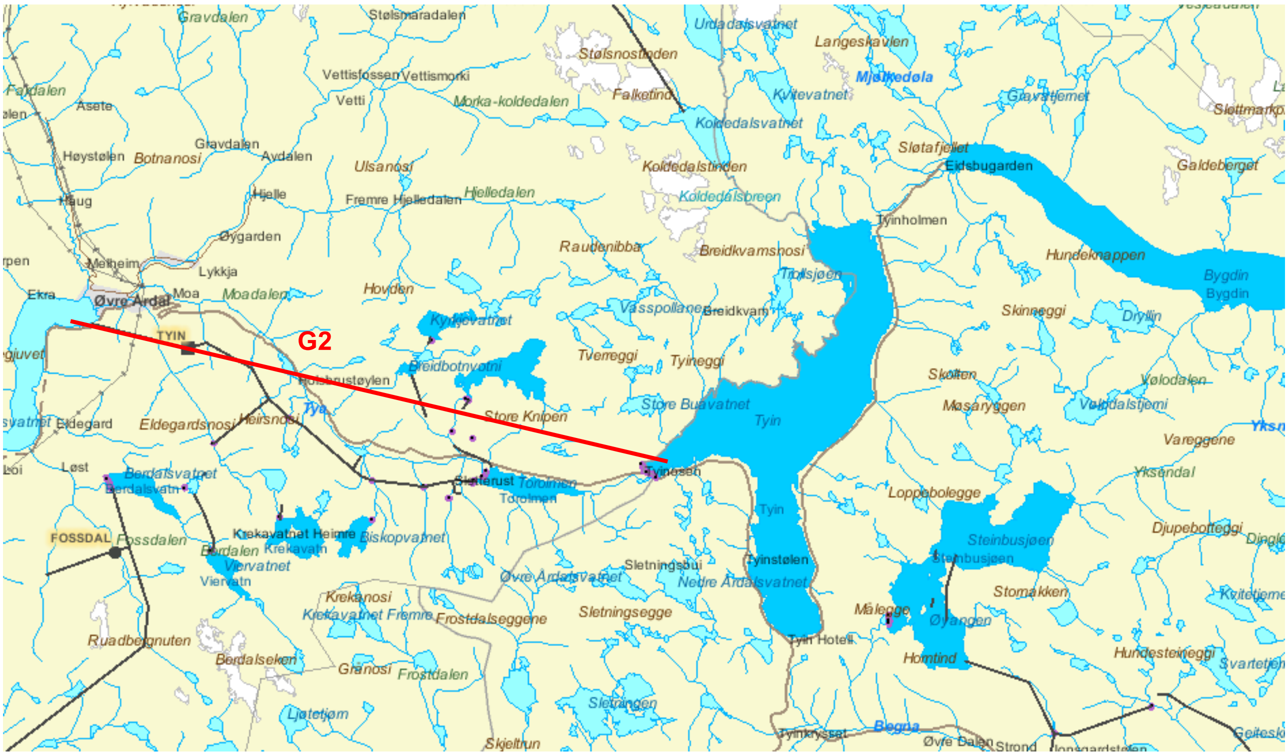


Figure 2.13: Case G2 Tyin.

The new hydro storage power station, tunnel and associated reservoirs in case G2 are illustrated in **Figure 2.16**.

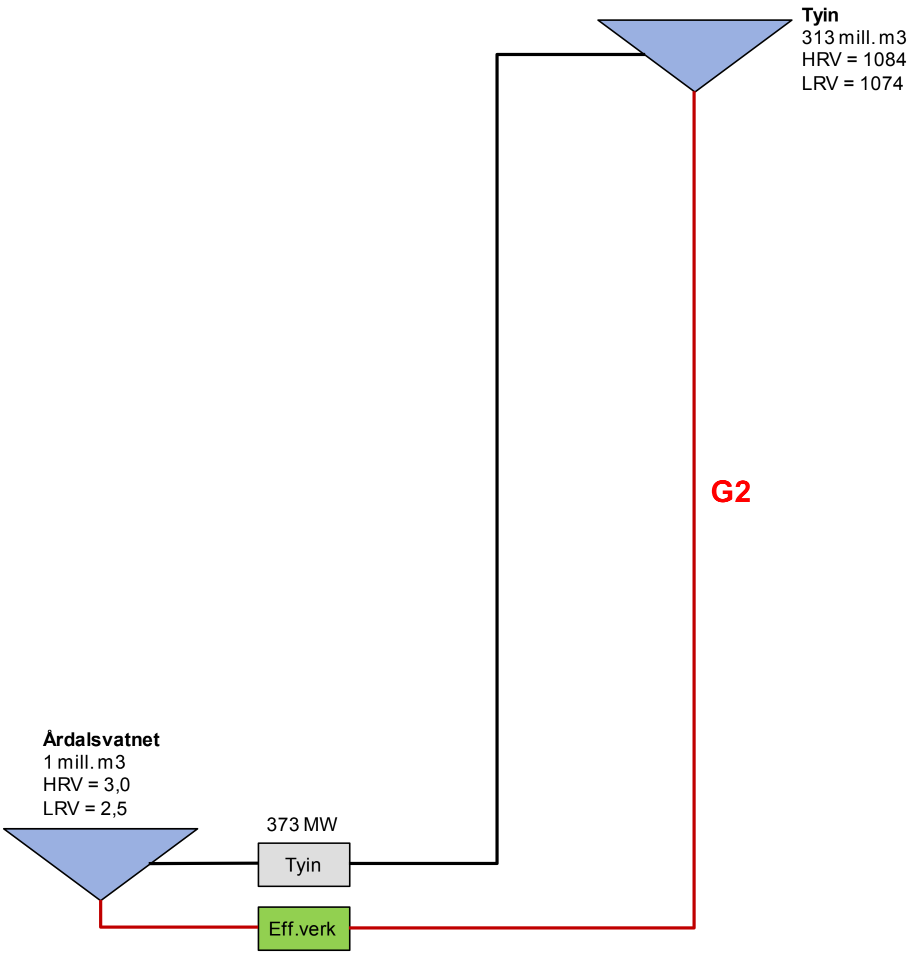


Figure 2.14: Case G2 Tyin.

G2 Tyin hydro storage power station (Tyin – Årdalsvatnet)

Table 2.47: Case G2 Tyin hydro storage power station (Tyin – Årdalsvatnet).

G2 Tyin hydro storage power station (Tyin - Årdalsvatnet)							
Reservoir	**Tyin**	**Årdalsvatnet**					
Volume	313.0	1.0	mill. m3	Power generation with max. power		24	hours/day
HRWL	1083.9	3.0	m	Pumping with max. power		0	hours/day
LRWL	1073.6	2.5	m				
HRWL - LRWL	10.3	0.5	m	Gross pressure head (2/3 res. level)		1077.6	m
Start level[1]	75	50	%	Distance intake-outlet		20000	m (horizontal)
Other inflow[2]		40.0	m3/s	Tunnel length		18929	m
Other discharge[3]	40.0	40.0	m3/s	Penstock length		1515	m
Max. power generated [MW]	Decrease in water level [cm/hour]	Decrease in water level 1 day [m]	Decrease in water level 3 days [m]	Decrease in water level 7 days [m]	Emptying of upper reservoir [days]	Increase in water level [cm/hour]	Filling of lower reservoir [days]
300	1	0.2	0.6	1.5	37.1	6	0.2
400	1	0.2	0.7	1.7	32.3	8	0.1
500	1	0.3	0.8	1.9	28.5	10	0.1
600	1	0.3	0.9	2.1	25.6	12	0.1
700	1	0.3	1.0	2.3	23.2	14	0.1
800	2	0.4	1.1	2.6	21.2	16	0.1
900	2	0.4	1.2	2.8	19.5	18	0.1
1000	2	0.4	1.3	3.0	18.1	20	0.1
Max. power generated [MW]	Max. absorp-tion capacity [m3/s]	Tunnel cross-section [m2]	Penstock cross-section [m2]	Tunnel volume [mill. m3]	Penstock volume [mill. m3]	Station hall volume [mill. m3]	Total excavated volume [mill. m3]
300	33	17	11	0.314	0.017	0.031	0.361
400	44	22	15	0.418	0.022	0.039	0.479
500	55	28	18	0.523	0.028	0.047	0.597
600	66	33	22	0.627	0.033	0.054	0.715
700	77	39	26	0.732	0.039	0.061	0.832
800	88	44	29	0.836	0.045	0.068	0.949
900	99	50	33	0.941	0.050	0.074	1.066
1000	110	55	37	1.046	0.056	0.081	1.182

[1] Start level is only used for calculating emptying time for upper reservoir and filling time for lower reservoir.
[3] Other discharge from Tyin (40.0 m^3/s) results from:

- 373 MW in Tyin power station

There is a lack of information about the discharge to Årdalsvatnet and further discharge to Årdalsfjorden via Hæreidselva which is needed to calculate the increase in water level in Årdalsvatnet. Årdalsvatnet is not regulated.

Table 2.54 shows the water level decrease in Tyin (upper reservoir) in the event of maximum power generation for 24 hours/day in Tyin hydro storage power station, when the design power output is 300 – 1,000 MW. The remaining inflow and discharge for these two reservoirs are indicated by the footnotes to the table. The start level in Tyin is 75 %.

Table 2.55 shows the water level reduction (m) per day and drawdown time (days) to LRWL for Tyin when the power generation in Tyin hydro storage power station is 700 MW. The number of hours/day of power generation and the start level (%) in Tyin are varied.

Table 2.48: Water level reduction and emptying time for Tyin when Tyin hydro storage power station is generating 700 MW

Power generation (hours/day)	Start level (%)	Reduction in 1 day (m)	Emptying (days)
24	100	0.3	30.9
	75		23.2
	50		15.4
18	75	0.3	30.9
12		0.2	46.3

3 Examples of new power generation and pumping capacity

3.1 Installations

Based on the calculations in Chapter 2, two examples were produced of scenarios involving new power generation and pump installations in Southern Norway for balance power purposes in **Table 3.1** and **Table 3.2**. Scenario 1 applies to 12 power stations with combined design output of 11,200 MW. Scenario 2 applies to 7 power stations, with the design output of each being somewhat higher, giving a combined output of 13,600 MW. One of the power stations in Scenario 2 (C3) is not included in Scenario 1. The water level variations in the upper and lower reservoirs include any inflow and discharge resulting from maximum power generation in other power stations associated with the reservoirs in each case.

Table 3.1: New power generation and pump installations – Scenario 1

Case	Power station	Output (MW)	Upper reservoir[1]	Lower reservoir[2]
A2	Tonstad pumped storage power station	1,400	Nesjen (14 cm/h)	Sirdalsvatn (3 cm/h)
B3	Holen pumped storage power station	700	Urarvatn (8 cm/h)	Bossvatn (8 cm/h)
B6a	Kvilldal pumped storage power station	1,400	Blåsjø (7 cm/h)	Suldalsvatn (4 cm/h)
B7a	Jøsenfjorden hydro storage power station	1,400	Blåsjø (7 cm/h)	Jøsenfjorden (sea)
C1	Tinnsjø pumped storage power station	1,000	Møsvatn (2 cm/h)	Tinnsjø (1 cm/h)
D1	Lysebotn hydro storage power station	1,400	Lyngsvatn (9 cm/h)	Lysefjorden (sea)
E1	Mauranger hydro storage power station	400	Juklavatn (14 cm/h)	Hardangerfjorden (sea)
E2	Oksla hydro storage power station	700	Ringedalsvatn (12 cm/h)	Hardangerfjorden (sea)
E3	Tysso pumped storage power station	700	Langevatn (9 cm/h)	Ringedalsvatn (7 cm/h)
F1	Sy-Sima hydro storage power station	700	Sysenvatn (9 cm/h)	Hardangerfjorden (sea)
G1	Aurland hydro storage power station	700	Viddalsvatn(12 cm/h)	Aurlandsfjorden (sea)
G2	Tyin hydro storage power station	700	Tyin (1 cm/h)	Årdalsvatnet[3]
	Total new power generation capacity	11,200		

[1] Water level decrease in parentheses.

[2] Water level increase in parentheses.

[3] Insufficient data to calculate water level increase in Årdalsvatnet.

Table 3.2: New power generation and pump installations – Scenario 2

Case	Power station	Output (MW)	Upper reservoir[1]	Lower reservoir[2]
A2	Tonstad pumped storage power station	1,400	Nesjen (14 cm/h)	Sirdalsvatn (3 cm/h)
B3	Holen pumped storage power station	1,000	Urarvatn (10 cm/h)	Bossvatn (12 cm/h)
B6b	Kvilldal pumped storage power station	2,400	Blåsjø (11 cm/h)	Suldalsvatn (6 cm/h)
B7b	Jøsenfjorden hydro storage power station	2,400	Blåsjø (11 cm/h)	Jøsenfjorden (sea)
C2	Tinnsjø pumped storage power station	2,000	Møsvatn (3 cm/h)	Tinnsjø (4 cm/h)
C3	Tinnsjø pumped storage power station	2,400	Kallhovd (7 cm/h)	Tinnsjø (4 cm/h)
D1	Lysebotn hydro storage power station	2,000	Lyngsvatn (13 cm/h)	Lysefjorden (sea)
	Total new power generation capacity	13,600		

[1] Water level decrease in parentheses.

[2] Water level increase in parentheses.

The power generation outputs (design) in the two scenarios were chosen mainly so that the water level change in the upper and lower reservoirs does not exceed 13 cm/hour. For two of the reservoirs (Nesjen and Juklavatn) the rate is 14 cm/hour. According to research into the stranding of salmon in rivers, the water level should not sink by more than 13 cm/hour [8]. Although this is not directly applicable to lakes, we have used this as a rule of thumb for acceptable water level reduction in reservoirs. Scenario 2 shows how the capacity of the 7 largest power stations in Scenario 1 can be further increased to provide 2,400 MW higher output than all the 12 power stations in Scenario 1.

Pumping/drawdown from Blåsjø and Svartevatn to Bossvatn (Cases B1 and B2) is not included in these scenarios since new generation facilities with discharge into Bossvatn in addition to 1,000 MW generation in Holen from Urarvatn will result in problematical water level increase in Bossvatn unless pumping is carried out during periods of power generation.

3.2 Potential for increased power generation and pumping capacity in Norway

In CEDREN's HydroPeak project, three scenarios are described with regard to the export of balance power from Norway [6]. The main scenario involves increasing output by 20,000 MW. **Table 3.3** shows that the output of the power stations studied in Chapter 2 can be increased by 18,200 MW without the water level changes in the upper and lower reservoirs exceeding 14 cm/hour. How long the power stations are able to deliver this power output will depend among other things on the current regulations regarding highest and lowest regulated water levels (HRWL and LRWL), as well as what strategies are adopted with regard to pumping in the case of pumped storage power stations. The figures shown in **Table 3.3** are from the tables in Chapter 2, and in the case of some of the power stations the capacity agrees with Scenario 1 or Scenario 2.

By including more cases in Southern Norway in addition to some in Northern Norway, it will be possible to increase the output of existing hydroelectric reservoirs by a further 1,800 MW to give a total of 20,000 MW for the whole country. Indications from NVE's study support this observation. If the usage time for each of the 89 power stations in NVE's study [1] is reduced to 2,000 hours by increasing their design power output, the total power output of these power stations can be increased by 16,500 MW. Of this increase, approximately 7,500 MW is connected with power stations which are not included in Scenario 3.

Table 3.3: New power generation and pump installations – Scenario 3

Case	**Power station**	**Output (MW)**	**Upper reservoir**[1]	**Lower reservoir**[2]
A2	Tonstad pumped storage power station	1,400	Nesjen (14 cm/h)	Sirdalsvatn (3 cm/h)
B3	Holen pumped storage power station	1,000	Urarvatn (10 cm/h)	Bossvatn (12 cm/h)
B6b	Kvilldal pumped storage power station	2,400	Blåsjø (11 cm/h)	Suldalsvatn (6 cm/h)
B7b	Jøsenfjorden hydro storage power station	2,400	Blåsjø (11 cm/h)	Jøsenfjorden (sea)
C2	Tinnsjø pumped storage power station	2,000	Møsvatn (3 cm/h)	Tinnsjø (4 cm/h)
C3	Tinnsjø pumped storage power station	2,400	Kallhovd (7 cm/h)	Tinnsjø (4 cm/h)
D1	Lysebotn hydro storage power station	1,800	Lyngsvatn (12 cm/h)	Lysefjorden (sea)
E1	Mauranger hydro storage power station	400	Juklavatn (14 cm/h)	Hardangerfjorden (sea)
E2	Oksla hydro storage power station	700	Ringedalsvatn (12 cm/h)	Hardangerfjorden (sea)
E3	Tysso pumped storage power station	1,000	Langevatn (13 cm/h)	Ringedalsvatn (11 cm/h)
F1	Sy-Sima hydro storage power station	1,000	Sysenvatn (11 cm/h)	Hardangerfjorden (sea)
G1	Aurland hydro storage power station	700	Viddalsvatn(12 cm/h)	Aurlandsfjorden (sea)
G2	Tyin hydro storage power station	1,000	Tyin (2 cm/h)	Årdalsvatnet[3]
	Total new power generation capacity	18,200		

[1] Water level decrease in parentheses.

[2] Water level increase in parentheses.

[3] Insufficient data to calculate water level increase in Årdalsvatnet

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4 Environmental impact

4.1 General

The environmental impact of increasing design power output and pumping capacity between existing reservoirs in Norway can be roughly divided into direct impact on the reservoirs in question and direct impact on affected land areas. Distinction can also be made between impact during the construction and operational phases. Impact on reservoirs and catchment areas results from the construction and operation of the power station facilities, while the impact on land areas is mainly due to infrastructure such as roads, rock dumps, connection facilities, transmission grids and other necessary installations. It is assumed that all water flow is routed through tunnels and that power stations are constructed in underground rock cavities. This report does not consider indirect environmental impacts such as the effect of replacing fossil-fuel based power generation with hydroelectric generation or those resulting from the manufacture of turbines.

Initially, this report comments in general terms on some possible environmental impacts before dealing with each individual case. Only established knowledge has been used, including the results of two projects in the comprehensive “EFFEKT” programme which was carried out at the end of the 1990s under the auspices of the Research Council of Norway [7, 8], as well as a limited selection of documentation used for making a rough estimate of environmental impact. This report must not in any way be seen as either an exhaustive assessment of environmental impact or an impact study.

4.1.1 The construction phase

In the construction phase, the majority of environmental impacts known from traditional power station operation and maintenance will be experienced, with the exception of all the impacts connected with the construction of dams and flooding, since it is assumed that reservoirs will only be used within the existing HRWL and LRWL constraints.

Reservoirs and water systems

In connection with tunnelling operations, construction work and the erection of other infrastructure, there may be some increase in erosion and sediment supply to reservoirs and water systems, but this cannot be considered a major environmental impact. We assume that modern principles of construction operations will be observed, with adequate environmental consideration. There may also be a need to adjust the operational pattern of existing installations for a period during construction operations, but we assume that in most cases the operation of existing installations will not be affected.

Land areas

Major construction operations will be needed, particularly in connection with tunnelling operations. SINTEF [9] has estimated the manpower requirements for tunnelling operations when constructing facilities for 20,000 MW of power generation and pumping power by 2030 at approximately 30,000 man-years.

The construction phase will affect the natural environment, game and recreational activities in the affected land areas, where it will be particularly important to pay attention to vulnerable species such as reindeer as well as special types of landscape. This will depend strongly on the location and it will be necessary to carry out impact studies and surveys.

It will be necessary to dispose of about 40 million m^3 of excavated rock mass [9], preferably close to the construction sites. It will be of considerable benefit both to the environment and the project’s economics if an alternative use can be found for the excavated rock, for example in roads, quays, breakwaters, embankments and dam reinforcements and as fill for commercial or residential building sites, and so on. However, there is reason to believe that a lot of the rock mass must be dumped and planted on, which will have an impact on flora and fauna. The impact will vary, depending on local conditions, and it will be important to find good local solutions.

4.1.2 The operational phase

Here we will not deal with the impact of existing water system regulation and encroachment, but with the *additional impact* of the expanded installation of power generation and pumping facilities.

Reservoirs

The environmental impact on reservoirs will generally be determined by their size and shape, combined with the size of the design output and the planned operational patterns adopted by the new hydro storage and pumped storage power stations. In all circumstances we anticipate an increased variation in water level from hour to hour and from day to day, while in many reservoirs to which water is pumped, the water level will be higher in the late winter and filling will probably occur slightly earlier in the spring. This is because wind-powered generation will be greatest in the winter, but it will also depend on many other factors, such as the market, grid connection and framework conditions.

Increased use of hydro storage and pumped storage will in many cases result in increased erosion in the affected reservoir, especially so-called internal erosion resulting from relatively rapid changes in water pressure. In most cases the drawdown zone between HRWL and LRWL will be subject to rises and falls in water level more frequently than it is the case with existing installations. Although on average this may result in higher water levels, there will also be less predictable variations in water levels, which may lead to greater problems for public use in the form of recreation, fishing and boat traffic.

Most regulated reservoirs are at present characterised by very moderate current flow rates. Larger installations with more pumping may lead to changes in current conditions which can have both positive and negative consequences. Increased current flow rates and increased through-flow can lead to better mixing of water bodies, more efficiently stirring up and transporting nutrients. In some cases this may locally result in increased erosion. It may result in changes in water stratification in reservoirs where this is normally established, and this in turn can affect water quality and temperature. Because most Norwegian reservoirs are generally nutrient-poor and cold, this is probably not of great significance, but in some low-lying water bodies which may be of interest as lower reservoirs in connection with pumped storage schemes, this may have consequences for the ecosystem.

The water temperature in reservoirs is indirectly affected by changes in water flow and stratification, but the greatest effect may result from variations in power generation and pumping. Increased power generation, with water from a mountain reservoir being released in lowland areas, will result in reduced water temperature in a downstream reservoir. Since the growth of most species depends on temperature, this will be reduced in periods of increased power generation. Conversely, interruptions in operations or pumping will result in lower or no transfer of cold water and thence higher than normal water temperature in a downstream reservoir. In an upstream reservoir there will be a similar, converse effect.

Ice cover may be strongly affected by increased power generation and pumping, and there is every reason to address this challenge very seriously. The existing operational pattern in which reservoirs are gradually drawn down in the course of the winter generally produces stable ice cover even though it may result in sloping ice layers and cracks in areas close to shore. A new operational pattern with alternating pumping and generation, and the possible transfer of sometimes warmer water combined with increased through-flow rates may result in reduced or non-existent ice cover in many places. This may represent a real danger to recreational access in winter and must be carefully evaluated in each case. A lack of ice cover may also have an effect on the behaviour of fish and result in increased energy consumption and reduced winter survival rate, but this must be studied in each individual reservoir.

Changes in physical conditions as described above will also impact the ecosystem of plants, algae, domestic animals, fish and terrestrial species which are associated with fresh water (water birds, otters, beavers, etc.). However, a reservoir normally already has an ecosystem which has been significantly affected by water level variation, and it is difficult to make any general statements about the effects of increased installation of hydro storage and pumped storage power stations. These will depend on local conditions and must be studied in each case. In general the effect on the regulated reservoir may be either positive or negative. It is particularly important to study the effects in a downstream reservoir carefully, since species diversity, fertility and vulnerability are often greater in regulated reservoirs located in low-lying areas.

Pumping water from a reservoir to a more elevated reservoir in the same catchment system may result in species from more low-lying areas of the catchment area being transported upstream to areas above their natural zone of distribution. This may threaten biological diversity. Similarly, pumping and generating flow between two reservoirs in different catchment areas may result in the transfer of alien species and impact biological diversity.

Water systems downstream of affected reservoirs

The above-mentioned changes in a reservoir will also have consequences for any river sections and water systems downstream, although these will be buffered and compensated to some extent. The potentially most serious negative impacts are probably the danger of increased sediment transport as a result of erosion in a reservoir, and changed temperature conditions. Reduced temperatures will also here lead to reduced population growth in most species, while increased temperature will have the opposite effect. The magnitude of the effects in downstream rivers and water systems will depend on local conditions and the nature of the regulating installations.

Fjords

In the case of power stations which discharge into fjords, the effects will to a certain extent be as for discharge into a reservoir, especially if the discharge takes place in relatively small and partly isolated fjord arms. Of course there will be no rapid changes in water level in a fjord, but certain impacts connected with through-flow pattern, water temperature and ice conditions (if the fjord becomes partly ice-covered) may be encountered. If increased power generation also results in increased erosion and sediment transport from upstream reservoirs and rivers, this will result in an increase in sediment transport to the fjord. Any changes in physical conditions can also have an impact on biological conditions. However, as long as increased output combined with reduced operating time does not entail an overall increase in water transport to the same point in the fjord, there is little reason to believe that increased power generation with water discharge into a fjord will lead to serious environmental consequences.

Land areas

In the operational phase there will be very little additional impact on land areas apart from that of infrastructure which was established during the construction phase, which in general means more, or more robust, transmission grids with larger masts and wider power line routes. These have direct impact on flora and fauna, as well as the resulting aesthetic impression and landscape appearance. Inspection, maintenance and other work at the installations will also result in more traffic in the area.

4.2 Environmental impacts of selected cases

Table 4.1 shows an overview of possible environmental impacts based on evaluations and general know-how, but with no location-specific background data. Evaluation was carried out for the hydro storage and pumped storage power stations included in Scenario 2. These are listed in **Table 3.2** (A2, B3, B6a, B7a, C1, D1, E1, E2, E3, F1, G1 and G2).

To enable description of environmental impacts during power generation and pumping in more detail, additional knowledge and more detailed studies of the individual reservoirs are needed. Research activities are going on in CEDREN which are contributing to improved knowledge of environmental impact and environmental design. Environmental impacts in specific reservoirs should be studied in more detail with regard to physical and biological conditions resulting from power generation and pumping.

Table 4.1: Environmental impacts

Possible environmental impacts based on evaluations and general know-how, but with no location-specific background data	Tonstad pumped storage power station (Nesjen – Sirdalvatn)	Holen pumped storage power station (Urarvatn – Bossvatn)	Kvilldal pumped storage power station (Blåsjø – Suldalsvatn)	Jøsenfjorden hydro storage power station (Blåsjø – Jøsenfjorden)	Tinnsjø pumped storage power station (Møsvatn – Tinnsjø)	Lysebotn hydro storage power station (Lyngsvatn – Lysefjorden)	Mauranger hydro storage power station (Juklavatn – Hardangerfjorden)	Oksla hydro storage power station (Ringedalsvatn – Hardangerfjorden)	Tysso pumped storage power station (Langvatn – Ringedalsvatn)	Sy-Sima hydro storage power station (Sysenvatn – Hardangerfjorden)	Aurland hydro storage power station (Viddalsvatn – Aurlandsfjorden)	Tyin hydro storage power station (Tyin – Årdalsvatnet)
	A2	B3	B6a	B7a	C1	D1	E1	E2	E3	F1	G1	G2
Encroachment on new, untouched land areas in the construction phase	Not very likely	Not very likely	Not very likely	Yes	Not very likely	Not very likely	Yes	Not very likely	Yes	Not very likely	Some	Some
Permanent encroachment in new, untouched land areas	Not very likely	Not very likely	Not very likely	Likely	Not very likely	Not very likely	Likely	Not very likely	Likely	Not very likely	Not very likely	Not very likely
Water level changes in upper reservoir	Some	Some	Small	Small	Small	Small	Small	Small	Small	Small	Small	Small
Erosion in upper reservoir	Possible	Some	Not very likely	No	Not very likely	No	Not very likely	Not very likely	Possible	No	Not very likely	No
Ice conditions in upper reservoir	Affected	Affected	Little impact	Little impact	Affected	Little impact	Little impact	Little impact	Affected	Little impact	Little impact	Little impact
Biological impacts in upper reservoir	Affected	Possible	Affected	Not very likely	Small	Not very likely	Not very likely	Not very likely	Affected	Not very likely	Not very likely	Not very likely
Impact on water systems downstream of upper reservoir	Possible	Possible	Not very likely	Not very likely	Not very likely	Not very likely	Not very likely	Not very likely	Not very likely	Not very likely	Not very likely	Not very likely
Water level changes in lower reservoir	Small	Affected	Small	N/A	Small	N/A	N/A	N/A	Small	N/A	N/A	Unknown[2]
Erosion in lower reservoir	Local	Likely	Local	N/A	Not very likely	N/A	N/A	N/A	Possible	N/A	N/A	Unknown[2]
Ice conditions in lower reservoir	Localised	Affected	Possible	Very localised[1]	Localised	Very localised[1]	Very localised[1]	Very localised[1]	Affected	Very localised[1]	Very localised[1]	Affected
Biological impacts in lower reservoir	Affected	Possible	Possible	N/A	Possible	N/A	N/A	N/A	Possible	N/A	N/A	Unknown[2]
Impact on water systems downstream of lower reservoir	Possible	Possible	Possible	Possible[1]	Possible	Possible[1]	Possible[1]	Localised[1]	Possible	Possible[1]	Possible[1]	Possible[2]

[1] Impacts on the fjord (sea)

[2] Discharge from hydro storage power station into an unregulated lake (Årdalsvatnet)

5 Grid connection

Each of the proposed power generating installations (400 – 1,400 MW) in **Table 3.1** will require a separate 420 kV link (cf. **Table 5.1**) at appropriate connection points in the central transmission grid if the power is to be transmitted abroad via the central transmission grid.

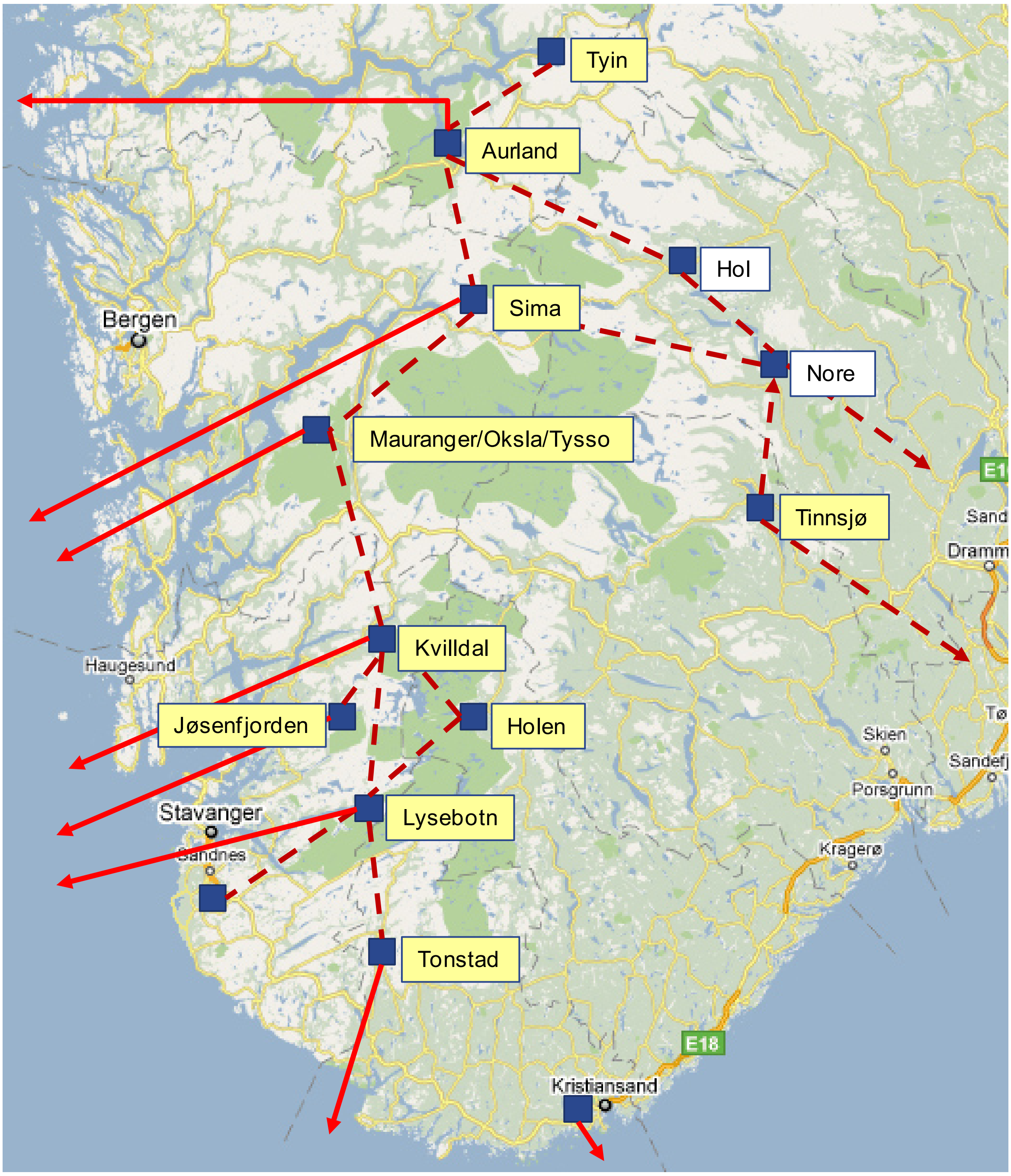

Figure 5.1: Possible international links

As regards the power stations at Tonstad, Lysebotn, Jøsenfjorden, Kvilldal, Mauranger/Oksla, Sima and Aurland/Tyin, these can in principle be linked directly to international grids via HVDC cables, since they are located close to a fjord or the sea. This is indicated by the solid red arrows in **Figure 5.1**.

A configuration using direct links from these power generation installations will in isolation not make demands on the transmission capacity of the central transmission grid. However, when international links are out of operation there will need to be spare capacity in the central transmission grid if power exchange is to be maintained. This also requires that the power stations in question are linked to the central transmission grid. The dotted links in **Figure 5.1** between the above-mentioned power stations can be such central transmission grid connections. This will call for the construction of new 420 kV links and upgrading to 420 kV at several points on the relevant routes. Existing plans for new links and voltage upgrades in the central transmission grid are described in [10].

The power generation installation at Holen (next to Bossvatn) will require a 420 kV link to the west, e.g. to Lysebotn or to Kvilldal, and from there an international link via HVDC cables. Holen may also be linked to the power generation installation at Jøsenfjorden (not shown in **Figure 5.1**). The choice of route for new power lines must be based on local environmental conditions.

The power generation installation at Tinnsjø may represent the greatest challenge with regard to grid capacity since the distance to appropriate international links is greatest here. The size of the installation will also determine which alternatives are possible. There will be several connection points in the central transmission grid which are appropriate for a new or upgraded 420 kV link from the Tinnsjø area. These may be located to the north towards Nore or to the east and south-east towards Flesaker and Rød/Hasle. The south-west link is a possible exchange route linking onwards to Europe.

In periods when power from Tinnsjø can relieve (take over) the power transmission between Western Norway and the south-eastern region, the need for grid capacity will be less than if this power is being supplied in addition to this transmission from west to east. However, it is not certain that this fact will be of significance when assessing grid capacity requirements.

Table 5.1: Transmission capacity of power lines with alternating current (source: NVE)

Voltage level	Transmission capacity (MVA)
22 kV	approx. 1-10
45 kV	approx. 10-60
66 kV	approx. 20-100
132 kV	approx. 50-400
300 kV	approx. 200-1000
420 kV	approx. 500-2000

If the proposed power generation installations in **Table 3.1** (Scenario 1) are seen in the light of international cable links, each of 700 MW capacity, the following 15 cables will be needed:

- 2 cables from Tonstad (1,400 MW)
- 5 cables from Jøsenfjorden/Kvilldal/Holen (1,400 + 1,400 + 700 MW)
- 2 cables from Lysebotn (1,400 MW)
- 3 cables from Mauranger/Oksla/Tysso (400 + 700 + 700 MW)
- 1 cable from Sy-Sima (700 MW)

- 2 cables from Aurland/Tyin (700 + 700 MW)

The outlined requirement for cable links is based on only very simplified reasoning to enable a rough estimate of cable requirements. **Figure 5.2** is a schematic diagram showing cable links to the United Kingdom, the Netherlands, Germany and Denmark from the proposed power stations in South-Western Norway. The diagram does not indicate the likely terminal points in these countries or which cables link to which countries. With the exception of the distance from Kristiansand to Denmark (the Skagerrak cables), distances measured along straight lines from the connection points on the Norwegian side to the countries on the other side of the North Sea are comparable.

Figure 5.2: Schematic diagram showing cable links to the United Kingdom, the Netherlands, Germany and Denmark (Google Maps)

A possible future "North Sea Supergrid", based on multi-terminal HVDC links along the coast of Norway and in the North Sea opens up interesting possibilities with regard to the connection of onshore and offshore wind farms combined with sea cable links between the Norwegian terminal points for the cables to the United Kingdom, the Netherlands, Germany and Denmark. The links between these terminal points reduce the need for grid expansion on land with an eye to backup capacity in the event of the failure of international cables from the balance power generating stations. See [11, 12] for information about offshore wind power development and network connection in the North Sea.

6 Costs

Table 6.1 shows the results of a simplified estimate of costs for the various cases in **Table 3.1**. The figures are based on [1, 13] and cost levels in 2008, but are approximately adjusted to the level of detail of this study since we have only very rough indications of the factors that determine the costs.

The figures for individual cost elements are very uncertain, but the total amounts can be used as a cost estimate.

The costs referred to 2008 levels have been scaled up to the 2011 cost level on the basis of consumer price indices (annual average) for 2008 (123.1) and 2011 (130.4, which is the average for January to October).

The financing costs comprise 6.5 % interest costs, rising linearly through the entire construction period, in accordance with [1, 13]. The following construction times and associated cost increases are used in **Table 6.1**:

Stations with 1,400 MW output: 5 years Increased cost resulting from interest: $1+2.5\times0.065 = 1.1625$
Station with 1,000 MW output: 4.5 years Increased cost resulting from interest: $1+2.25\times0.065 = 1.1463$
Stations with 700 MW output: 4 years Increased cost resulting from interest: $1+2.0\times0.065 = 1.1300$
Station with 1,000 MW output: 3.5 years Increased cost resulting from interest: $1+1.75\times0.065 = 1.1138$

The total of all 12 cases (11,200 MW) is approximately NOK 28,000 million. This gives an average of approximately NOK 2.6 million per MW. The average for the pumped storage power stations is approximately 2.9 MNOK/MW and for hydro storage power stations approximately 2.3 MNOK/MW.

The costs apply to output voltage from the stations up to 420 kV. Any costs for connection to the central transmission grid, and any necessary reinforcements or expansion of the central transmission grid will come in addition, as well as connection costs (HVDC converters, etc.) and HVDC cables for the international links.

Table 6.1 Costs

Scenario 1

	Unit	A2 Pumped storage power station Tonstad (Nesjen - Sirdalsvatn)	B3 Pumped storage power station Holen (Urarvatn - Bossvatn)	B6a Pumped storage power station Kvilldal (Blåsjø - Suldalsvatn), 1 400 MW in hydro storage power station Jøsenfjorden	B7a Hydro storage power station Jøsenfjorden (Blåsjø - Jøsenfjorden), 1 400 MW in pumped storage power station Kvilldal	C1 Pumped storage power station Tinnsjø (Møsvatn - Tinnsjø)	D1 Hydro storage power station Lysebotn (Lyngsvatn - Lysefjorden)	E1 Hydro storage power station Mauranger (Juklavatn - Hardangerfjorden)	E2 Hydro storage power station Oksla (Ringedalsvatn - Hardangerfjorden)	E3 Pumped storage power station Tysso (Langevatn - Ringedalsvatn)	F1 Hydro storage power station Sy-Sima (Sysenvatn - Hardangerfjorden)	G1 Hydro storage power station Aurland/Vangen (Viddalsvatn - Aurlandsfjorden)	G2 Hydro storage power station Tyin (Tyin - Årdalsvatnet)	Total
Installed power	MW	1400	700	1400	1400	1000	1400	400	700	700	700	700	700	11200
Number of units	Count	4	2	4	4	3	4	2	2	2	2	2	2	33
Approach/discharge tunnel length	km	22.4	12.4	19.1	14.1	29.3	5.6	5.3	4.0	3.2	21.7	9.1	18.9	165.1
Penstock length	km	0.9	0.9	1.2	1.3	1.0	0.9	1.3	0.5	1.1	1.2	1.2	1.5	13.2
Tunnel cross-section	m2	128	66	88	82	82	125	23	100	56	45	46	39	
Penstock cross-section	m2	85	44	59	55	55	83	16	67	37	30	31	26	
Tunnel volume	mill. m3	2.853	0.815	1.688	1.157	2.411	0.693	0.122	0.404	0.180	0.986	0.418	0.732	12.459
Penstock volume	mill. m3	0.076	0.040	0.072	0.072	0.055	0.075	0.021	0.035	0.041	0.037	0.037	0.039	0.601
Station hall volume	mill. m3	0.117	0.068	0.109	0.107	0.088	0.117	0.039	0.074	0.066	0.063	0.063	0.061	0.971
Construction period	years	5.0	4.0	5.0	5.0	4.5	5.0	3.5	4.0	4.0	4.0	4.0	4.0	
Costs:														
Approach/discharge tunnel	MNOK	995.5	333.6	631.5	443.2	922.5	244.8	73.5	147.0	78.5	447.6	188.1	350.2	4856.0
Penstock	MNOK	142.4	64.4	117.2	115.6	88.6	138.2	39.9	58.7	67.9	65.5	66.5	73.5	1038.5
Station hall	MNOK	218.2	126.2	202.7	199.9	163.4	217.2	73.2	137.2	122.1	117.1	117.3	113.4	1808.2
Cross gallery to approach tunnel	MNOK	29.9	10.0	18.9	13.3	27.7	7.3	2.2	4.4	2.4	13.4	5.6	10.5	145.7
Access/cable tunnel + portal	MNOK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	360.0
Intake	MNOK	12.8	9.2	10.6	9.9	9.9	12.5	7.4	11.0	8.9	10.0	10.1	9.3	121.5
Roads, places, landscape	MNOK	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	60.0
Rigging and operation of site	MNOK	501.8	202.5	355.6	285.9	436.5	229.3	81.0	137.7	110.2	241.0	147.9	207.1	2936.5
Total construction and infrastructure	**MNOK**	**1935.6**	**780.9**	**1371.5**	**1102.8**	**1683.6**	**884.3**	**312.2**	**531.1**	**425.0**	**929.6**	**570.7**	**799.0**	**11326.4**
Planning construction and infrastructure	MNOK	7.3	5.3	7.3	7.3	6.3	7.3	5.3	5.3	5.3	5.3	5.3	5.3	72.0
Total machines incl. planning	MNOK	560.0	280.0	700.0	350.0	400.0	350.0	120.0	175.0	280.0	175.0	175.0	175.0	3740.0
Total electro incl. planning	MNOK	630.0	315.0	630.0	630.0	480.0	630.0	220.0	315.0	315.0	315.0	315.0	315.0	5110.0
Site management	MNOK	26.4	20.4	26.4	26.4	23.4	26.4	18.0	20.4	20.4	20.4	20.4	20.4	269.4
Total constr./infrastr./machines/electro	**MNOK**	**3159.3**	**1401.5**	**2735.2**	**2116.5**	**2593.3**	**1898.0**	**675.5**	**1046.8**	**1045.6**	**1445.2**	**1086.3**	**1314.7**	**20517.8**
Building contractor costs	MNOK	5.0	4.0	5.0	5.0	4.5	5.0	3.5	4.0	4.0	4.0	4.0	4.0	52.0
Various/unpredictable costs (15 %)	MNOK	473.9	210.2	410.3	317.5	389.0	284.7	101.3	157.0	156.8	216.8	162.9	197.2	3077.7
Total costs before financing (2008)	MNOK	3638.2	1615.8	3150.4	2438.9	2986.8	2187.7	780.3	1207.8	1206.4	1666.0	1253.3	1515.8	23647.4
Total costs before financing (2011)	**MNOK**	**3853.9**	**1711.6**	**3337.3**	**2583.6**	**3163.9**	**2317.4**	**826.6**	**1279.4**	**1278.0**	**1764.8**	**1327.6**	**1605.7**	**25049.7**
Total costs incl. 6,5 % p.a. financing	**MNOK**	**4480.2**	**1934.1**	**3879.6**	**3003.4**	**3626.6**	**2694.0**	**920.6**	**1445.7**	**1444.1**	**1994.3**	**1500.2**	**1814.5**	**28737.2**
Total costs/MW incl. financing (2011)	MNOK/MW	3.200	2.763	2.771	2.145	3.627	1.924	2.302	2.065	2.063	2.849	2.143	2.592	2.566

7 Conclusions

It is not clear how great the demand for balance power in Europe and Scandinavia will be in the future, but there is definitely a need to balance generation and consumption on time scales ranging from minutes to weeks. An increased proportion of wind and solar power generation will probably create new demands and new market potential for Norwegian hydroelectricity.

Our studies show that it will probably be technically feasible to increase the design power output of Norwegian hydroelectric power stations by 20,000 MW without using new regulated reservoirs or exceeding the current stipulations with regard to highest and lowest regulated water levels (HRWL and LRWL). The main scenario which has been considered consists of twelve new power stations in Southern Norway with a combined power output of 11,200 MW (cf. Table 3.1). It is envisaged that these power stations would be constructed with new tunnels to an upstream reservoir and for downstream outflow into a reservoir, a fjord or the sea. Five of the power plants are pumped storage power stations with a combined output of 5,200 MW, while the remainder are hydro storage power stations with a combined output of 6,000 MW, all but one of which discharge into a fjord or the sea.

None of the selected power stations with increased design power output will result in water level variations exceeding 14 cm per hour in affected upstream or downstream reservoirs. For most upstream reservoirs, it will take 2-4 weeks of continuous power generation before the reservoir is drawn down from HRWL to LRWL, although in many cases there will be stricter restrictions related to a downstream reservoir. For the two largest reservoirs (Blåsjø and Møsvatn), it will take 10 and 7 weeks when power output from the two reservoirs is increased by 2,800 MW and 1,000 MW, respectively. It is assumed that the operation of existing power stations will remain unaffected.

The output of the 12 power stations in the main scenario can be increased by 18,200 MW without the water level changes in the upper and lower reservoirs exceeding 14 cm/hour (cf. Table 3.3). How long the power stations are able to deliver this power output will depend among other things on the current regulations regarding highest and lowest regulated water levels (HRWL and LRWL), as well as what strategies will be adopted with regard to pumping in the case of pumped storage power stations. By including more cases in Southern Norway in addition to some in Northern Norway, it will be possible to increase the output of existing hydroelectric reservoirs by a further 1,800 MW to give a total of 20,000 MW for the whole country.

The most serious environmental challenges affecting reservoirs resulting from increased power generation installation are connected with the risk of increased erosion, changes in circulation, changes in water temperature, reduced ice cover and increased danger of unsafe ice. All these physical changes can have an impact on ecosystems. In relatively large reservoirs these changes will probably only be localised. The ecosystems of many of the selected reservoirs are at present strongly affected by water level regulation. Here, increased design power output will not necessarily have additional impact on the ecosystem, as in reservoirs where regulation currently has moderate or insignificant impact. Good environmental design can reduce the detrimental impact and in some cases even improve conditions.

Environmental consequences and environmental design must however be studied in detail with special focus on low-lying downstream reservoirs, since species diversity, fertility and vulnerability are often greatest in these. In reservoirs which receive pumped water from lower reservoirs or neighbouring water systems, environmental impacts can be considerable because transferred water can result in major changes in water chemistry and temperature, and a range of organisms may be transferred from the lower reservoir to the upper one. Knowledge of the possible effects of such water transfer is incomplete. The environmental challenges connected with balance power will vary from project to project and will depend on the type of operational pattern and restrictions implemented. Our ability to develop and use knowledge of environmental effects will determine what sort of local impacts balance power projects may have.

Each of the power station installations studied will require connection through a separate 420 kV line to appropriate points in the central supply grid if power exchange with other countries is to take place by way of the central transmission grid. New power stations at Tonstad, Lysebotn, Jøsenfjorden, Kvilldal, Mauranger/Oksla, Sima and Aurland/Tyin can be linked directly to international grids via HVDC cables, since they are located close to a fjord or the sea. These aspects have not been considered in detail in this study.

A system of direct international transmission links will in isolation not make demands on the transmission capacity of the central transmission grid, but operationally it will be an advantage for both the cable links and the transmission grid if these power stations are robustly connected to the central grid. However, when international links are out of operation there will need to be spare capacity in the central transmission grid if power exchange is to be maintained. This requires that the power stations in question are linked to the central transmission grid. This will call for the construction of new 420 kV links and upgrading to 420 kV at several points on the relevant routes.

The power generation installation at Tinnsjø may represent the greatest challenge with regard to grid capacity since the distance to appropriate international links is greatest here. The size of the installation will also determine which alternatives are most appropriate. The south-west link is a possible exchange route linking to the continent.

The themes described in this preliminary study must be followed up with research and more detailed studies before it will be possible to form an accurate picture of the balance power capacity of hydroelectric power plants at existing reservoirs in Norway. The selection of power generation output and pumping power capacity, as well as of an operational strategy for balance power generation in combination with existing power generation calls for detailed studies, using models and simulation tools developed for development planning and production optimisation in systems with predominantly hydroelectric generation. The need for national grid capacity for the purposes of balance power generation must be determined on the basis of thorough analysis of the central transmission grid in the areas affected.

To enable description of environmental impacts during power generation and pumping in more detail, additional knowledge and more detailed studies of the individual reservoirs are needed. Research activities are going on in CEDREN which are contributing to improved knowledge of environmental impacts and environmental design. Environmental impacts in specific reservoirs should be studied in more detail with regard to physical and biological conditions resulting from power generation and pumping.

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