Technical Report

Impacts and mitigation of hydropeaking in Gaula-Lundesokna River

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Executive summary

The River Gaula (Trondheim, Norway) is a natural river which has high conservation value thanks to its wild salmon population. Decreasing salmon stock in the river calls for special requirements for environmental protection. In contrast, the River Lundesokna, a major tributary to the River Gaula, is highly regulated due to extremely fluctuating production discharge (hydropeaking) from the Sokna hydropower plant. Hydropower operation according to market demand has potentially negative impacts on the freshwater ecosystem.

This report assessed the impacts of the hydropeaking in Lundesokna on the natural Gaula in terms of hydrological and thermal regimes, and evaluated how these consequences affect the ecosystem of the salmon population in Gaula River. Potential mitigation measures were also considered and the socio-economical costs and benefits of adapting hydropower regulation to protect Salmon population at early life stage.

The most critical hydrological period is winter, when natural flows are more sensitive to Sokna´s hydropeaking. Under this condition, natural flows strongly differ from regulated hydropeaking at Lundesokna and at the confluence with Gaula and below. Hydropeaking impacts were classified according to the categorization by CEDREN. Impact at Lundesokna was categorized as Large to Very large, whereas the impact at Gaula was categorized as Moderately to Large depending on the indicator.

The analyses of temperature data in regulated condition and natural condition (modelled) at Lundesokna River showed that the critical thermal period is from April to September during the day (7.00 to 15.00 o'clock), in which the water temperature was influenced the most by hydropower discharge. In general, hydropower discharge from Sokna cools down the downstream water up to 0.4 ^{o}C in summer and increases it up to 0.35 ^{o}C in winter.

Spawning and early life stages were assessed for the Atlantic salmon according to flow depth and velocity parameters induced by hydropeaking. Lundesokna is strongly susceptible to low and high flows for both habitats. On the other hand, Gaula is susceptible to high velocities due to hydropeaking for the spawning stage, and to both flow depth and velocity for the age-0 stage. Based on the thermal habitat analysis, the most critical period for early life survival of the Atlantic salmon at the Gaula-Lundesokna confluence is from October to April.

In order to protect spawning and early life development of the Atlantic salmon, we proposed different measures that can be applied on the hydropower plant operation and infrastructure, and on the downstream and in-stream systems. Moreover, the cost-effectiveness of the operational measure for the Sokna hydropower plant was analysed. The cost of increasing the minimum flow during the critical period from October to April to protect the redds from dewatering and freezing was estimated to be 1.1% of the actual revenue. This cost is considered low for its effectiveness in minimising early life mortality of the Atlantic salmon.

0. Introduction

The River Gaula (Trondhei, Norway) is a natural 150.6 km long river, which starts from a mountainous region and drains through a 3635.8 km^2 catchment area to Trondheim fjord. The river has high conservation value thanks to its wild salmon population. However, salmon stock has decreased estimatedly 90% in the last 50 years, which requires special requirements for environmental protection. The River Lundesokna is a major tributary to the River Gaula. In contrast to the natural Gaula, it is highly regulated due to extreme daily flow fluctuations from hydropower production discharge (hydropeaking). Three reservoirs (Håen, Samsjøen and Holtsjøen) supply 145 Mm^3 of water to the Lundesokna cascade hydropower system.The highest daily flow fluctuations in the Lundesokna occur at the Sokna power plant, which operates according to daily and weekly market demand. Such operations, by discharging into the Gaula mainstream, potentially pose negative impacts on the protected freshwater ecosystem downstream of Gaula. This report assessed the impacts of the hydropeaking in Lundesokna on the natural Gaula in terms of hydrological and thermal regimes, and evaluated how these affect the ecosystem of the salmon population in Gaula River. Potential mitigation measures were also considered and the socio-economical costs and benefits of adapting hydropower regulation to protect Salmon population at early life stage.

1. Hydro-model

1.1. Critical hydrological periods

Which are the most critical hydrological periods?

At River Lundesokna, hourly flow data records as well as natural modeled flows were analyzed for the period 2002-2015. Figure 1.1 shows the natural and regulated flow conditions at Lundesokna for the year 2008. Regulated flows differ the most from natural conditions during winter (December - February) and during the end of spring (May).

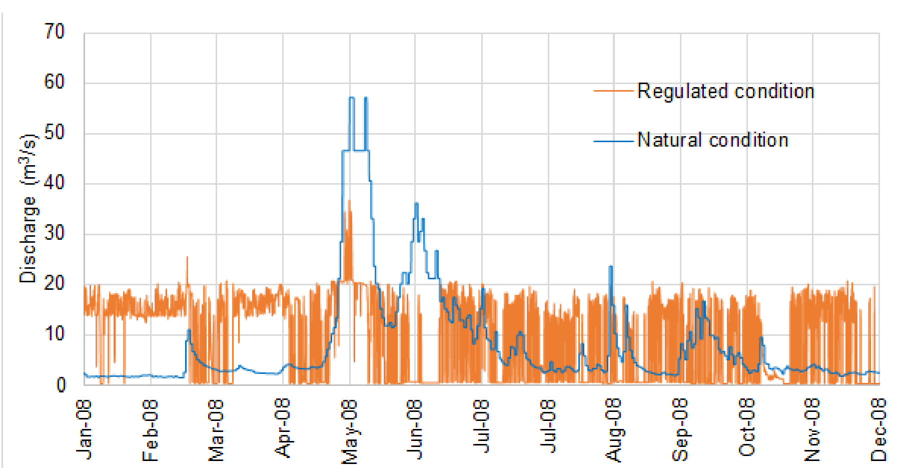

Figure 1.1 Regulated and natural flow conditions at Lundesokna - Year 2008

Monthly average flows were calculated at Lundesokna for the period 2002-2015. Table 1.1 shows the monthly averaged, maximum and minimum flows for Lundesokna regulated and natural conditions. Monthly flows per year are shown in Appendix A. Hydropower plant operation, represented by the regulated conditions, average maximum flows between 20 - 25 m^3/s and minimum flows between 0.3 - 0.5 m^3/s every month.

The most critical periods identified are December - February, when natural average flow ranges 2.3 - 3.5 m^3/s and regulated flows can reach maximum values of 20 m^3/s. It should be noted that there are isolated cases where the regulated flow reached values up to 50 - 70 m^3/s, even 200 m^3/s, which represent extreme hydropeaking events. The second critical period was identified during May, when natural average flow of 27 m^3/s and regulated conditions present a minimum average flow of 1.8 m^3/s. The lowest flow that bypasses the power house is 0.3 m^3/s throughout the year.

Table 1.1 Monthly discharges at Lundesokna during 2002 - 2015 (m^3/s)

Season	Month	Average flow		Average of maximum flow		Average of minimum flow	
		Regulated	Natural	Regulated	Natural	Regulated	Natural
Winter	January	12.8	2.3	20.6	4.7	0.3	1.5
	February	13.5	2.3	21.2	5.4	1.2	1.4
Spring	March	10.4	3.4	21.9	8.5	1.4	1.7
	April	15.8	11.9	26.1	32.7	0.7	3.1
	May	14.3	27.1	29.2	53.2	1.8	11.8
Sumer	June	10.0	19.4	26.8	39.7	0.3	9.5
	July	7.2	8.7	22.3	22.6	0.3	3.9
	August	10.2	7.8	25.4	25.4	0.4	2.5
Autumn	September	11.8	9.2	43.9	25.3	0.4	3.2
	October	10.7	7.1	21.0	17.3	0.3	3.3
	November	9.8	4.8	24.4	11.3	0.5	2.1
Winter	December	11.9	3.5	21.7	8.7	0.5	1.6

At River Gaula, daily flow data records were analyzed for the period 1990-2019. The hydropeaking variation at Sokna impacts flow regimes at the confluence with Gaula and downstream. The most critical condition at Gaula occurs when its flow is lowest since it becomes sensitive to Sokna´s hydropeaking.

Table 1.2 shows the monthly averaged, maximum and minimum flows for Gaula upstream of the confluence with Lundesokna for the period 1990-2019. Monthly flows per year are shown in Appendix A. The most critical period downstream the confluence takes place during winter (December - February), where the average flow and average minimum flow are approximately 20

m^3/s and 10 m^3/s, respectively. During this period, Sokna hydropeaking flows of 20 m^3/s may have a significant impact at the confluence and downstream.

Table 1.2. Monthly discharges at Gaula during 1990 - 2019 (m^3/s)

Season	Month	Average flow	Average of maximum flow	Average of minimum flow	Maximum flow	Minimum flow
Winter	January	18.5	46.3	10.3	288.9	3.5
	February	18.1	48.7	9.5	219.4	3.7
Spring	March	22.6	67.6	10.6	531.5	3.8
	April	93.9	311.0	20.0	635.5	4.4
	May	267.1	609.6	88.7	1111.0	28.3
Sumer	June	198.4	481.7	84.7	1190.3	14.0
	July	83.0	261.2	27.2	785.2	7.7
	August	73.2	291.6	19.9	779.1	5.1
Autumn	September	75.4	253.3	21.9	790.5	7.5
	October	59.3	179.7	23.2	433.2	8.8
	November	37.9	118.8	13.5	325.8	3.4
Winter	December	26.6	74.7	11.8	337.5	3.3

1.2. Wetted area variation

Which areas of both Ludesokna and Gaula are most affected by flow alterations? Can you assess and quantify the wetted area variation due to Hydropeaking alteration from Sokna power plant in different parts of the study area?

A HEC-RAS 2D model was set up in order to assess the most affected areas at Lundesokna and Gaula. Based on Table 1.1 and 1.2, a number of scenarios were established to simulate the hydropeaking effects at both Lundesokna and Gaula throughout the year. Table 1.3 shows the proposed scenarios for modelling. These scenarios represent the regulated minimum and maximum flow at Lundesokna due to hydropeaking, as well as natural flows recorded at Gaula.

Scenarios SC1 to SC10 evaluate hydropeaking with average monthly flows at Gaula, whereas SC11 to SC12 evaluate its effect during the maximum and minimum average daily flows at Gaula.

Table 1.3. Proposed modelling scenarios

Scenario	Months	Flow in Lundesokna (m^3/s)	Flow in Gaula (m^3/s)	Condition Lundesokna	Condition Gaula
SC1	Dec - Mar	0.3	20	Regulated	Monthly average
SC2	Dec - Mar	20	20		
SC3	Oct - Nov	0.3	50		
SC4	Oct - Nov	20	50		
SC5	Apr, Jul - Set	0.3	80		
SC6	Apr, Jul - Set	20	80		
SC7	Jun	0.3	200		
SC8	Jun	20	200		
SC9	May	0.3	265		
SC10	May	20	265		
SC11	Dec - Mar	0.3	10		Averaged daily minimum
SC12	Dec - Mar	20	10		
SC13	May	0.3	610		Average daily maximum
SC14	May	20	610		

Flow depth results along the main channel downstream of Sokna for scenarios SC11 and SC12 are shown in Figure 1.2. Results from other scenarios can be found in Appendix B.

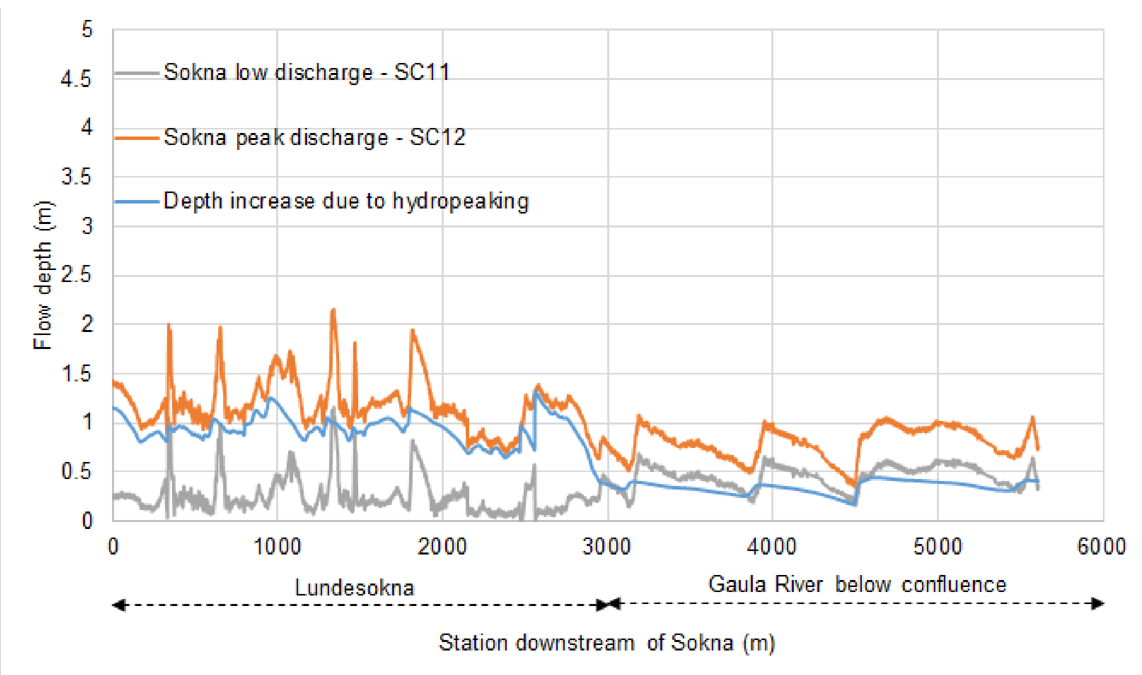

Figure 1.2. Flow depth downstream of Sokna - SC11 / SC12

Lundesokna is affected greatly by hydropeaking, showing flow depth increases of 1 m approximately, while Gaula shows variation of 0.4 m approximately. The most affected areas, in terms of flow depth, are primarily located in stations 1+000, 1+800, 2+600, 3+900 and 4+500. The location of these areas can be identified in Appendix C.

The wetted area variation was calculated for Lundesokna and Gaula separately, according to the flood extent due to Lundesokna flow variation from 0.3 m^3/s to 20 m^3/s. Table 1.4 shows the wetted area variation due to hydropeaking. The wetted area variation is the same at Lundesokna since all the scenarios consider flow change from 0.3 m^3/s to 20 m^3/s. The impact of hydropeaking is high, doubling the wetted area, or vice versa, dewatering half the wetted area when the flow is dropped from 20 m^3/s to 0.3 m^3/s.

At Gaula, the wetted area was measured from the confluence with Lundesokna and approximately 2.5 km below until the model limit. The wetted area variation at Gaula depends on its flow according to the season. The bigger impacts are found for scenarios SC1-SC2 and SC10-SC11, which correspond to the winter period, where the flow at Gaula is lowest. During June and May, however, hydropeaking does not significantly affect Gaula´s hydraulic conditions due to the high flows at Gaula at the end of the spring.

Table 1.4. Wetted area variation due to hydropeaking at Lundesokna and Gaula

Scenario	Lundesokna wetted area			Gaula wetted area		
	Initial (m^2)	Final (m^2)	Variation	Initial (m^2)	Final (m^2)	Variation
SC1-SC2	30,500	65,490	53%	192,993	208,988	8%
SC3-SC4	30,500	65,490	53%	217,097	227,981	5%
SC5-SC6	30,500	65,490	53%	232,801	240,385	3%
SC7-SC8	30,500	65,490	53%	262,179	263,932	1%
SC9-SC10	30,500	65,490	53%	270,407	271,855	1%
SC11-SC12	30,500	65,490	53%	182,908	201,870	9%
SC13-SC14	30,500	65,490	53%	294,877	296,423	1%

2. Temperature

2.1. Critical thermal periods

What are the most critical thermal periods where the thermal regime (thermopeaking) in Lundesokna strongly differs from what it would be expected naturally and contrasts with the thermal regime in Gaula?

At River Lundesokna, hourly water temperature records as well as natural modeled (unregulated) temperature were analyzed for the period 2002-2015. Critical thermal periods are identified by the largest difference in temperature between regulated and unregulated conditions. Hourly average temperatures were calculated and compared between regulated and unregulated conditions to identify critical thermal periods during a day. Similarly, daily and monthly average temperatures were calculated, which show the critical thermal periods during a year. Monthly average temperature at Lundesokna was also compared with monthly average temperature at Gaula River to identify the different thermal regime.

Hourly average temperature at Lundesokna from 2002-2015 shows that during the day, from 7.00 o'clock to 15.00 o'clock is the period with the biggest difference between the regulated and unregulated conditions (0.5 °C) (Figure 2.1). At night between 0.00 o'clock and 5.00 o'clock, the temperature difference is at its minimum 0.25 (°C).

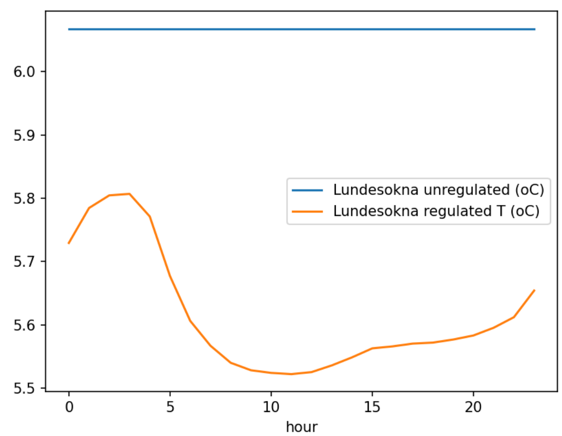

Figure 2.1. Hourly average water temperature at Lundesokna in unregulated (modelled data) and regulated (observed data) conditions of the whole 2002-2015 period

In addition, the hourly average temperature was also calculated for summer months (June to August) and winter months (December to February) separately (Figure 2.2). The temperature in regulated condition is lower than natural condition in summer months and higher in winter months, which means hydropower discharge cools down the water in summer and warms up in winter. Figure 2.2 also shows that the temperature difference was higher in summer months (up to 1.4 °C) than in winter months (up to 0.175 °C).

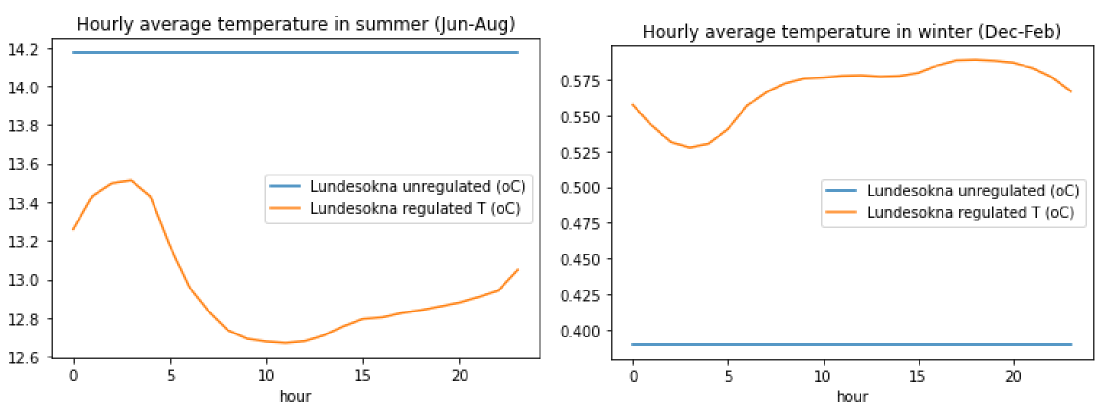

Figure 2.2. Hourly average water temperature at Lundesokna in unregulated (modelled data) and regulated (observed data) conditions during summer and winter of the 2002-2015 period

Similarly, the daily average temperature also shows that the biggest temperature difference between regulated and unregulated conditions at Lundesokna is during the summer months from June to September (about 2 to 5°C) (Figure 2.3).

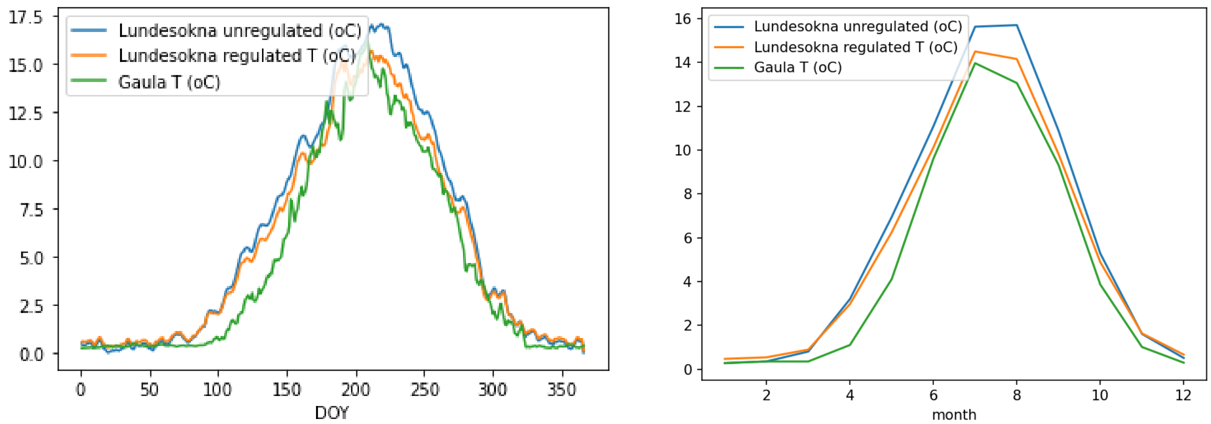

Figure 2.3 Daily average water temperature by day of year (left) and monthly average (right) at Lundesokna in unregulated (modelled data) and regulated (observed data) conditions during the 2002-2015 period and at Gaula during the 2015-2020 period.

Temperature in Lundesokna under regulated condition is lower than unregulated condition and higher than temperature in Gaula (Figure 2.3). The biggest difference between temperature in Gaula and Lundesokna is in April - September. In conclusion, the critical thermal period at Lundesokna River is from April to September during the day (7.00 to 15.00 o'clock).

2.2. Impact of hydropower on temperature variation

Is the contribution of Lundesokna affecting (if yes, how) the maximum/minimum temperature values in Gaula river? Is this a seasonal or persistent pattern?

The temperature at the confluence Gaula-Lundesokna is computed using simple mixing model (Casas-Mulet et al., 2016):

$$T_c = \frac{T_a Q_a + T_b Q_b}{Q_c}$$

Where T is the water temperature (°C) and Q is the flow discharge (m^3/s) at Lundesokna (a), Gaula (b), and the confluence (c). The flow discharge at the confluence was assumed to be the sum of the flow discharge in Lundesokna and Gaula Rivers.

First, the daily average temperature and discharge by day of year (DOY) at Lundesokna of the period 2002-2015 and at Gaula of the period 2015-2020 were calculated and applied to the mixing model equation. The daily average temperature at the Gaula-Lundesokna confluence differs between the regulated and unregulated condition from -0.4 °C in winter to +0.3 °C in summer (Figure 2.4).

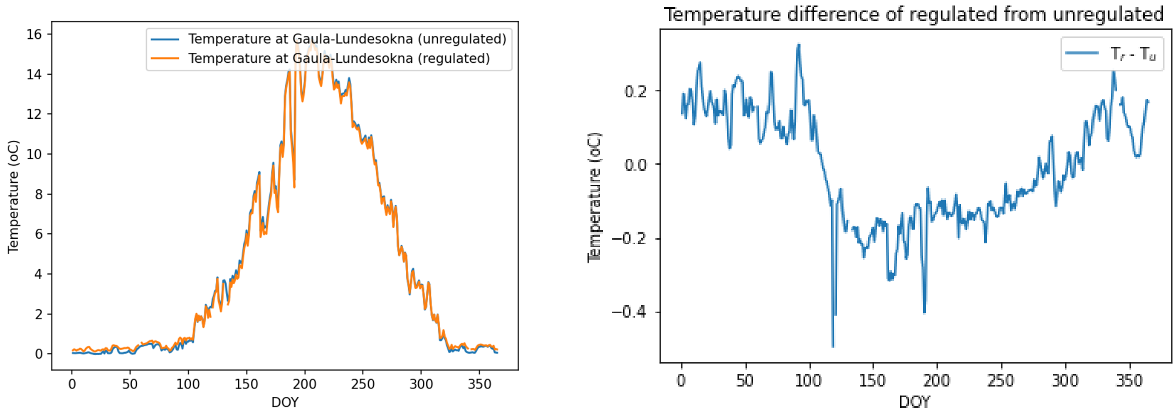

Figure 2.4 The estimated average temperature (left) and temperature difference (right) at the Gaula-Lundesokna confluence under regulated and unregulated conditions. DOY: Day of Year

Since the hourly data at Gaula is not available, we assumed that temperature and flow were constant during the day in Gaula. Figure 2.5 shows the hourly average results of the mixing model based in summer and winter. Due to the mixing effect, the temperature at the confluence increases about 0.15 °C in winter during the hydropeaking and decreases about 0.15 °C in summer.

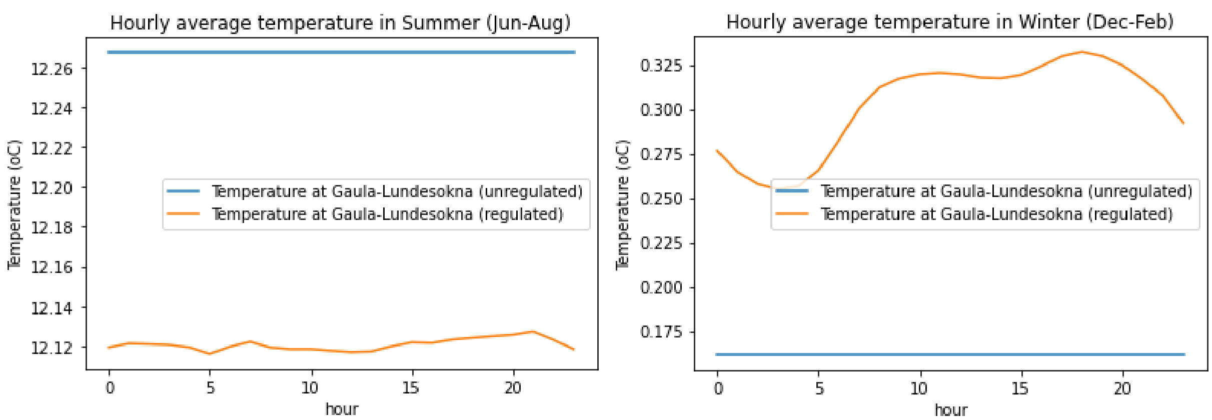

Figure 2.5 The estimated hourly average temperature in summer (left) and winter (right) at the Guala-Lundesokna confluence under regulated and unregulated conditions.

Since the only year with available data at both Lundesokna and Gaula is 2015, the same calculation was done for the year 2015 only to reduce the inter-annual mismatch in the daily average approach (Figure 2.6). When considering a single year (2015), the difference of temperature at the confluence between unregulated and regulated conditions is more significant (increase 0.35 °C in winter and decrease 0.4 °C in summer).

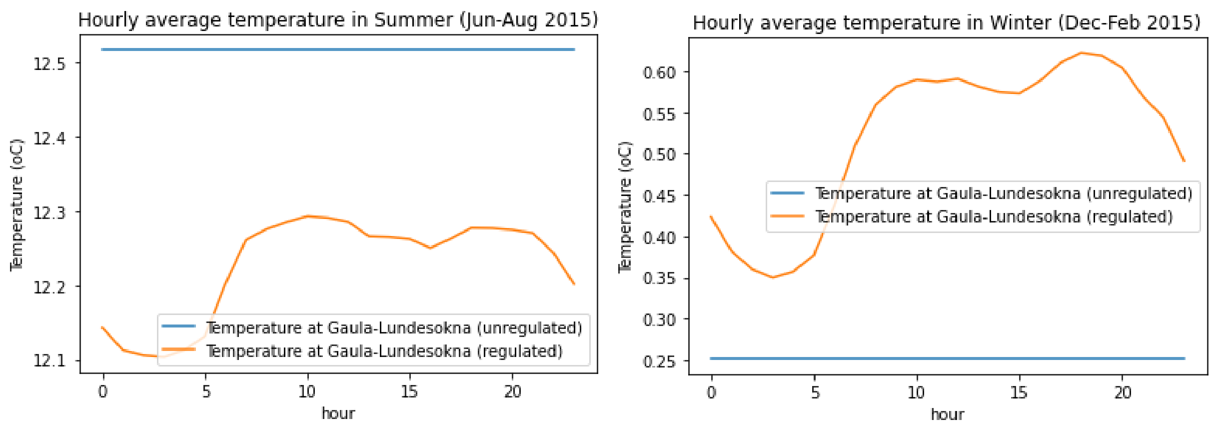

Figure 2.6 The estimated hourly average temperature in summer (left) and winter (right) of the year 2015 at the Guala-Lundesokna confluence under regulated and unregulated conditions.

3. Ecology

3.1. Environmental impacts characterization

Characterize the environmental impacts from hydropeaking operations at Lundesokna based on the categorisation system for environmentally-adapted hydropeaking operations created by CEDREN

E1. Rate of change

Typical hydropeaking occurs from a minimum and maximum flow of 0.3 and 20 m^3/s at Sokna, respectively, as shown in Table 1.1. On average, this flow change occurs in a period of 2 to 3 hours. Table 3.1 shows the rate of change at Lundesokna and Gaula throughout the year, considering hydropeaking from 0.3 and 20 m^3/s in 2 hours, and categorizes this indicator according to CEDREN impact categorization.

The rate of change at Lundesokna is considered very large at any month during the year. At Gaula, the rate of change depends on the month and flow. The most critical months are December - March, where the rate of change is 16 cm/h and 18 cm/h for average and minimum flows, respectively, and categorized as Large according to CEDREN.

Table 3.1 Rate of change characterization at Lundesokna and Gaula due to hydropeaking

Scenario	Months	Lundesokna		Gaula	
		Water level change ratio (cm/h)	CEDREN categorization	Water level change ratio (cm/h)	CEDREN categorization
SC1-SC2	Dec - Mar	50	Very large	16	Large
SC3-SC4	Oct - Nov	50	Very large	9	Moderately

Scenario	Months	Lundesokna		Gaula	
		Water level change ratio (cm/h)	CEDREN categorization	Water level change ratio (cm/h)	CEDREN categorization
SC5-SC6	Apr, Jul - Set	50	Very large	9	Moderately
SC7-SC8	Jun	50	Very large	6	Moderately
SC9-SC10	May	50	Very large	5	Moderately
SC11-SC12	Dec - Mar	50	Very large	18	Large
SC13-SC14	May	50	Very large	1	Small

E2: Dewatered area

The dewatered area indicator is measured as the porcentual change of area from a peak to a low flow. Table 3.2 shows the dewatered area categorization at Lundesokna and Gaula throughout the year due to hydropeaking at Gaula.

At Lundesokna, the impact remains constant for the analyzed scenarios and averages a dewatered area of 53%, which is categorized as Very large. Similarly to indicator E.1, the most critical period at Gaula occurs during December - March, where the flow is lowest. The dewatered area at Gaula during this period is approximately 8%, categorized as Moderately according to CEDREN.

Table 3.2 Dewatered area characterization at Lundesokna and Gaula due to hydropeaking

Scenario	Months	Lundesokna		Gaula	
		Dewatered area (%)	CEDREN categorization	Dewatered area (%)	CEDREN categorization
SC1-SC2	Dec - Mar	53	Very large	8	Moderately
SC3-SC4	Oct - Nov	53	Very large	5	Moderately
SC5-SC6	Apr, Jul - Set	53	Very large	3	Small
SC7-SC8	Jun	53	Very large	1	Small
SC9-SC10	May	53	Very large	1	Smal
SC11-SC12	Dec - Mar	53	Very large	9	Moderately
SC13-SC14	May	53	Very large	1	Small

E3. The Magnitude of Flow

Magnitude of flow of a Hydropeaking is viewed from the Flow ratio ((Q_max)/Q_min) downstream of Lundesokna river. For this calculation a flow ratio of 1.4 and higher are considered to be hydropeaking. occurrence of Hydropeaking in the year 2002-2015 would happen in all characterizations. Figure 3.1 would show that when a hydropeaking did happen it mostly be with a flow ratio 5 or more, while the biggest hydropeaking in 26 March 2012 showed a spike in the flow from 0.3 to 32.07 in 1 hour. Based on the classification by CEDREN in for this indicator Lundeksona HP is characterized as Very Large impact to the environment.

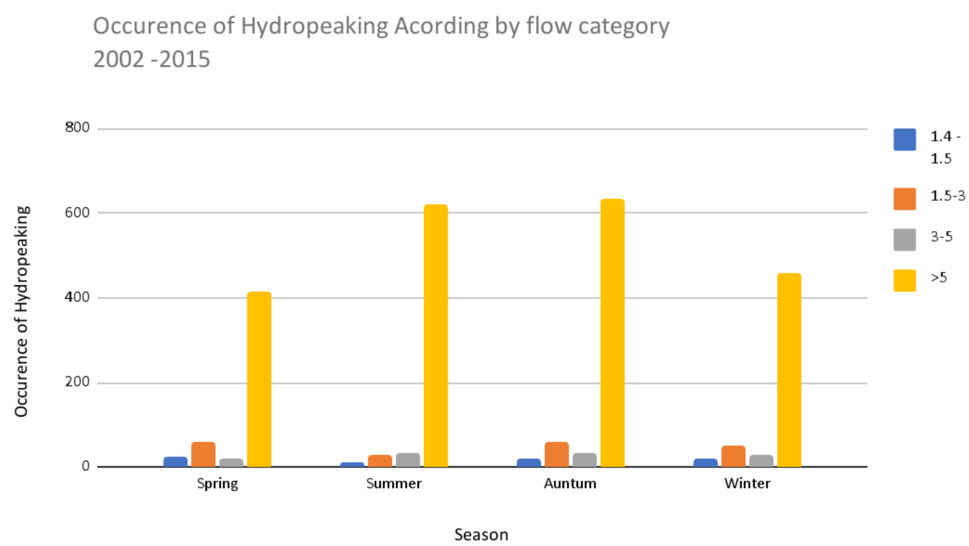

Figure 3.1 Magnitude of Hydropeaking in Sokna River from 2002 - 2015

E4. Frequency

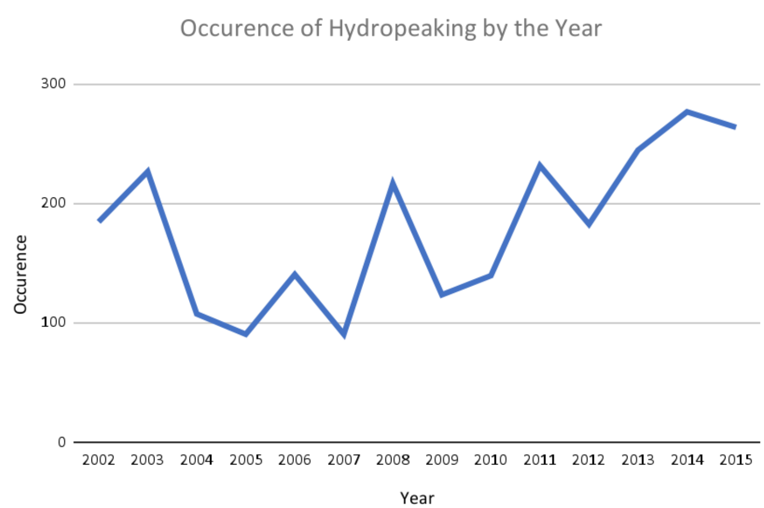

Figure 3.2 Frequency of Hydropeaking from 2002 - 2015

Frequency of Hydropeaking in one year is determined by the number of days where a hydropeaking occurs for the whole year. Figure 3.2 showed the number of days where hydropeaking occurs from 2002 – 2015. Hydropeaking occurrences fluctuated from year to year with the smallest in 2007 with 91 days and biggest in 2014 with 277 days. The average rate of hydropeaking in 1 year at Lundeksona HP is 181 days or 49,6% of the whole year, which is characterized by CEDREN to have a Very Large impact to the environment.

E5. Distribution

The distribution of Lundeksona HP by the month from 2002 – 2015 is displayed in Figure 3.3, it shows that the number of hydropeaking in each month is different for every year. From this it is determined that hydropeaking is happening irregularly throughout the year. While on average hydropeaking would occur more during summer and autumn.

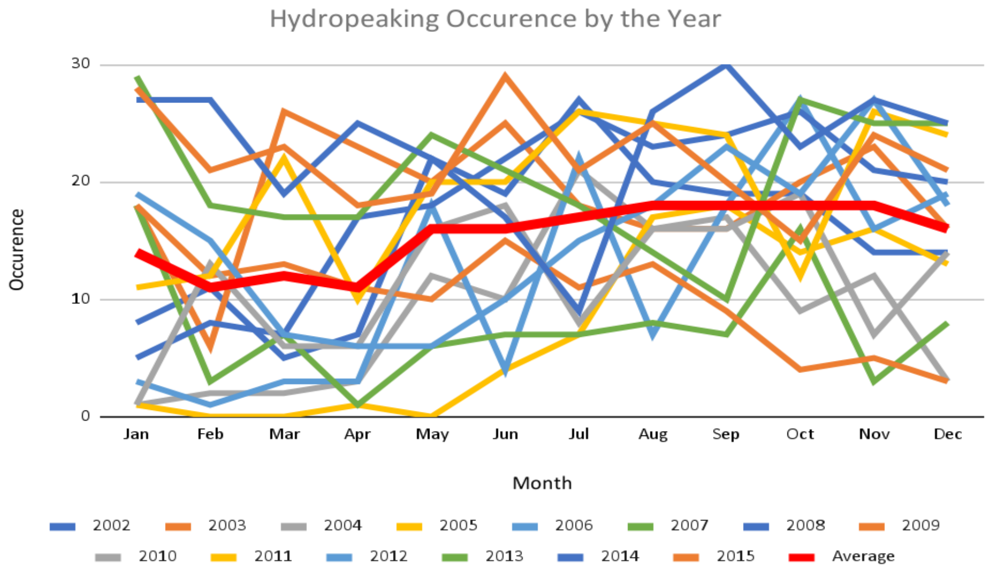

Figure 3.3 Hydropeaking Distribution in Sokna River from 2002 - 2015

E6. Timing

In viewing the timing of hydropeaking the biggest difference in flow ratio hour by hour in 3 hour is considered to be the time where a hydropeaking happens. Based on the data from 2002 -2015, hydropeaking happened in the morning from 4 AM to 10 AM and in the evening from 4 PM to 7 PM. According to the CEDREN characterization, Hydropeaking timing in Lundeksona HP is categorized as Large where the peaking happens during the night of winter.

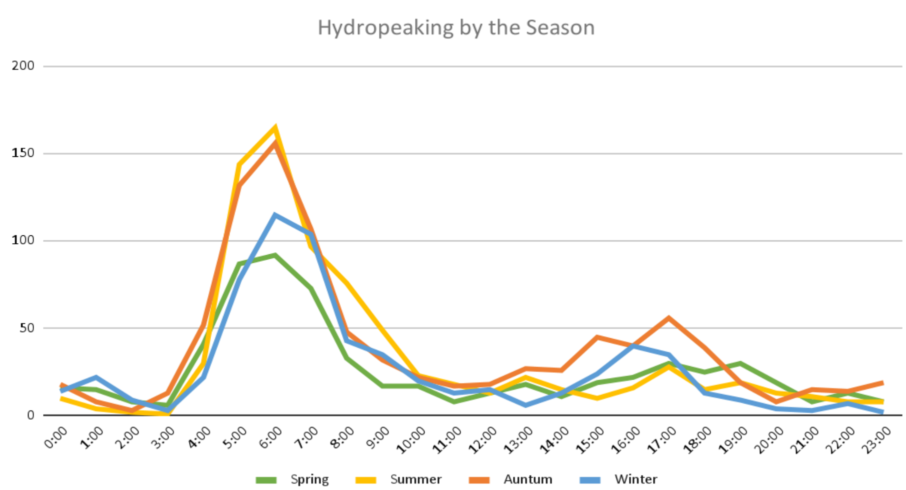

Figure 3.4 Hydropeaking Timing by the Season in Sokna River

3.2. Critical areas and periods for Atlantic salmon

Where and when you find the most critical areas and periods for Atlantic salmon during: age 0 and spawning.

According to Jonsson and Jonsson (2011), Atlantic salmon spawn in autumn or winter, embryos develop in winter and alevins hatch in the subsequent spring; also, most alevins suffer natural death in the months of high flow during the spring. Based on this, for this study, the period October - February and February - April are considered for analyzing the spawning and age-0 stages of Atlantic salmon, respectively.
An additional scenario "PSA" was simulated considering natural conditions at both Lundesokna and Gaula during winter, which was used for identifying potential spawning areas (PSA) that could be most affected due to flow alterations. This scenario considers an average natural flow at Lundesokna of 3 m^3/s during winter and of 20 m^3/s at Gaula. Potential spawning areas were located based on the flow depth and velocity, according to CEDREN spawning habitat hydrologic features. CEDREN ideal hydrological conditions for spawning considera flow depths between 0.3 - 1.5 m and flow velocities between 0.3 - 0.6 m/s. Based on these criteria, 9 PSA, shown in Appendix C, were identified at Lundesokna and Gaula.

These PSA were analyzed under regulated hydrological conditions, which consider hydropeaking at Sokna. Appendix D shows flow depths and flow velocities at 5 representative points of each area for spawning areas.

Table 3.3 shows the most critical conditions in terms of flow depths for spawning, which occur when flow depth is below 0.3 m or above than 1.5 m (Forseth and Harby, 2014). The most critical area in Lundesokna is A4, where flow depth is 0.25 m. At Gaula, the most critical area is A7, which may drop to 0.19 m when the flow is the minimum during winter.

Table 3.3 Critical spawning periods and areas at Lundesokna and Gaula in terms of flow depth

Scenario	Months	Potential Spawning Areas								
		Lundesokna					Gaula			
		A1	A2	A3	A4	A5	A6	A7	A8	A9
SC1	Dec - Mar	0.31	0.42	0.36	0.25	0.30	0.44	0.41	0.54	0.43
SC3	Oct - Nov	0.31	0.42	0.36	0.25	0.30	0.69	0.85	0.95	0.69
SC11	Dec - Mar	0.31	0.42	0.36	0.25	0.30	0.31	0.19	0.33	0.30

Table 3.4 shows the most critical conditions in terms of flow velocities for spawning, which occurs when flow velocity is below 0.3 m/s or above 0.6 m/s (Forseth and Harby, 2014). Lundesokna presents critical spawning conditions for both low and high hydropeaking flows, where area A1 and A8 are more susceptible to these variations. At Gaula, the most critical condition occurs at A9 during October - November when flow from Lundesokna is 20 m^3/s, leading to high velocities at Gaula.

Table 3.4 Critical spawning periods and areas at Lundesokna and Gaula in terms of flow velocity

Scenario	Months	Potential Spawning Areas								
		Lundesokna					Gaula			
		A1	A2	A3	A4	A5	A6	A7	A8	A9
SC1	Dec - Mar	0.12	0.18	0.17	0.20	0.09	0.56	0.48	0.56	0.62
SC4	Oct - Nov	1.01	1.18	0.94	1.09	0.82	0.76	0.74	0.63	0.87

For this study, age - 0 stage is considered during February - March and at the same PSA identified, assuming that alevins are able to move a few meters from their spawning location. Appendix E shows flow depths and flow velocities at 5 representative points of each area for age - 0 stage periods.

Table 3.5 shows the most critical conditions in terms of flow depths for age-0, which occur when flow depth is below 0.1 m or above than 0.45 m (Jonsson and Jonsson, 2011). The most critical area in Lundesokna is A1 and A4, where flow depth is 0.98 m. At Gaula, the most critical area is A7, where flow depth is to 1.28 m during April and when flow at Lundesokna is 20 m^3/s.

Table 3.5 Critical age-0 periods and areas at Lundesokna and Gaula in terms of flow depth

Scenario	Months	Potential Age-0 Areas								
		Lundesokna					Gaula			
		A1	A2	A3	A4	A5	A6	A7	A8	A9
SC6	Apr	0.98	0.97	0.90	0.98	0.95	0.90	1.28	1.21	1.01

Table 3.6 shows the most critical conditions in terms of flow depths for age-0, which occur when flow depth is below 0.05 m/s or above than 0.60 m/s (Jonsson and Jonsson, 2011). The most critical area in Lundesokna is A2, where flow velocity is 1.18 m/s. At Gaula, the most critical area is A9, where flow velocity is 0.98 m/s m during April and when flow at Lundesokna is 20 m^3/s.

Table 3.6 Critical age-0 periods and areas at Lundesokna and Gaula in terms of flow velocity

Scenario	Months	Potential Age-0 Areas								
		Lundesokna					Gaula			
		A1	A2	A3	A4	A5	A6	A7	A8	A9
SC6	Apr	1.01	1.18	0.94	1.10	0.82	0.92	0.85	0.73	0.98

In summary, Lundesokna is strongly susceptible to low and high flows for both spawning and age-0 habitats in terms of flow depth and velocity. On the other hand, Gaula is more susceptible to high velocities for spawning habitats. For age-0 habitats, Gaula is susceptible to both flow depth and velocity during hydropeaking.

3.3. Thermal habitat for salmonids

With a focus on the confluence Gaula-Lundesokna area, can you identify the periods where thermal habitat for salmonids is most and least suitable?

Based on the estimated temperature at the Gaula-Lundesokna confluence (Figure 2.4) and the overview of thermal biology and temperature tolerances for survival in the life histories of Atlantic salmon by Heggenes et al. (2021), we estimated the best period for growth and survival period for each life stage of the Atlantic salmon (Table 3.3).

Table 3.7 The best period for growth and survival period for life stages of Atlantic salmon

Life stage		Optimal temperature (ºC)	Tolerance Low (ºC)	Tolerance High (ºC)	Best period	Survival period
Eggs	Incubation	5 (100days), 2 (160 days)	0	16	Depends on degree-days	Whole year
	Survival	6 to 8?			Depends on temperature and oxygen level	
Alevins	Development	7.5 (100days)	0 to 2	23 to 25	D100 to D300 (mid April to Nov)	Whole year
	Survival	<22				
Fry		4 to 22				
Parr	Max growth	16	0 to 7 (-0.8 ULT)	22 to 28 (30 to 33 ULT)	D200 to D225 (July to Aug)	Whole year
	Avoided temperature	5-6 to 22				
Smolt		3 to 10				
	Migration	10			D175 to D250 (late June to mid Sep)	
	Swimming	> 5			D150 to D275 (June to early Oct)	
	Spawning migration	5 to 16			D150 to D275 (June to early Oct)	
Adult	Ovulation	14 to 16			D200 to D225 (late July to mid Aug)	Whole year
	Spawning	1 to 8			D260 to D325 (late Sep to late Nov)	

We estimated that spawning at the confluence starts about late September until late November, which agrees with the spawning period based on the observation in other parts of Gaula and information from the local hatchery in Lundesokna (Casas-Mulet et al., 2016) (from 1 October and peak on 1 November). After spawning, the survival of the eggs depends on oxygen level and degree-day. In general, the water temperature at the confluence is between the survival range of the eggs (0 to 16) for the whole year. However, the most critical period of early life survival of Atlantic salmon is from October (Spawning) to April (Alevins development).

4. Socio-economics

4.1. Mitigation options

What are the possible and most feasible mitigation options given the current conditions in Soka Power Plant?

The freshwater ecosystem in Gaula is mainly affected by hydropeaking and low flow due to hydropower operation. Therefore, possible mitigation options can be:

- Hydropower plant measures:
  - Adjusting hydropower operation: Changing the magnitude, speed of change, frequency and timing of change to the better for the ecosystem exposed to hydropeaking
  - Technical measures directly on the power plant/infrastructure: For example, a technical setup that allows a wider range of turbine discharges, slower stop and start-up, etc.
- Downstream measures:
  - Construction of bypass channel from Sokna hydropower plant to Gaula river in condition of high hydro-peaking: In order to reduce high flow change downstream on Lundesokna, a channel bypassing Sokna River and into Gaula River can be constructed. The channel will transfer a portion of the flow from the HP when a sudden spike in the flow occurs, while Sokna river flow would gradually increase. This will avoid a high change of flow magnitude in a short period. The channel can also be used as a diversion channel in case a flood were to happen.
  - Construction of off-channel habitats: Creating an area outside the main river for resting and survival can be vital during hydro-peaking and low flow. Areas such as oxbows, sidearms, and small ponds that are not affected by the river flow.
- In-stream measures:
  - Fish refuge under hydropeaking conditions: Abrupt hydropeaking can have impacts on physiology of some aquatic species. Fish flow-refuges that mimic natural refuges can be deployed in rivers, such as lateral deflectors and overhead covers.
  - Construction of 'River in the River' for low flow condition: For location where the river has a broad stream bed with low flow, confining the stream flows creating alternatif rifles and pools. A semi permanent current deflectors, groynes, rocks and

other structures are used to increase the velocities and height of the water when long periods of low flow are happening.

In addition, studies have shown that due to Climate Change, an increase of flow in winter and autumn will happen in the 2040-2069 period, while a decrease in flow in summer will occur. Further studies for mitigation of high flow impact in winter and autumn to be conducted in the future.

4.2. Cost-effectiveness of mitigation measure

Based on the production data and energy market price of the period 2011-2013, model the costs and benefits of applying mitigation measures, with a focus on flow changes adapted to mitigate early life survival?

We assessed the costs and benefits of mitigation measures for early life survival of Atlantic salmon. In particular, the critical periods for Atlantic salmon early life stages survival in Lundesokna is considered (from October to April). The critical flow is defined by 3.5 m^3/s when air temperatures are below 0 ^oC, which dry and freeze the redds where embryos are developing. The mitigation measure considered is rising production discharge to at least 3.5 m^3/s during the October-April period. Since the total capacity of reservoirs that supply water to the Sokna hydropower plant is 145 Mm^3 , there is a limitation of water to release during this period due to low natural river flow (Figure 1.1). Therefore, we assumed that production discharges during high demand periods need to be reduced in order to store water in the reservoirs for the mitigation measure.

First, we estimated how much water needs to be reserved for mitigation production discharge based on the actual production discharge at Sokna power plant and air temperature data of the 2011-2013 period. For this, we consider two options:

- Option 1: Rise minimum production discharge to 3.5 m^3/s in October-April period only when air temperature is lower than 0 ^oC.
- Option 2: Rise minimum production discharge to 3.5 m^3/s in October-April period always

We compared the total water requirements for each option with the total production discharge during May-September that can be reduced to store water in the reservoir for the mitigation measure. On average, the total reducible discharge would be 145.21 Mm^3/year, which means the reservoirs would have enough capacity to store water for the mitigation measure if less than total reducible discharge were stored in the reservoirs (Table 4.1). The ratio of discharge requirement to reducible discharge is 3.7% on average and up to 6.7% in 2013 if option 1 is applied. Meanwhile, total water requirement would be up to 21.4% for option 2. Therefore, we suggested reducing the production discharge during the May-September period by 7% of its actual amount for option 1 and 22% for option 2 in order to ensure water requirements for increasing production discharge during the October-April period.

Table 4.1 Estimated total reducible discharge and discharge requirement for mitigation measure

Year	*Total reducible discharge* (Mm^3)	*Option 1*		*Option 2*	
		Total discharge requirement (Mm^3)	*Ratio*	*Total discharge requirement* (Mm^3)	*Ratio*
2011	*147.11*	*5.16*	*3.5%*	*14.76*	*10.0%*
2012	*171.17*	*3.22*	*1.9%*	*11.54*	*6.7%*
2013	*117.36*	*7.89*	*6.7%*	*25.08*	*21.4%*
Average	*145.21*	*5.42*	*3.7%*	*17.12*	*11.8%*

We estimated the annual costs and benefits including:

- The benefits from additional production during critical periods (October-April) calculated assuming that it was sold to actual market price
- The costs from reducing actual production during May-September periods by 7% for option 1 and 22% for option 2

We assumed that there is no other cost to produce additional power during critical periods. On average, increasing minimum flow when air temperature is below 0 during critical periods while reducing the production discharge during other periods by 7% might reduce the actual revenue by about 1.1% (Table 4.2). This cost is considered rather low assuming that it would help minimise early life stages mortality of Atlantic salmon. The second mitigation option is more conservative since it increases minimum flow under any air temperature. This option reduces even further the impact of low flow on Atlantic salmon during critical periods since it also creates ideal spawning habitat (Appendix D). However, this might cost 4% of actual revenue.

Table 4.2 Annual economic cost and benefit of implementing the proposed mitigation measure options (in thousand Euro).

Year	Actual revenue	Option 1				Option 2			
		Cost	Benefit	Balance	%Actual revenue	Cost	Benefit	Balance	%Actual revenue
2011	5,186	139	79	-61	-1.2%	451	212	-238	-4.6%
2012	6,067	164	48	-116	-1.9%	530	169	-361	-5.9%
2013	4,046	111	116	5	0.1%	357	344	-13	0.3%
Total	15,299	414	242	-172	-1.1%	1338	725	-613	-4.0%

5. Conclusions

- Hydropeaking at Sokna produces an average flow variation from 0.3 m^3/s to 20 m^3/s on a regular basis, although single events that elevated discharge to 50 - 70 m^3/s, even 200 m^3/s have been identified for the period 2002 - 2015, which affects downstream ecological environment for Atlantic Salmon at River Lundesokna and River Gaula.

- The most critical condition in Gaula occurs when its flow is lowest, which occurs in winter during the months of December - March, since it becomes sensitive to Sokna´s hydropeaking. This period is also the critical period for the early life survival of Atlantic salmon since low flow can cause dewatering of the redds.

- On the other hand, the months of April - September are more critical thermal periods as the impact of discharge from the Sokna hydropower plant on downstream water temperature was more significant. In general, the hydropower discharges cool down the downstream water up to 0.4 ^oC in summer and increase it up to 0.35 ^oC in winter.

- Evaluation of Lundesokna HP shows that 5 out of 6 Indicators for hydro-peaking impact are categorized as Very Large according to CEDREN categorization. In Gaula, it is categorized as Large and Moderately for the change of rate and dewatered area indicators, respectively, according to CEDREN categorization.

- Lundesokna is strongly susceptible to low and high flows for both spawning and age-0 habitats in terms of flow depth and velocity. On the other hand, Gaula is more susceptible to high velocities for spawning habitats. For age-0 habitats, Gaula is susceptible to both flow depth and velocity during hydropeaking.

- In order to protect the spawning and early life development of the Atlantic salmon, several measures can be applied. One of them is adjusting the hydropower operation to minimise mortality and create ideal habitat for eggs and juvenile salmon. The cost of two hydropower operation options were estimated. Option 1 considers increasing minimum flow to protect the redds from freezing would cost 1.1% of the actual power production revenue, which is rather low cost. Option 2 is more conservative as it also improves spawning habitat for juvenile salmon. However, this would cost 4% of the actual revenue.

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Appendix A - Flow record statistics at River Lundesokna and River Gaula

Lundesokna regulated monthly average flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	16.2	14.6	16.7	18.9	9.9	6.8	7.3	3.7	6.1	9.3	4.9	4.6
2003	10.3	15.2	11.4	10.5	7.8	9.3	3.3	12.1	12.4	11.3	6.8	12.2
2004	6.8	17.1	15.4	19.0	13.0	6.4	6.7	3.4	13.3	12.0	14.9	17.1
2005	15.8	17.8	17.8	20.3	20.0	17.6	4.2	13.9	10.9	5.6	7.9	11.8
2006	17.0	18.0	17.0	18.0	12.5	7.5	7.5	4.9	7.5	10.8	12.2	12.4
2007	13.2	15.8	4.1	19.2	22.4	9.7	10.7	14.9	23.1	11.0	18.6	15.6
2008	14.8	13.4	13.6	11.8	11.9	8.4	8.6	7.3	7.6	7.6	6.3	7.4
2009	10.9	11.5	4.4	19.1	18.6	15.4	8.8	14.2	14.7	16.9	14.7	16.8
2010	16.0	1.5	0.7	16.3	13.3	8.7	14.4	9.6	13.9	13.1	4.6	7.8
2011	10.3	14.3	6.6	19.1	14.6	7.1	9.6	13.7	12.1	14.9	10.6	12.6
2012	15.8	15.0	16.1	17.7	18.9	17.3	7.1	12.0	11.0	14.3	9.0	11.7
2013	10.5	12.2	10.8	4.8	8.7	8.7	5.3	13.7	9.5	6.3	8.6	14.5
2014	11.9	8.7	4.2	12.9	14.5	7.2	1.9	9.2	9.6	6.1	8.7	9.1
2015	9.3	13.1	7.3	13.1	14.1	9.2	5.7	10.1	13.0	10.5	9.0	13.4
Total	12.8	13.5	10.4	15.8	14.3	10.0	7.2	10.2	11.8	10.7	9.8	11.9

Lundesokna regulated monthly maximum flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	19.9	19.4	19.8	20.4	20.2	20.3	19.8	18.7	20.4	20.0	19.8	19.7
2003	19.5	18.9	20.2	20.1	20.3	20.4	19.7	51.4	20.2	31.9	19.4	20.5
2004	18.4	20.4	20.2	25.8	20.1	20.1	19.9	17.7	106.1	19.0	51.0	20.1
2005	20.3	21.0	20.8	21.4	21.3	20.6	19.3	20.9	20.8	20.4	20.8	40.8
2006	25.8	35.5	20.8	32.4	61.2	21.0	20.9	19.3	40.3	20.6	20.3	20.7
2007	20.6	20.7	19.3	36.5	53.8	25.0	21.0	42.1	46.5	20.1	46.3	19.6
2008	19.9	25.5	20.8	34.4	36.8	20.7	20.2	19.6	20.6	19.4	20.1	20.8
2009	20.6	20.0	20.0	35.2	37.2	24.2	49.3	20.7	24.3	19.5	20.8	20.8
2010	20.6	12.2	17.3	20.7	31.4	69.2	21.1	19.6	20.4	20.7	19.9	19.9
2011	19.9	19.8	20.0	36.2	20.9	20.5	20.5	29.3	30.7	21.1	20.5	20.4
2012	20.8	20.8	46.1	20.3	23.6	34.7	20.3	20.8	19.9	19.9	19.8	19.5
2013	20.6	20.4	20.4	20.9	20.8	27.6	20.5	28.4	202.9	20.3	20.6	20.8
2014	20.6	20.8	20.2	20.8	20.8	30.8	19.2	25.9	21.1	20.9	20.6	20.1
2015	20.7	20.8	20.1	20.8	20.8	20.8	20.4	21.0	20.7	20.5	21.3	20.4
Total	25.8	35.5	46.1	36.5	61.2	69.2	49.3	51.4	202.9	31.9	51.0	40.8

Lundesokna regulated monthly minimum flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2003	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2004	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2005	0.3	13.1	12.8	5.3	13.5	0.4	0.4	0.4	0.3	0.4	0.4	0.3
2006	0.3	0.3	2.7	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3
2007	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.8	0.3	2.4	0.3
2008	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.3	0.3	0.3
2009	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.4	0.4	2.5
2010	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.3	0.3	0.3
2011	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.3	0.3	0.3
2012	0.3	0.3	0.3	0.3	8.4	0.5	0.5	0.5	0.3	0.3	0.3	0.3
2013	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2014	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.6	0.3	0.3	0.3
2015	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Lundesokna unregulated monthly average flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	3.0	2.0	1.9	19.6	29.9	9.5	7.6	2.0	6.9	5.5	1.6	0.6
2003	1.2	1.2	2.4	8.4	23.4	13.7	4.0	15.3	9.6	7.4	3.8	5.0
2004	2.0	3.9	5.4	20.4	27.4	16.9	7.8	3.9	20.6	5.8	7.5	6.2
2005	3.8	3.9	2.9	11.2	29.2	32.4	10.3	12.7	8.9	3.5	4.8	5.5
2006	2.8	5.2	2.1	5.9	30.8	17.5	5.4	3.5	9.0	6.8	7.1	7.4
2007	3.3	2.9	3.9	15.8	27.7	15.7	7.5	6.6	15.2	11.1	7.2	3.0
2008	1.8	3.4	2.8	9.0	29.8	18.2	6.5	5.1	4.3	7.8	3.7	2.5
2009	3.5	1.4	1.7	16.2	29.5	18.7	11.7	8.0	12.0	8.0	3.5	2.1
2010	1.4	1.0	2.7	6.7	26.5	26.4	10.0	4.0	8.4	6.6	3.1	0.8
2011	1.2	1.1	1.6	23.7	27.8	17.2	9.9	13.3	10.7	11.5	7.3	3.7
2012	2.7	1.6	15.6	8.7	27.8	29.4	14.3	9.4	8.2	7.6	6.1	1.3
2013	1.3	0.9	1.2	5.2	29.2	19.2	7.1	10.6	4.6	6.2	5.2	5.8
2014	2.0	1.2	1.7	8.3	20.8	14.5	4.4	8.9	4.3	5.7	2.7	1.2
2015	1.9	2.6	2.1	7.5	20.1	22.9	14.7	5.3	6.7	5.6	2.9	3.9
Total	2.3	2.3	3.4	11.9	27.1	19.4	8.7	7.8	9.2	7.1	4.8	3.5

Lundesokna unregulated monthly maximum flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	4.1	2.3	5.3	46.6	57.1	17.5	18.2	7.6	18.2	19.1	3.0	1.1
2003	2.2	1.7	5.8	21.2	36.2	28.5	8.9	46.6	30.6	15.9	9.9	16.6
2004	3.0	12.8	16.6	36.2	57.1	30.6	26.7	14.6	57.1	15.2	15.2	13.4
2005	6.6	7.9	5.3	25.1	57.1	57.1	20.1	40.6	22.3	7.6	10.3	16.6
2006	14.0	17.5	2.6	25.1	57.1	28.5	11.0	9.2	36.2	12.4	12.4	20.1
2007	6.0	3.8	7.6	57.1	57.1	46.6	16.6	16.6	33.0	30.6	20.1	4.5
2008	2.5	11.0	3.9	46.6	57.1	36.2	19.1	23.6	15.9	16.6	9.5	3.3
2009	7.1	1.8	3.0	46.6	57.1	33.0	57.1	23.6	33.0	16.6	7.4	3.0
2010	2.4	2.3	10.6	25.1	57.1	57.1	36.2	8.9	18.2	18.2	11.9	1.9
2011	3.9	1.4	4.1	57.1	57.1	40.6	16.6	57.1	28.5	23.6	14.6	8.6
2012	3.7	2.2	46.6	17.5	57.1	57.1	25.1	16.6	17.5	26.7	14.0	1.7
2013	2.7	1.1	1.5	19.1	57.1	40.6	15.9	40.6	14.0	14.0	17.5	14.0
2014	3.2	1.5	2.7	16.6	46.6	46.6	8.2	33.0	15.2	10.3	5.8	1.6
2015	5.0	8.2	3.8	18.2	33.0	36.2	36.2	16.6	14.6	14.6	6.6	15.9
Total	14.0	17.5	46.6	57.1	57.1	57.1	57.1	57.1	57.1	30.6	20.1	20.1

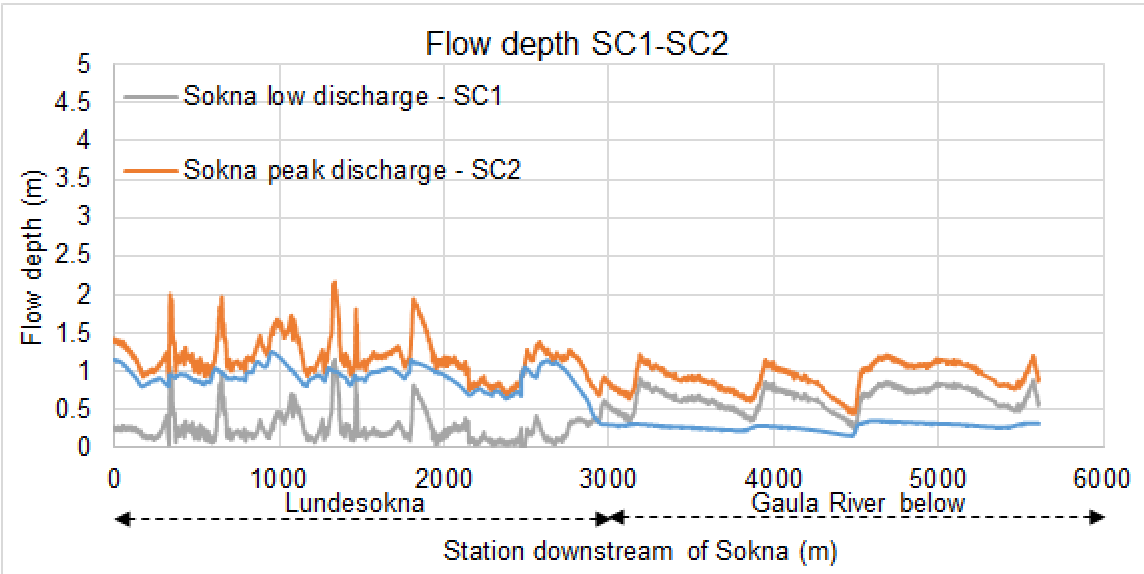
Lundesokna unregulated monthly minimum flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2002	2.1	1.8	1.4	5.0	18.2	4.4	4.0	0.8	1.2	1.6	0.6	0.4
2003	0.4	0.8	0.6	2.0	7.9	5.5	1.3	1.1	3.0	3.2	1.7	1.1
2004	1.5	1.7	3.1	5.6	15.2	5.1	3.1	1.3	2.7	2.7	2.8	3.0
2005	3.0	2.1	1.9	4.4	14.0	18.2	4.4	3.8	3.5	1.5	2.9	1.7
2006	1.7	2.6	1.7	1.7	13.4	6.6	1.6	1.8	2.5	4.1	4.0	2.3
2007	2.1	2.1	2.0	4.8	16.6	6.6	3.8	2.4	6.0	4.4	4.0	2.1
2008	1.6	1.5	2.3	3.0	11.5	8.2	2.5	2.6	1.9	2.4	2.3	1.8
2009	2.0	1.3	1.3	1.9	20.1	10.6	4.7	2.8	5.5	5.0	0.9	1.1
2010	1.0	0.9	0.8	3.4	6.9	14.0	4.5	1.5	2.1	3.3	0.8	0.4
2011	0.4	0.8	0.8	1.9	15.2	6.9	3.1	5.3	5.5	6.4	3.7	1.9
2012	1.5	1.2	3.9	5.0	8.9	14.6	7.9	5.1	4.7	3.7	1.5	1.2
2013	0.8	0.8	1.0	1.0	4.7	8.6	3.2	3.2	2.0	2.4	1.8	3.2
2014	1.1	1.0	1.1	1.5	6.9	7.4	1.6	2.2	1.6	3.2	1.0	1.0
2015	1.0	1.0	1.3	1.5	5.8	16.6	8.9	1.2	2.5	2.5	1.2	1.7
Total	0.4	0.8	0.6	1.0	4.7	4.4	1.3	0.8	1.2	1.5	0.6	0.4

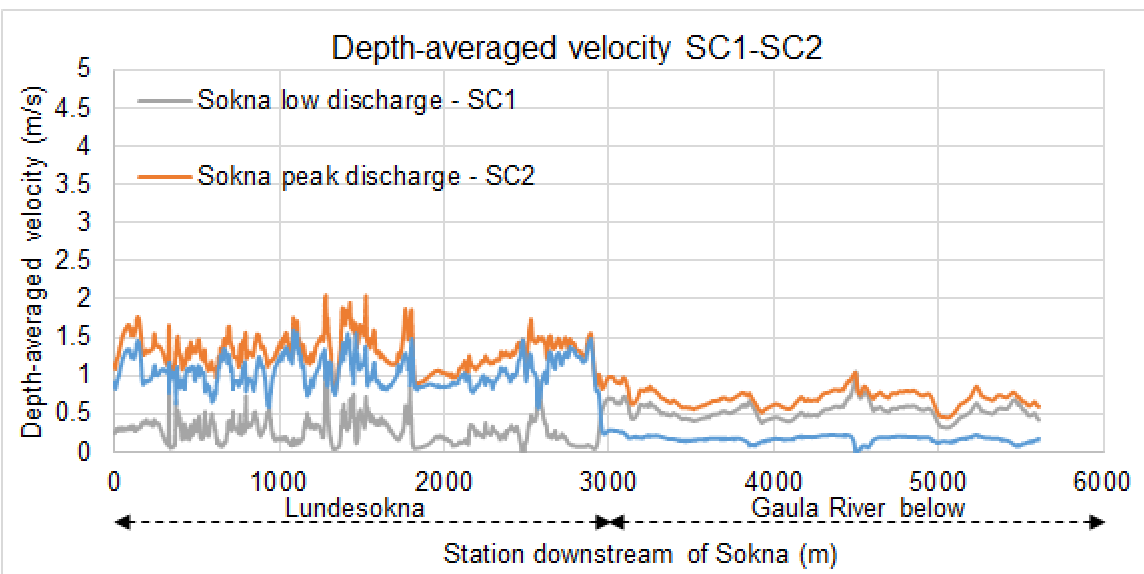
Gaula monthly average flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
1994	4.2	3.7	4.3	68.2	146.6	205.4	50.5	68.0	48.7	112.7	35.6	21.1
1995	12.0	10.5	10.9	27.8	321.7	369.9	82.0	80.3	26.8	67.9	37.1	19.0
1996	8.5	5.0	4.9	75.2	164.4	249.8	105.8	30.5	35.0	41.1	19.2	18.8
1997	12.1	14.2	14.9	42.2	293.9	512.2	128.0	26.2	215.7	101.0	51.3	15.9
1998	10.4	55.4	27.8	115.0	267.0	229.3	103.9	163.0	49.1	52.4	15.6	12.3
1999	9.2	35.5	12.5	121.3	168.5	182.7	115.6	26.0	21.5	62.6	68.7	20.8
2000	20.3	20.2	17.1	130.5	397.6	155.9	119.3	113.1	45.5	20.2	13.8	12.0
2001	6.4	6.1	5.7	31.5	224.7	125.5	110.7	94.4	95.5	51.5	87.8	47.1
2002	20.9	12.9	12.9	186.6	296.8	78.3	59.9	13.9	57.8	43.1	10.7	4.4
2003	8.2	8.1	16.3	71.8	222.7	121.8	28.5	145.4	81.1	57.9	27.5	38.3
2004	13.4	28.8	40.3	196.8	271.4	154.8	62.8	29.9	207.1	44.4	58.8	47.4
2005	26.5	27.5	19.4	94.8	290.8	323.1	88.1	112.0	73.3	24.4	34.7	42.3
2006	20.2	39.7	13.6	48.6	301.0	161.5	41.0	25.1	77.5	52.4	55.1	60.9
2007	22.9	20.3	27.2	147.7	274.5	144.8	59.9	53.1	138.0	95.1	56.7	21.0
2008	11.8	24.7	19.7	81.4	297.9	167.3	50.4	39.5	31.6	62.4	26.8	17.0
2009	24.9	9.3	11.6	150.8	291.4	172.6	108.5	64.5	103.9	64.0	24.6	13.9
2010	9.3	6.8	18.9	52.4	266.1	270.5	84.0	28.7	69.9	50.8	22.4	5.4
2011	8.3	7.1	10.4	231.7	274.6	159.2	83.5	123.2	90.4	97.7	57.1	26.2
2012	18.7	11.3	144.2	70.1	266.9	297.6	127.0	77.5	64.9	60.7	45.9	8.6
2013	8.3	5.8	7.5	41.6	308.0	178.7	55.1	91.7	34.3	47.8	40.3	44.0
2014	13.8	7.7	11.4	69.5	204.5	130.4	31.8	76.3	32.4	41.6	18.8	7.6
2015	12.5	18.3	13.9	60.1	187.2	218.4	131.2	41.0	53.3	42.5	19.9	28.7
2016	8.1	6.3	27.8	42.6	256.3	97.5	51.6	70.1	53.9	27.4	53.5	106.2
2017	49.6	22.6	35.6	68.3	327.0	331.5	104.5	44.5	26.1	74.6	61.1	28.2
2018	13.4	7.4	6.5	95.6	238.3	37.1	16.3	110.5	64.3	76.4	54.9	19.4
2019	57.2	23.7	20.9	162.1	245.7	152.7	54.2	46.9	102.4	51.8	24.5	24.7
Total	18.5	18.1	22.6	93.9	267.1	198.4	83.0	73.2	75.4	59.3	37.9	26.6

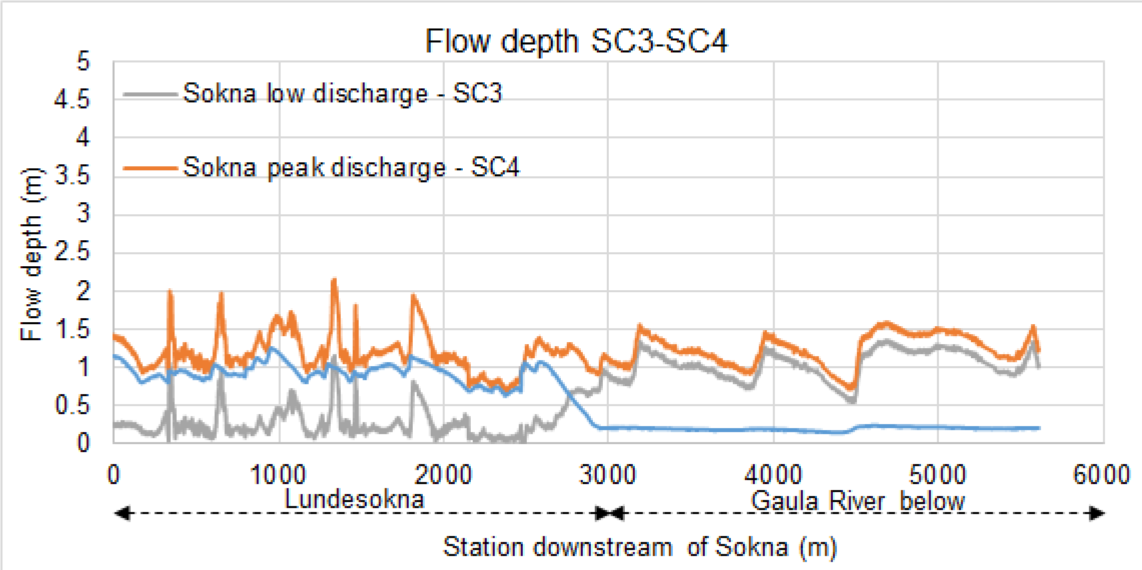
Gaula monthly maximum flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	September	October	November	December
1994	18.3	109.3	223.4	363.4	556.5	416.7	607.8	277.4	330.2	111.3	224.4	144.9
1995	39.8	13.3	61.4	250.2	403.1	699.1	222.5	130.1	399.4	246.3	171.7	41.2
1996	288.9	135.9	55.0	144.1	744.6	424.3	172.6	511.4	79.2	433.2	22.3	25.1
1997	13.8	51.6	23.2	421.5	774.9	346.4	357.1	482.5	290.6	392.8	57.5	5.6
1998	4.6	3.9	11.1	285.2	329.9	484.4	244.2	292.7	136.4	294.8	97.1	50.3
1999	13.1	11.5	21.8	59.4	1111.0	1190.3	176.0	285.5	82.4	232.6	175.8	35.2
2000	11.2	6.1	5.4	217.9	429.7	581.6	282.6	174.9	98.4	88.9	36.0	77.5
2001	31.0	28.8	34.2	94.5	535.0	1035.6	458.7	220.8	790.5	223.8	181.0	25.2
2002	15.1	219.4	93.9	504.4	516.1	416.0	244.9	477.7	116.6	207.6	31.8	27.4
2003	18.5	129.0	36.6	338.7	595.2	564.0	364.5	76.7	50.5	182.0	178.4	34.5
2004	28.0	27.2	25.9	635.5	792.1	396.5	320.5	465.0	123.0	37.3	22.8	35.6
2005	6.9	8.4	7.2	155.7	385.7	254.8	521.4	526.1	694.5	110.3	203.2	149.9
2006	28.3	15.3	36.3	495.7	613.5	164.9	171.0	60.0	173.3	176.4	21.7	6.8
2007	14.5	11.1	40.7	203.9	368.2	269.2	72.3	487.9	293.2	141.6	80.8	153.7
2008	21.8	111.0	154.4	387.1	718.0	293.5	260.0	131.3	712.1	136.0	136.8	118.3
2009	52.1	64.4	36.3	240.0	632.8	557.0	193.7	414.8	207.1	60.5	85.4	154.8
2010	127.1	159.3	18.5	241.5	602.4	282.9	93.1	73.6	366.8	105.8	104.2	190.2
2011	42.0	26.0	61.0	633.6	717.2	539.5	153.8	154.2	344.5	306.6	193.8	30.8
2012	16.8	91.2	26.7	518.9	621.4	367.4	174.9	222.3	142.6	155.2	77.9	23.5
2013	56.4	11.7	21.9	506.8	630.3	332.1	785.2	227.4	323.6	155.6	57.9	22.0
2014	15.9	15.1	88.9	239.0	694.8	989.5	367.0	71.7	171.7	167.4	101.2	12.5
2015	26.9	9.3	28.1	563.7	629.3	434.0	155.3	779.1	282.3	226.7	128.1	69.1
2016	25.5	26.7	531.5	159.2	573.4	881.6	245.4	151.2	157.0	266.0	122.1	11.0
2017	19.2	7.2	10.2	174.6	971.5	400.6	142.0	419.1	126.4	125.0	157.2	120.8
2018	22.9	9.6	19.5	151.3	527.9	468.6	66.6	328.8	134.5	82.8	40.1	10.8
2019	34.0	64.8	26.4	170.8	341.0	372.6	354.8	152.1	132.1	131.5	51.3	142.7
Total	17.0	7.5	80.6	96.7	522.9	315.0	115.8	158.9	164.4	139.7	270.2	337.5

Gaula monthly minimum flow (m^3/s)												
Year	January	February	March	April	May	June	July	August	Septembe	October	Novembe	Decembe
1994	12.2	15.8	15.5	28.5	77.5	53.6	34.5	26.2	18.3	9.1	8.9	10.3
1995	5.6	4.3	4.8	24.2	58.0	141.9	29.4	26.6	21.8	31.5	8.1	16.1
1996	24.3	20.0	23.2	20.4	108.0	41.6	29.1	39.0	19.0	10.5	9.4	9.8
1997	7.5	9.0	9.6	9.5	89.5	63.4	27.5	39.6	26.0	23.7	5.6	4.6
1998	3.9	3.7	3.8	13.5	58.9	98.7	13.1	13.0	26.3	33.5	13.4	12.6
1999	11.4	8.9	7.0	15.5	28.3	95.0	30.9	26.9	10.6	16.2	19.3	9.4
2000	5.0	4.7	4.5	4.4	39.2	87.0	31.2	7.9	14.1	21.9	6.4	8.0
2001	8.2	9.5	9.2	25.8	79.6	261.8	37.9	9.9	31.1	59.0	9.9	9.8
2002	7.6	10.0	18.2	16.8	108.1	104.8	36.9	35.7	24.8	23.9	7.9	5.6
2003	7.0	11.9	9.1	44.1	62.3	65.6	26.6	11.9	11.4	19.2	29.2	13.2
2004	14.1	14.8	13.2	19.9	156.9	81.9	25.6	24.0	20.0	14.4	3.4	4.0
2005	5.6	4.2	4.5	5.0	87.0	55.9	29.9	28.9	27.4	21.2	36.4	20.1
2006	13.9	11.6	9.4	34.3	166.7	30.4	27.4	5.1	7.5	10.8	4.1	3.3
2007	3.5	5.2	4.5	13.1	62.3	37.9	8.4	7.0	22.0	23.3	10.8	7.5
2008	9.8	11.3	22.5	39.4	140.0	34.7	22.5	8.1	19.6	18.9	20.0	21.8
2009	21.9	14.0	12.7	30.3	125.5	168.1	30.0	26.5	24.9	10.1	20.8	11.3
2010	10.8	17.4	11.3	11.4	116.1	50.2	10.5	11.6	16.8	28.2	27.4	15.4
2011	14.1	14.2	12.9	32.8	152.6	50.2	26.4	16.5	43.2	30.1	27.6	13.3
2012	10.4	9.9	15.4	21.4	93.8	65.5	17.0	17.3	12.5	16.3	15.3	11.5
2013	12.8	8.1	8.6	12.8	183.3	85.7	31.8	20.6	37.5	33.9	6.0	7.2
2014	6.2	5.7	5.6	24.3	54.7	127.1	31.0	10.2	13.9	23.7	5.5	3.9
2015	3.9	5.6	5.6	11.9	141.5	53.0	22.4	35.8	37.9	49.0	25.6	12.0
2016	10.3	8.0	26.9	34.0	72.5	131.0	62.6	35.2	32.4	25.5	10.2	7.7
2017	5.3	5.5	6.3	6.3	31.7	67.5	23.0	22.9	12.8	16.6	11.5	23.2
2018	6.9	6.3	6.7	10.0	53.9	58.9	10.8	14.9	10.4	23.3	6.6	6.1
2019	6.5	6.2	8.4	10.1	41.3	149.7	71.6	7.8	16.9	17.0	7.7	11.2
Total	5.7	5.6	5.8	24.7	99.5	36.4	23.6	26.0	22.9	8.8	13.3	40.1

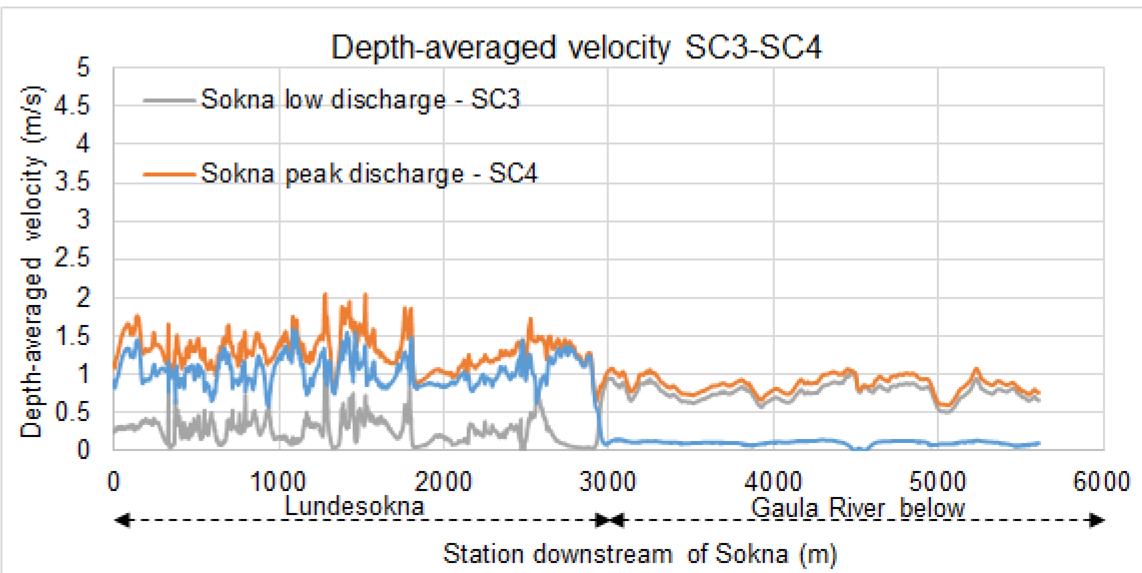
Appendix B - Modelling results - Flow depth and flow velocity downstream of Sokna



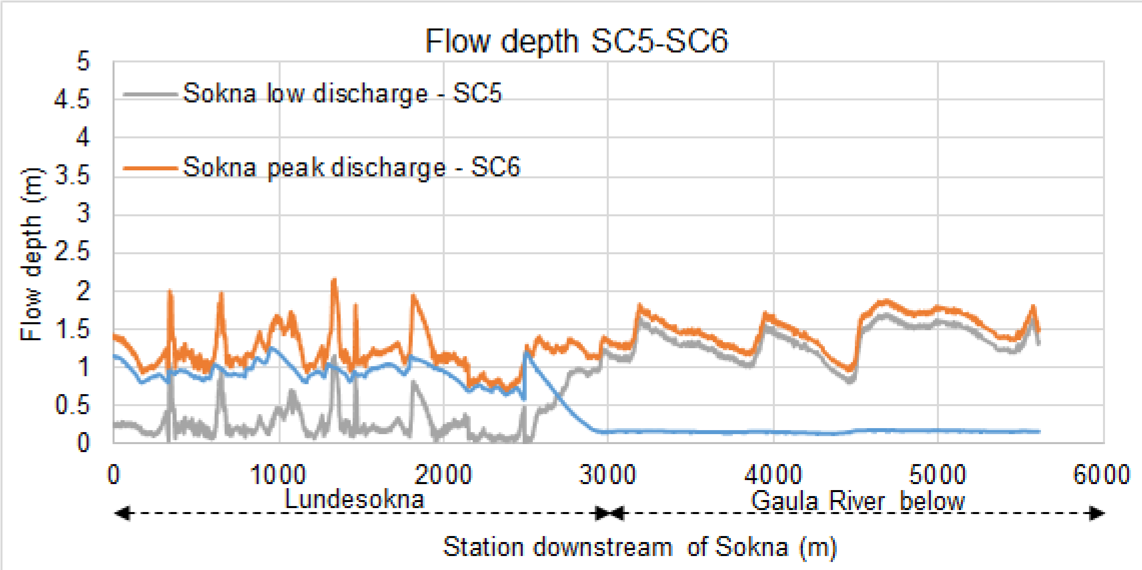




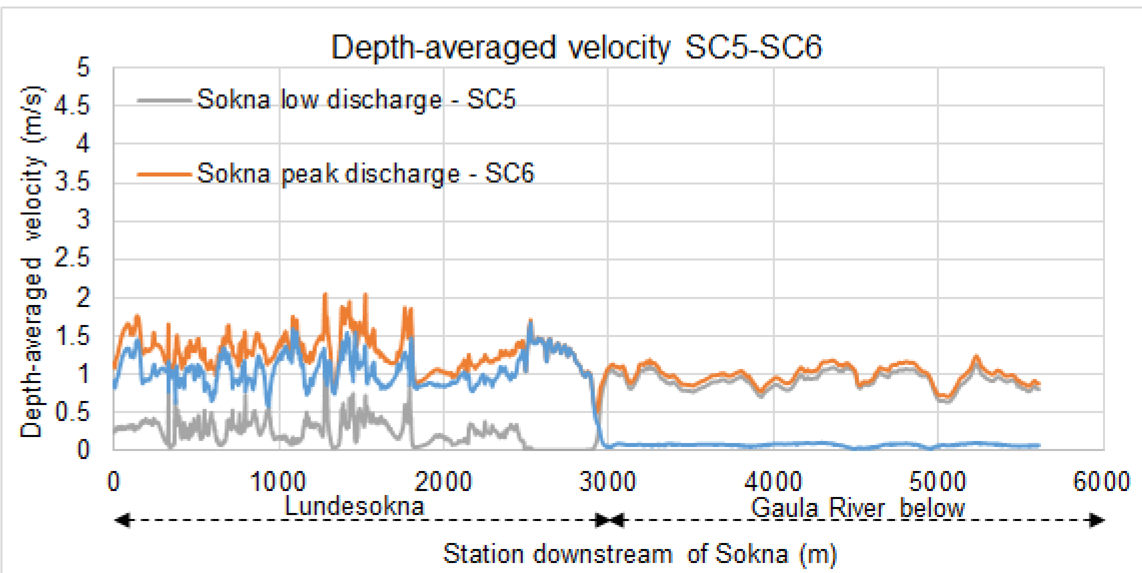
Flow depth SC3-SC4
Sokna low discharge - SC3
Sokna peak discharge - SC4
Flow depth (m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)



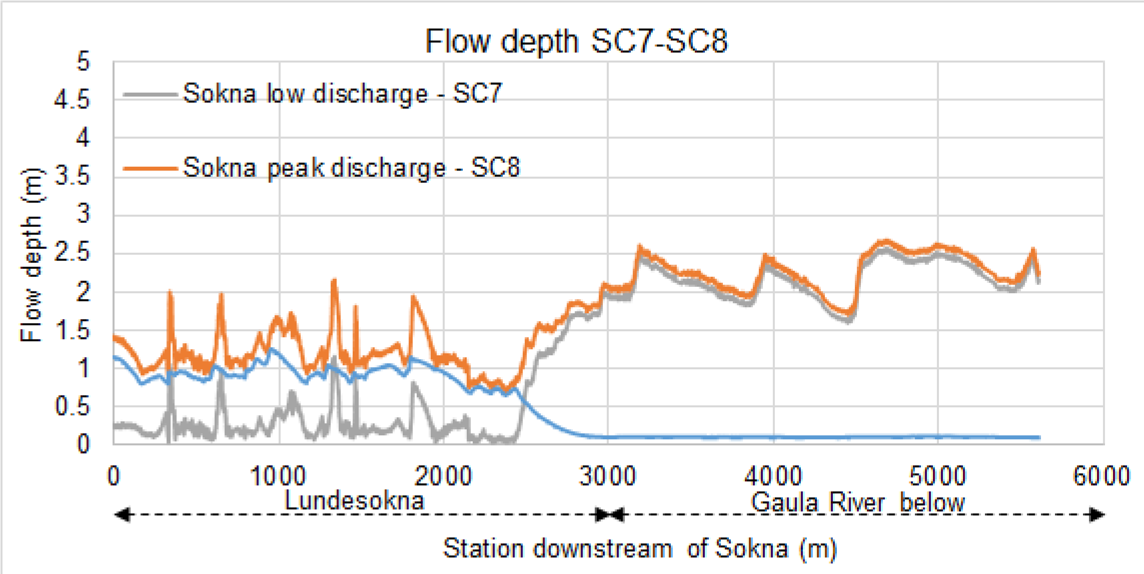
Depth-averaged velocity SC3-SC4
Sokna low discharge - SC3
Sokna peak discharge - SC4
Depth-averaged velocity (m/s)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)



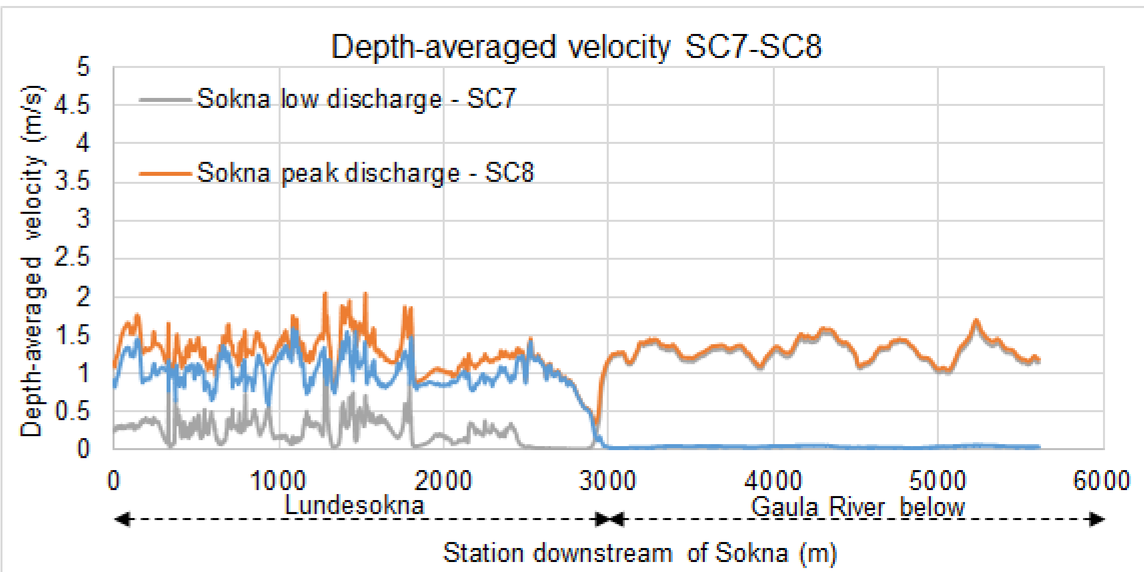
Flow depth SC5-SC6
Sokna low discharge - SC5
Sokna peak discharge - SC6
Flow depth (m)
Lundesokna
Gaula River below
Station downstream of Sokna (m)



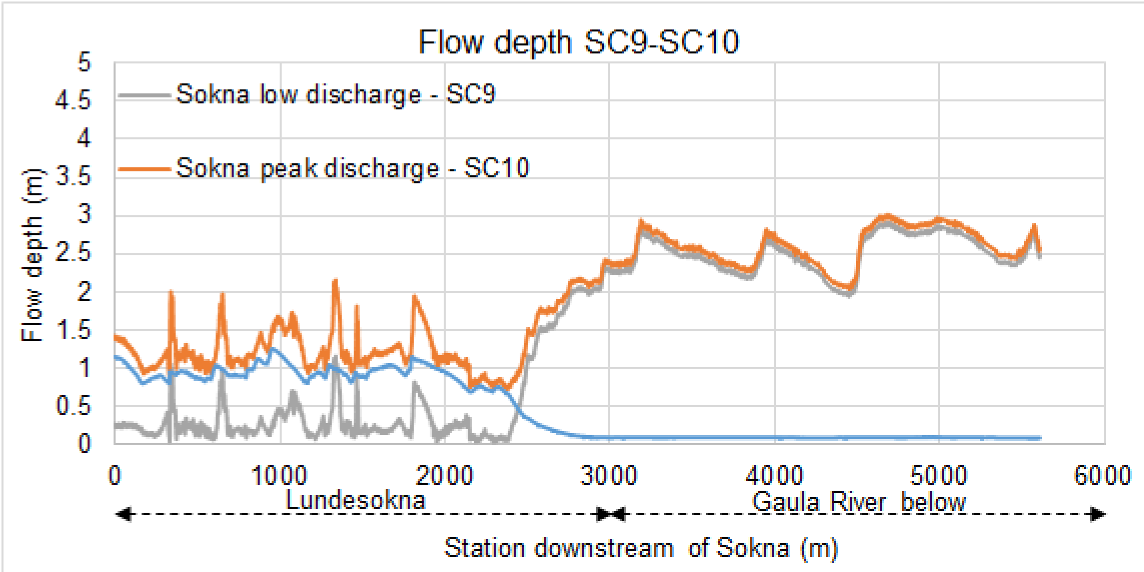
Depth-averaged velocity SC5-SC6
Sokna low discharge - SC5
Sokna peak discharge - SC6
Depth-averaged velocity (m/s)
Lundesokna
Gaula River below
Station downstream of Sokna (m)

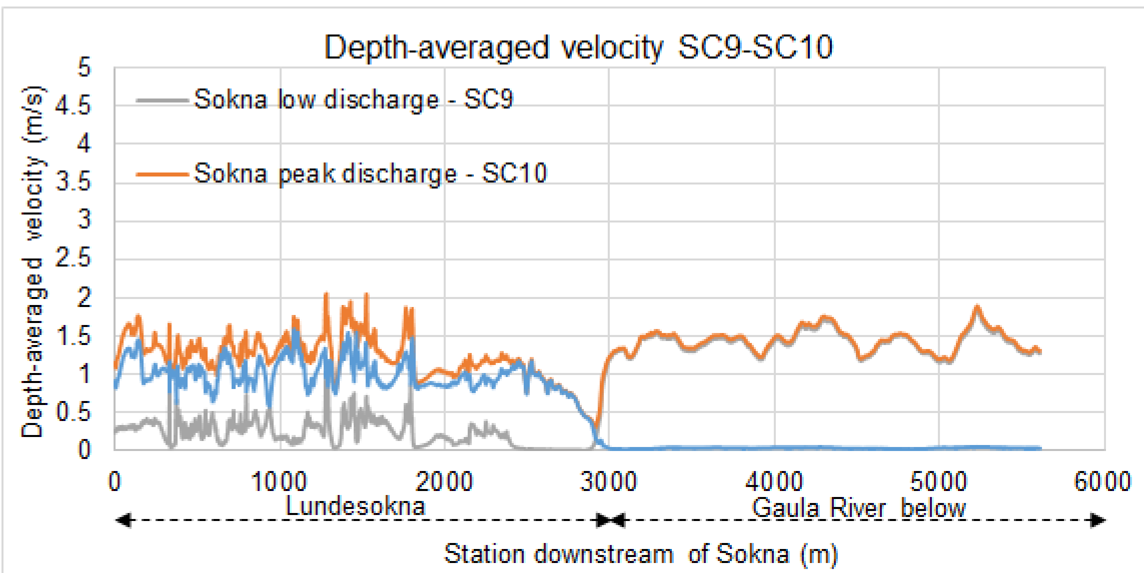


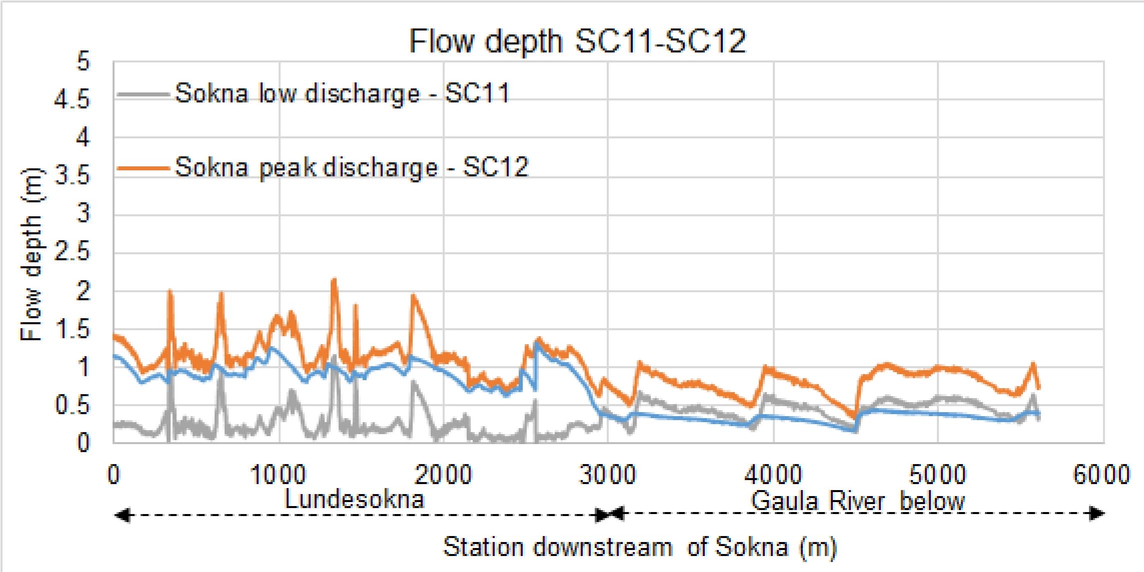
Flow depth SC7-SC8
Sokna low discharge - SC7
Sokna peak discharge - SC8
Flow depth (m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)

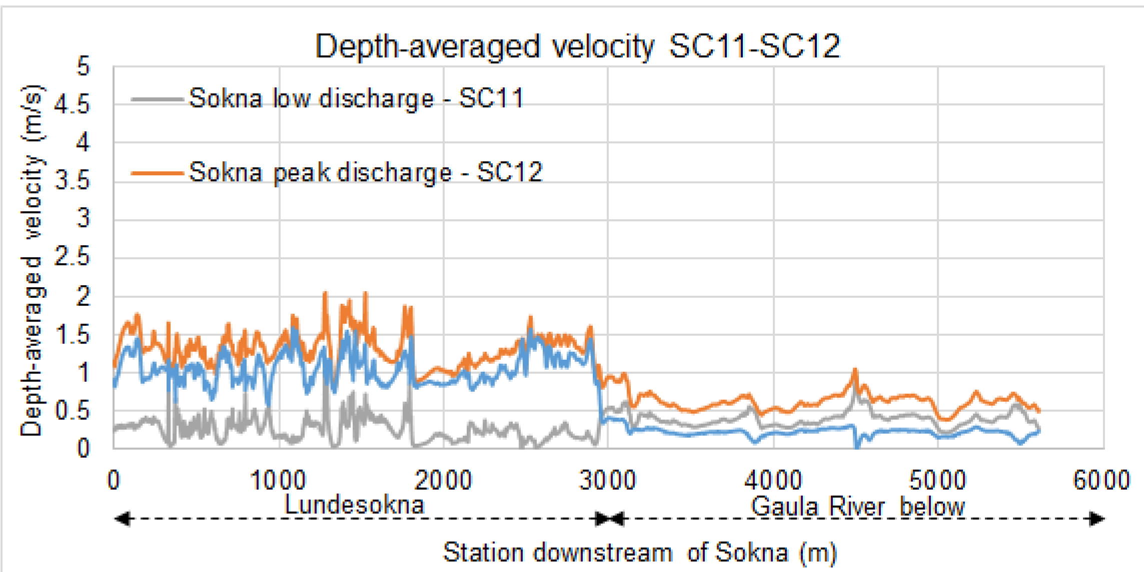


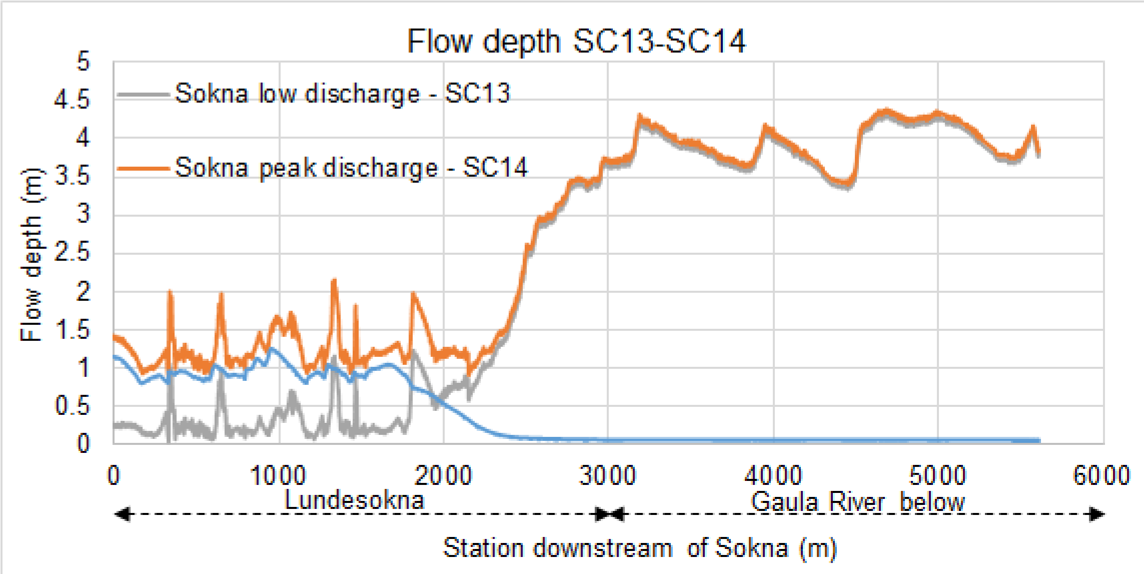
Depth-averaged velocity SC7-SC8
Sokna low discharge - SC7
Sokna peak discharge - SC8
Depth-averaged velocity (m/s)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)

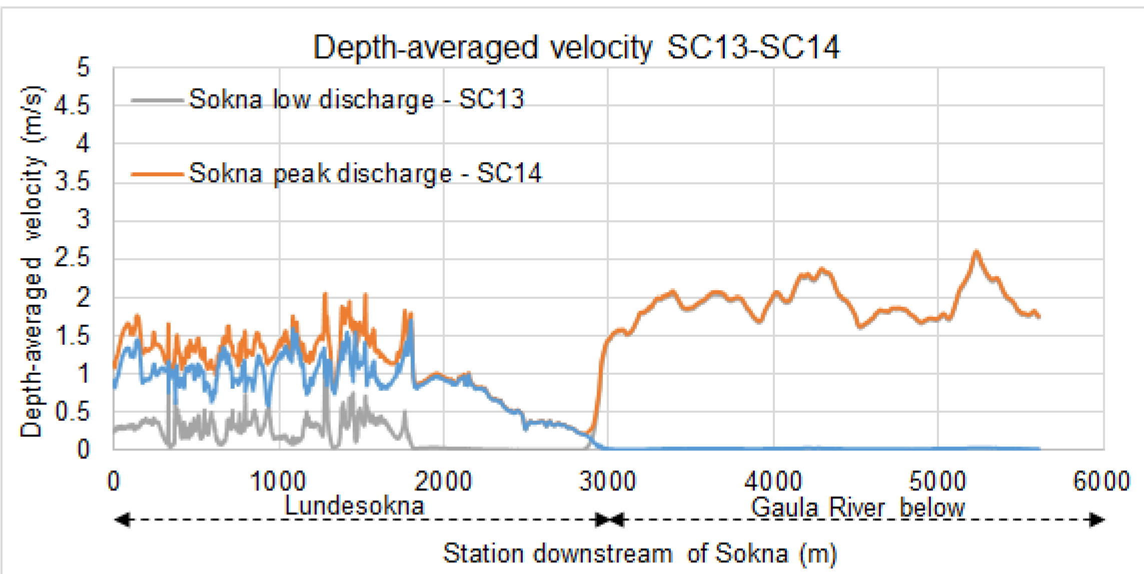

Flow depth SC9-SC10
Sokna low discharge - SC9
Sokna peak discharge - SC10
Flow depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)


Depth-averaged velocity SC9-SC10
Sokna low discharge - SC9
Sokna peak discharge - SC10
Depth-averaged velocity (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)

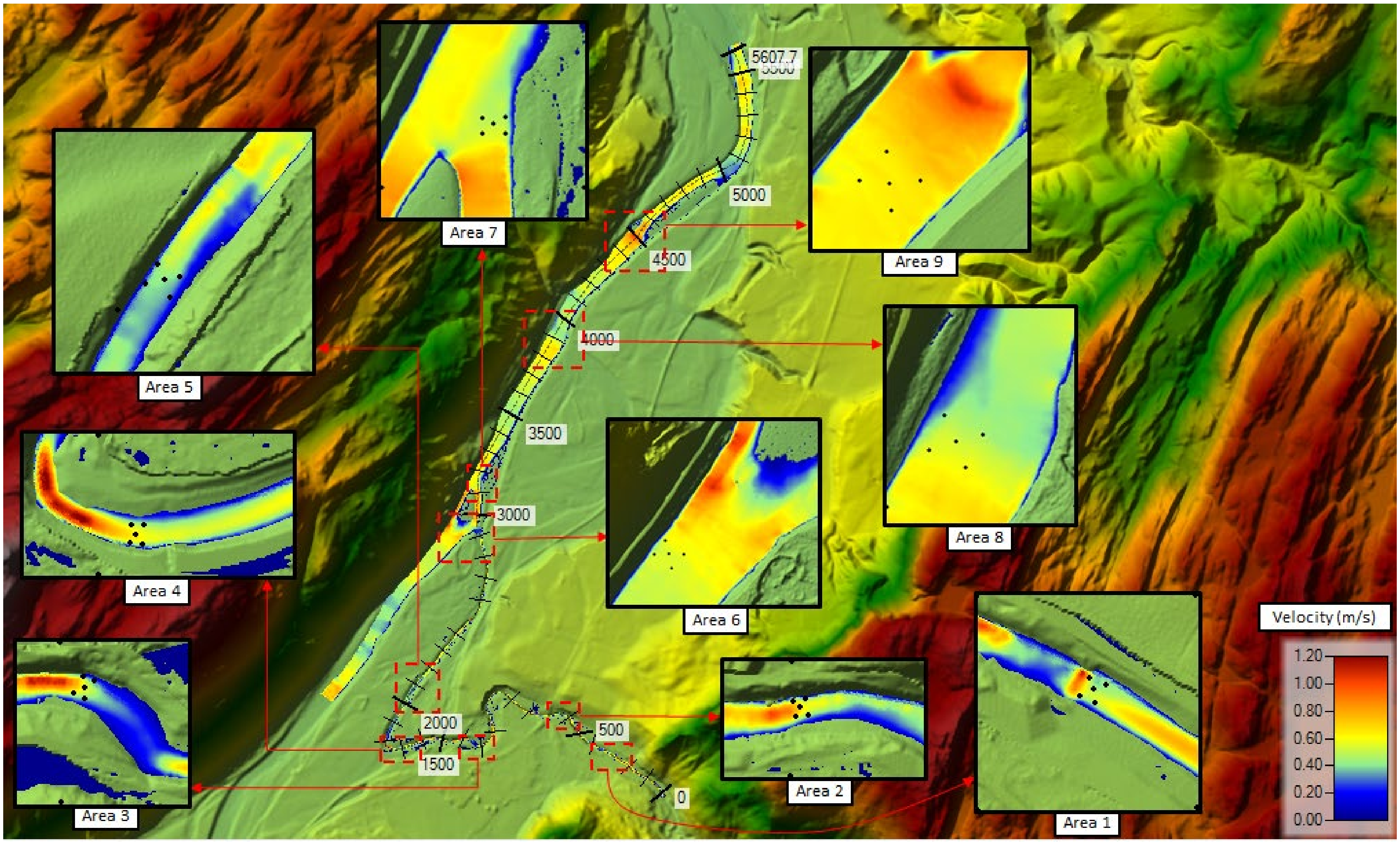

Flow depth SC11-SC12
Sokna low discharge - SC11
Sokna peak discharge - SC12
Flow depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)


Depth-averaged velocity SC11-SC12
Sokna low discharge - SC11
Sokna peak discharge - SC12
Depth-averaged velocity (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)

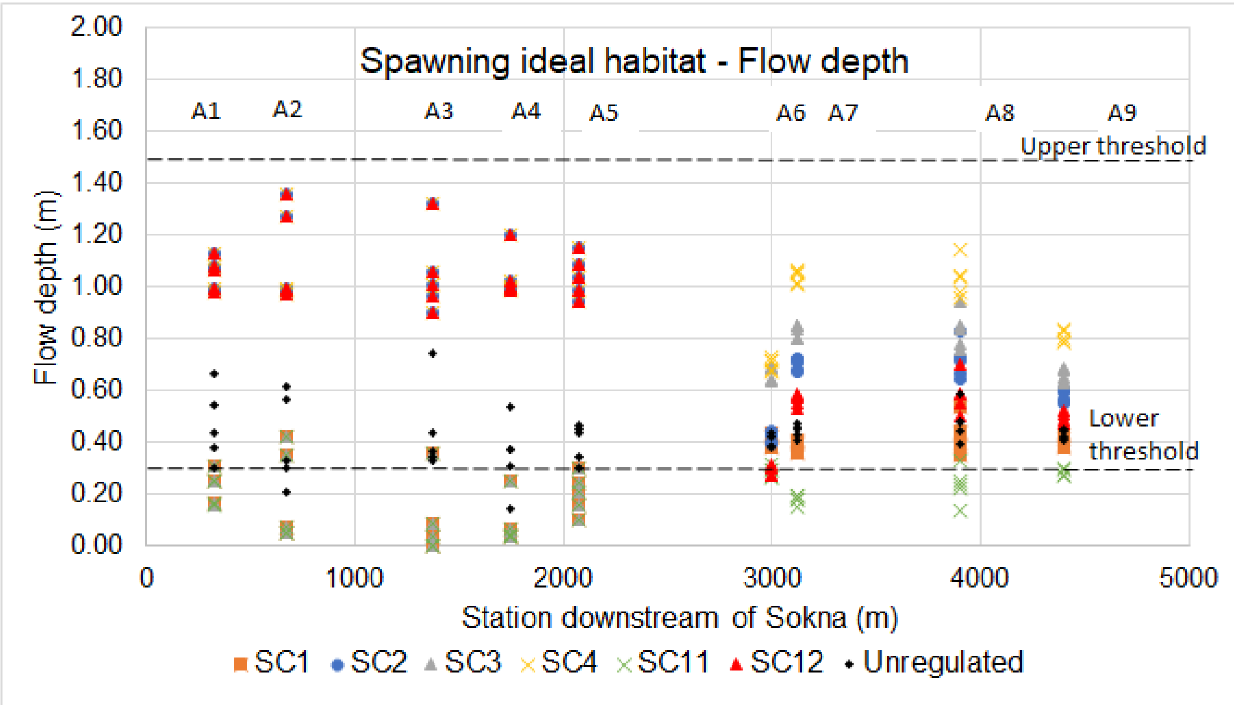

Flow depth SC13-SC14
Sokna low discharge - SC13
Sokna peak discharge - SC14
Flow depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)

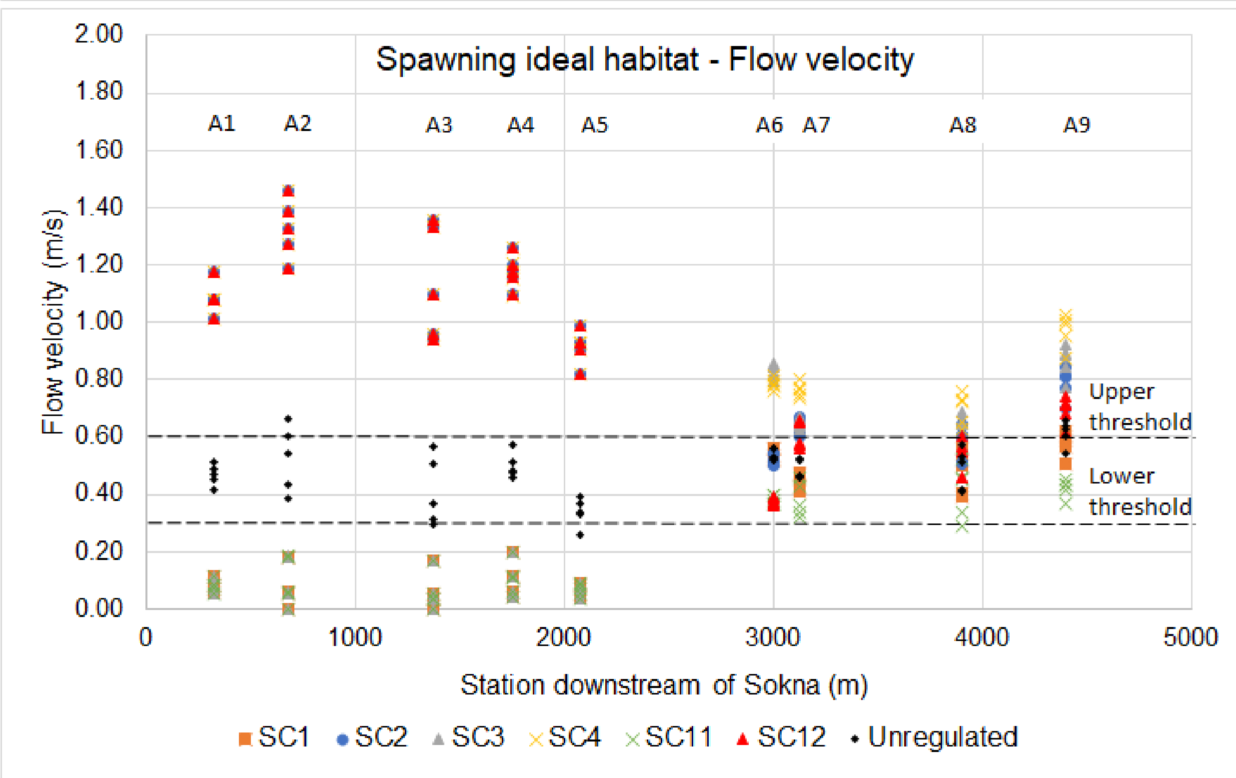

Depth-averaged velocity SC13-SC14
Sokna low discharge - SC13
Sokna peak discharge - SC14
Depth-averaged velocity (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1000
2000
3000
4000
5000
6000
Lundesokna
Gaula River below
Station downstream of Sokna (m)

Appendix C - Potential Spawning Areas (PSA) at Lundesokna and Gaula

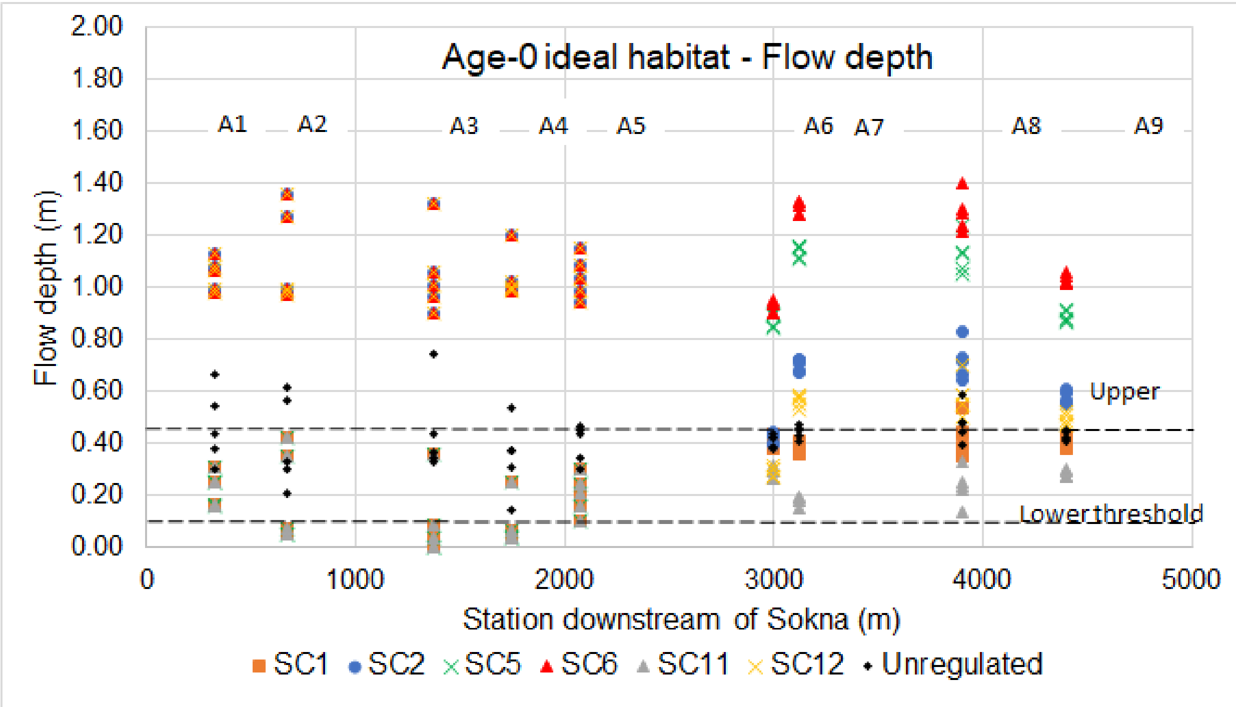


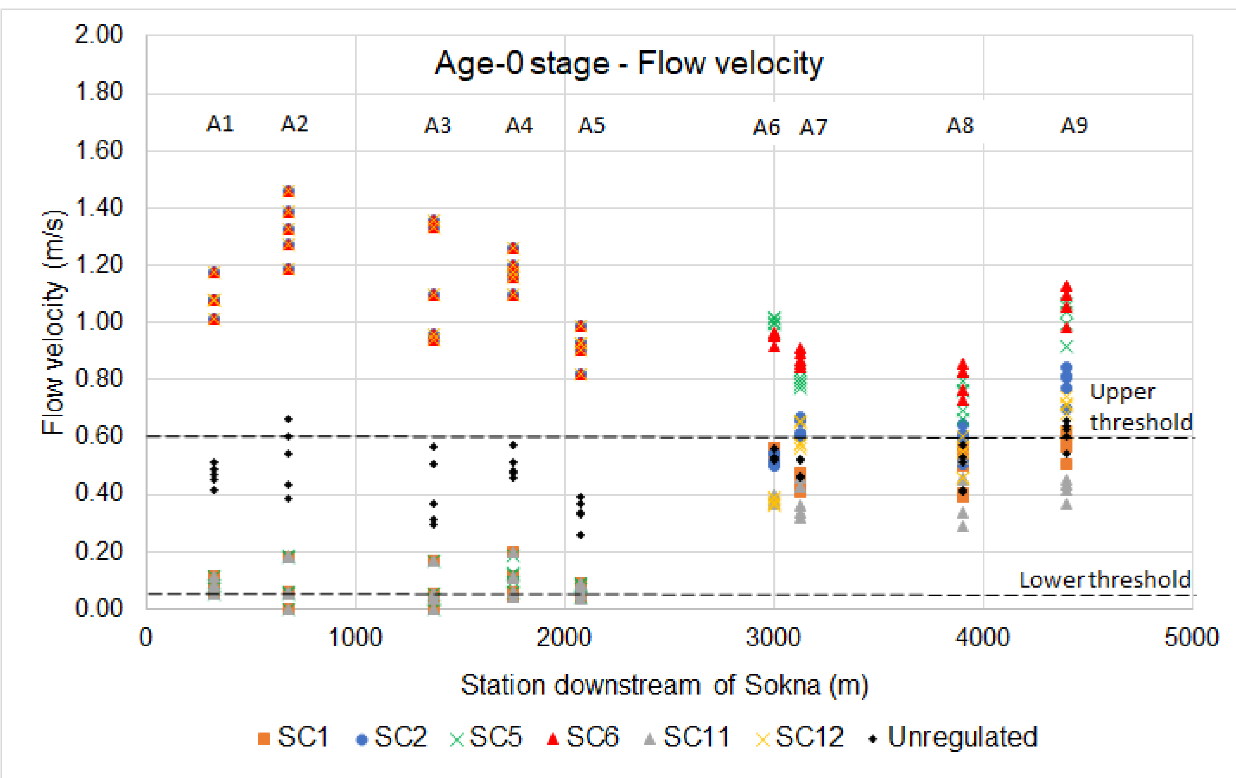
Appendix D - Flow depth and velocity during spawning months





Appendix E - Flow depth and velocity during age-0 months





Appendix F - Hydro-Peaking Characterization in Lundeksokna

	Effect Factor	Classification	Description
E.1	Rate of Change	Very Large	Water Level Change 50 (cm/h)
E.2	Dewatered area	Very Large	Dewaterd Area 53% Increase
E.3	Magnitude of Flow	Very Large	Average 152 High Ratio
E.4	Frequency	Very Large	Average of 181 Days of Hydro-peaking per year
E.5	Distribution	Very Large	Irregular Distribution for every year
E.6	Timing	Larger	Hydropeaking in Winter at Night

Hydro-Peaking Occurrence by the Year

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	Average
Jan	8	18	1	1	3	18	5	18	1	11	19	29	27	28	187	14
Feb	11	6	2	0	1	3	8	12	13	12	15	18	27	21	149	11
Mar	5	26	2	0	3	7	7	13	6	22	7	17	19	23	157	12
Apr	7	23	3	1	3	1	17	11	6	10	6	17	25	18	148	11
May	22	20	12	0	18	6	18	10	16	20	6	24	22	19	213	16
Jun	19	25	10	4	4	7	22	15	18	20	10	21	17	29	221	16
Jul	27	18	21	7	22	7	26	11	8	26	15	18	9	21	236	17
Aug	20	16	16	17	7	8	23	13	16	25	18	14	26	25	244	18
Sep	19	16	17	18	18	7	24	9	16	24	23	10	30	20	251	18
Oct	19	20	9	14	27	16	26	4	19	12	19	27	23	15	250	18
Nov	14	23	12	16	16	3	21	5	7	26	27	25	27	24	246	18
Dec	14	16	3	13	19	8	20	3	14	24	18	25	25	21	223	16
Total	185	227	108	91	141	91	217	124	140	232	183	245	277	264	2525	181

Magnitude of Hydro-Peaking

Ratio of Flow	Spring	Summer	Autumn	Winter
1.4 - 1.5	24	12	19	22
1.5-3	58	30	62	51
3-5	22	36	32	29
>5	414	623	634	457
Total	518	701	747	559

Hydro-Peaking Timing by the Month													
Month/Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0:00	6	0	2	7	7	3	0	7	5	6	7	8	58
1:00	7	3	5	7	3	1	2	1	3	0	5	12	49
2:00	4	3	6	1	1	1	0	1	1	1	1	2	22
3:00	1	0	1	0	5	0	1	0	5	7	1	2	23
4:00	6	6	5	16	20	14	2	14	17	30	5	10	145
5:00	24	23	12	20	55	50	51	43	53	53	26	31	441
6:00	38	39	21	34	37	45	40	80	60	41	55	38	528
7:00	33	35	28	18	27	33	31	33	38	18	51	36	381
8:00	15	8	10	6	17	22	30	24	14	12	22	20	200
9:00	10	5	6	2	9	14	22	13	12	4	16	20	133
10:00	7	4	7	5	5	10	5	8	8	5	9	9	82
11:00	4	3	1	3	4	6	6	6	6	4	7	6	56
12:00	5	3	2	9	2	5	3	5	5	9	4	7	59
13:00	1	1	5	8	5	8	7	7	4	18	5	4	73
14:00	4	1	4	5	2	6	5	4	2	13	11	8	65
15:00	10	5	4	3	12	4	5	1	10	14	21	9	98
16:00	15	7	4	5	13	6	5	5	9	16	15	18	118
17:00	10	14	10	12	8	11	9	8	14	22	20	11	149
18:00	5	6	12	8	5	5	6	4	18	15	6	2	92
19:00	3	4	10	11	9	5	5	9	10	5	4	2	77
20:00	2	1	9	4	6	3	3	7	3	1	4	1	44
21:00	1	1	2	2	4	1	5	5	5	2	8	1	37
22:00	3	1	4	2	7	4	3	1	4	7	3	3	42
23:00	1	1	2	3	3	2	2	4	4	5	10	0	37
Total	215	174	172	191	266	259	248	290	310	308	316	260	3009

Hydro-Peaking Timing by the Season				
Season / Time	Spring	Summer	Auntum	Winter
0:00	16	10	18	14
1:00	15	4	8	22
2:00	8	2	3	9
3:00	6	1	13	3
4:00	41	30	52	22
5:00	87	144	132	78

Hydro-Peaking Timing by the Season				
Season / Time	Spring	Summer	Auntum	Winter
6:00	92	165	156	115
7:00	73	97	107	104
8:00	33	76	48	43
9:00	17	49	32	35
10:00	17	23	22	20
11:00	8	18	17	13
12:00	13	13	18	15
13:00	18	22	27	6
14:00	11	15	26	13
15:00	19	10	45	24
16:00	22	16	40	40
17:00	30	28	56	35
18:00	25	15	39	13
19:00	30	19	19	9
20:00	19	13	8	4
21:00	8	11	15	3
22:00	13	8	14	7
23:00	8	8	19	2
Total	629	797	934	649