Key Issue:
2 -Hydrological Regimes
3 -Fish Migration

Climate Zone:
Cfb: Temperate Humid Climate with Main Precipitation in Fall and Semi Severe Winter

Subjects:
- Hydrological regime that best provides both hydropower and riverine ecology

Effects:
- Maintained power production in the Ulla-Førre power scheme and a sustainable stock of Atlantic salmon *(Salmo salar)* in the river Suldalslågen

Project Name: Ulla-Førre Hydropower Complex
Country: Norway

Implementing Party & Period
- Project: Statkraft SF
1980 -
- Good Practice: Statkraft SF
1990 - 2004

Key Words:
Riverine Ecology, Atlantic Salmon, Flow Regulation, Flush Flood, Water Temperature

Abstract:
The river Suldalslågen, situated in the south-western part of Norway, has been subject to two hydropower developments. It was presumed that the population of Atlantic salmon (Salmo salar) in Suldalslågen was affected by the new hydrological regime following these hydropower developments. Since completion, mitigation measures have continuously been implemented and evaluated. Today efforts are being concentrated on research in combination with testing of different hydrological regimes. The aim is to find a regime that encourages salmon reproduction in the river and gives increased power production.

1. Outline of the Project

The River Suldalslågen is situated in the county of Rogaland in south-western Norway (Figure 1). The river has its source in the Suldalsvatn reservoir, from which it runs 22 km and drops 68 m before it runs into the Sandsfjord. The river's catchments area has been subject to two regulation schemes; the Røldal-Suldal regulation in 1967 (operated by Hydro) and the Ulla-Førre regulation in 1980 (operated by Statkraft) (Figure 2).

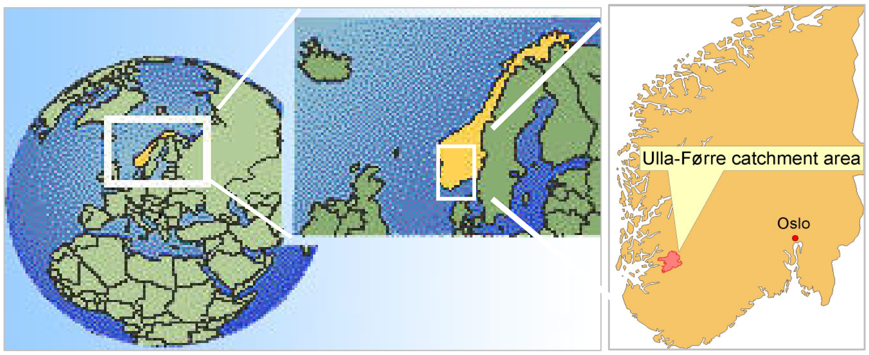

Fig.-1 Location of the Ulla-Førre Catchments

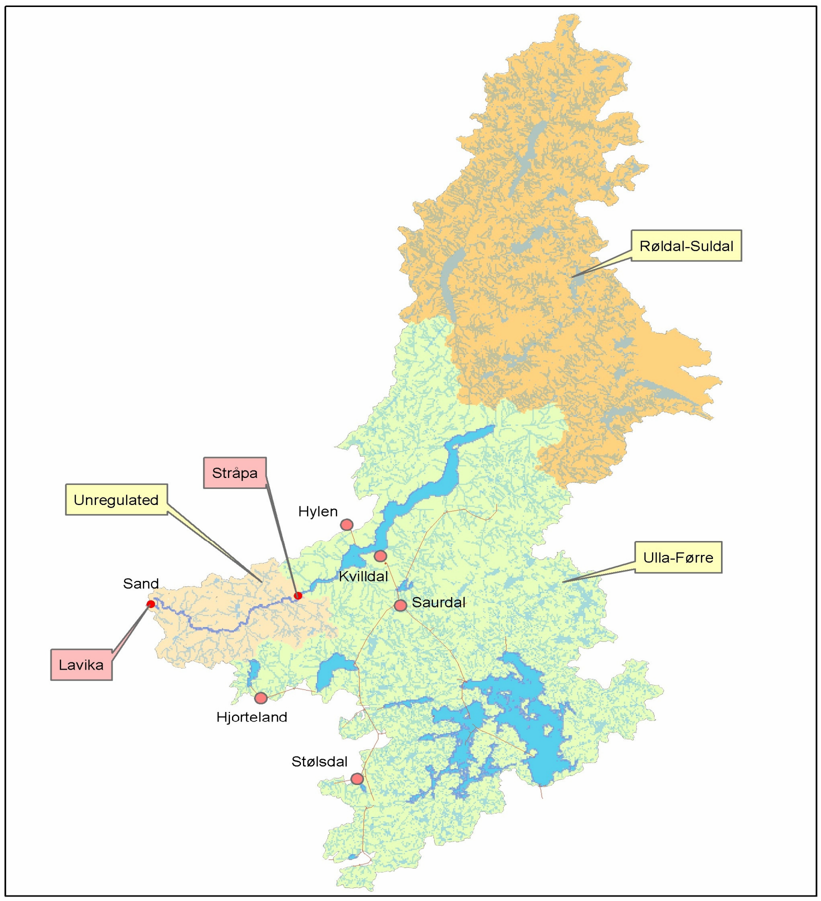

Fig.-2 The catchment area of the river Suldalslågen is affected by the Røldal Suldal and the Ulla-Førre hydropower schemes

Ulla-Førre is Norway's largest hydropower complex, with a total capacity of 2.057 MW and an annual mean production of 4.5 TWh. Its main power station Kvilldal with a capacity of 1.240 MW is also Norway's biggest station. The main intake for the complex is established at 600 m, where altogether 39 rivers and brooks are collected. Storage capacity is limited at this level and the water is pumped through the combined pump and power station Saurdal to the main storage in the Blåsjø reservoir. Blåsjø is an artificial lake at a level of 1000 m, established by damming a number of small lakes. The intake system at 600 m level feeds the Kvilldal power station for a head of 530 m down to Lake Suldalsvatn. From the Blåsjø reservoir the water is utilized first in the Saurdal pump/power station, then in Kvilldal and finally 68 m from Lake Suldalsvatn to sea level in the Hylen power station. The profile of the Ulla-Førre scheme is shown in figure 3.

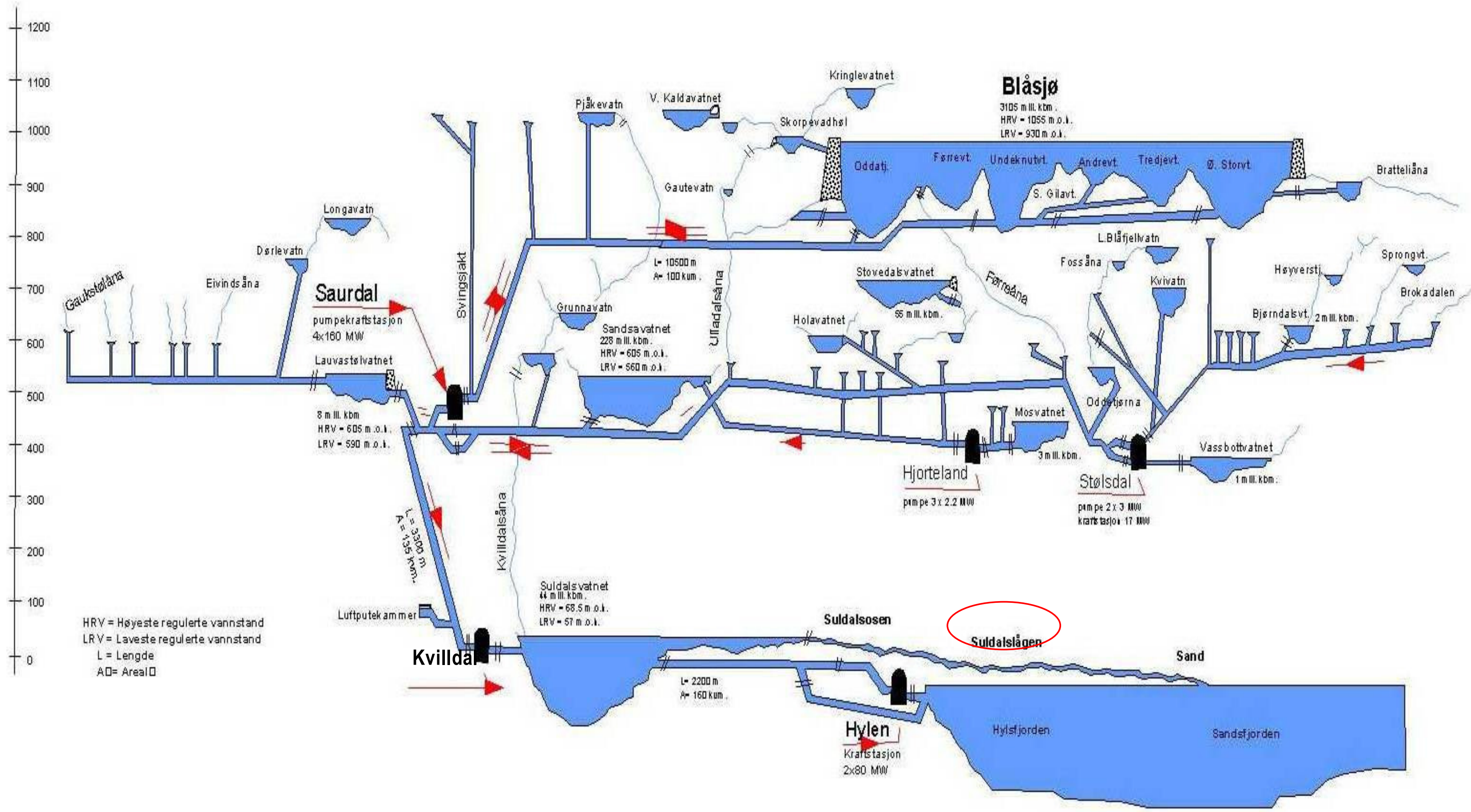

Fig.-3 Profile of the Ulla-Førre scheme

2. Features of the Project Area

Suldalslågen River is situated in the county of Rogaland in south-western Norway. The river has its source in the Suldalsvatn reservoir, from which it runs 22 km to sea level where it runs into the Sandsfjord, in the town of Sand. Sand has about 1200 inhabitants. The area is famous for its scenic beauty, and the Suldalsågen river is known for holding large salmon and is therefore a highly-prized fishing location. Catches have been listed since 1880 and the mean annual catch taken by rod is approximately 3000 kg. Fishing licences and accommodation for visiting anglers make the salmon very valuable to the local community.

Suldalslågen is the river system with the largest natural water flow in the region. The unregulated water flow was 91 m^3/sec in average during the year. During flood episodes the water flow could reach 700 m^3/sec, while in cold periods in winter the flow could be as little as 5 m^3/sec. As most of the catchment area is situated in mountainous areas (a great deal above 1000 m elevation) most of the water from melted snow flows from mid-June until late July. Mean precipitation and temperature in the cathcment area is illustrated in figure 4.

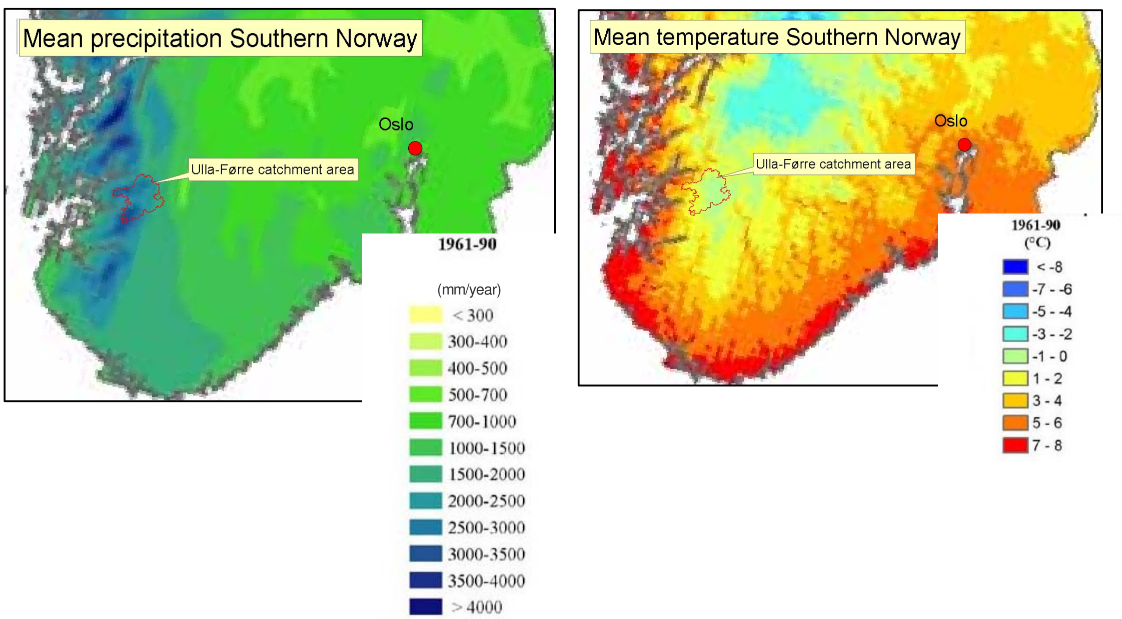

Fig.-4 Mean precipitation and mean temperature in Southern Norway
(The border of the Ulla-Førre catchment area is marked with a red line.)

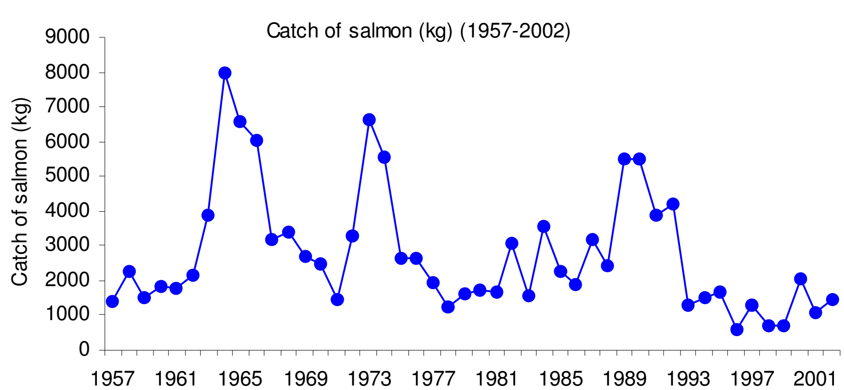

Fig.-5 Catch of salmon in the River Suldalslågen according to anglers' catch statistics from the years 1957-2002

Production of hydropower will always affect the riverine environment. In the River Suldalslågen the Atlantic salmon (Salmo salar) has been an important consideration. Atlantic salmon (Salmo salar) and trout (Salmo trutta) are produced along the entire the River Suldalslågen. Regulating the river has been presumed to aggravate the situation. The only data on salmon from before the regulation is catch statistics from anglers. These data do not support the presumed effect (Figure 5).

The stress on natural salmon populations has increased during the last 30 years. The stress is not only related to the river phase of the salmon life cycle. The variations in figure 5 are probably mainly explained by sea temperature, fishing and salmon lice. However, this report will focus on possibilities for managing the hydro system in a way that satisfies both hydro power production and the principles of environmental management.

Originally, efforts were made to maintain the Atlantic salmon population in Suldalslågen by concentrating on stocking the river with artificially produced salmon. From the late 1980's the program took a different approach, focusing on enhancements of the Suldal salmon stock by attending to natural processes in the river and without interfering with the salmon life cycle through hatchery rearing. Huge efforts have been made in research to identify the factors with a negative impact on juvenile salmon. Today's mitigation measures are being concentrated on managing the river in a way that will provide a hydrological regime adjusted to salmon life cycles (Figure 6). Due to naturally low water temperatures and food source availability, the river has a marginal ability to produce salmon.

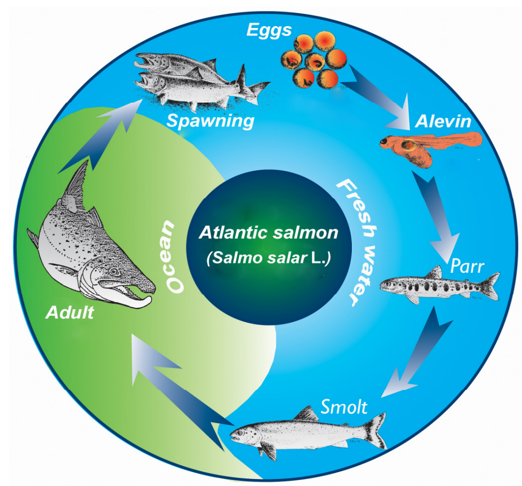

Fig.-6 Atlantic salmon life cycle

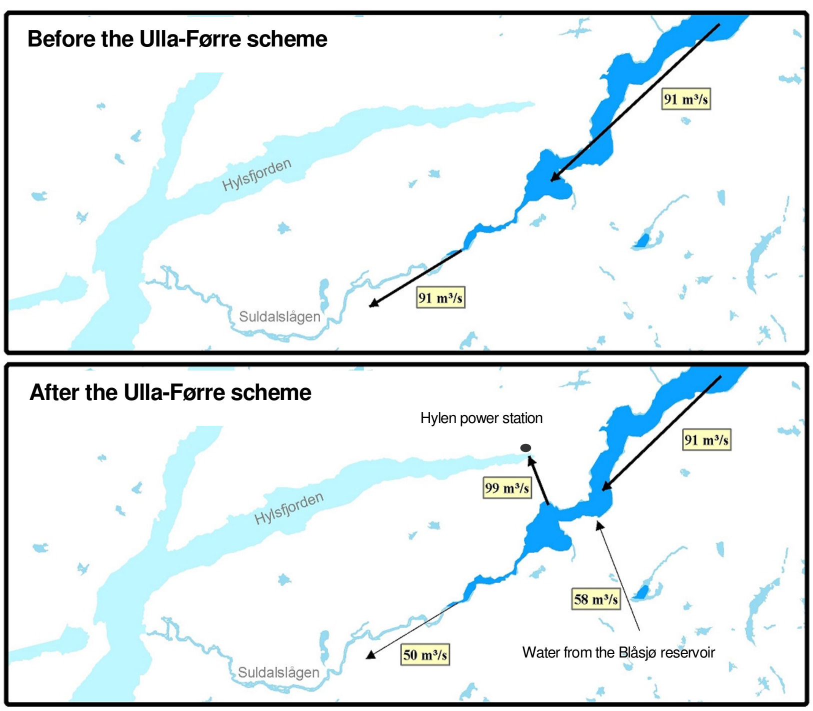

Fig.-7 Changes in water flow in Suldalslågen due to the Ulla-Førre regulation scheme

The first regulation scheme in the catchment area of Suldalslågen river led to reduced water flow in summer, increased flow in winter and hence higher temperature in winter. The Ulla-Førre scheme resulted in reduced water flow throughout the year, close to natural temperature in winter, but lower temperature in the salmon growth season (from May through to October). These changes may have a biological impact. Changes in water flow are illustrated in figure 7.

3. Major Impacts

The density of juvenile Atlantic salmon was reduced in the years following the Ulla-Førre regulation. Compensation was paid to the owners of fishing rights, and in 1988 Statkraft was compelled to compensate for the loss by release of artificially produced salmon. These releases did not prove to be sufficiently effective. There were also potential negative effects of releasing salmon; the river's carrying capacity could be exceeded, leaving the well-fed salmon from the hatchery as the winners and the naturally-bred salmon as the losers. During the sea phase, however, the natural stock seemed to have higher rates of survival than individuals returning to their natal river. It was therefore important to allow juvenile salmon to develop in their natural habitats in the river's ecosystem. Results of extensive research concluded that low food source availability and low temperature in the growth season are natural bottleneck factors in the River Suldalslågen. The regulations can further aggravate the conditions for the salmon by causing:

Stranding due to water flow reductions.

Sudden reductions in water flow can leave fish stranded in shallow pools and on dried out river beds. Stranding episodes may cause a severe decline in the salmon population.

- **Loss of preferred habitat due to sedimentation and growth of moss and algae.**

Lack of flood episodes can reduce the river's ability to transport sediments and organic material. Keeping the material in the river can help the low food source availability, but can also leave the preferred habitat covered in finely grained sediments or overgrown by moss.

- **Reduced temperature in the growth season (from May through to October).**

Reduced water temperature in the salmon growth season will entail reduced growth of juvenile salmon.

- **Disarranging the migration of smolt from river to sea due to lack of flood episodes.**

Flood episodes are factors triggering the migration of smolt from river to sea. The amount of fresh water in the fjord and the time of the smolt migration are considered critical factors for surviving the sea phase.

- **Disarranging the migration of mature salmon from sea to river due to lack of water flow fluctuations.**

The migration of mature salmon to the river depends on water flow fluctuations in summer.

- **Mature salmon wrongly migrating to the Hylsfjord.**

The amount of fresh water in the fjord is one of the factors affecting salmon migration to the river. The Hylen power station is situated at the head of the Hylsfjord, which is a part of the Sandsfjord (Figure 8). The outlet of Suldalslågen is further out in the Sandsfjord and water from the Hylen power station is therefore thought to be affecting the salmon migration.

Fig.-8 Suldalslågen and the Sand fjord

4. Mitigation Measures

In Norway permission to develop hydropower is given through Government concessions. These concessions include river management regulations. The original river management regulations for Ulla-Førre from 1974 required a minimum flow, at a measuring point located near sea level ("Lavika", see map in figure 1), of 12 m^3/sec in winter and 51 m^3/sec in summer (Figure 9). This was the highest regulated minimum flow in Norway. During the fishing period 50 million m^3 were to be available for the owners of the fishing rights to make floods to initiate salmon migration from the sea to the river. These regulations still proved to be inadequate in safeguarding the Atlantic salmon. The flow regime had no restrictions on the speed of flow reduction out of Lake Suldalsvatn and hence resulted in sudden reductions in the water flow. The sudden reductions in water flow left juvenile fish stranded in shallow pools and on dried-out river beds.

Features of the original regime (1974-1990):

- The Hylen power station could not produce in June/July due to fear of salmon wrongly migrating to the Hylsfjord.
- The flow from Suldalsvatn in May, June and July must not be less than the natural discharge plus 9 m^3/sec.
- 50 million m^3 are to be available in the fishing season to make flash floods to initiate migration of salmon.

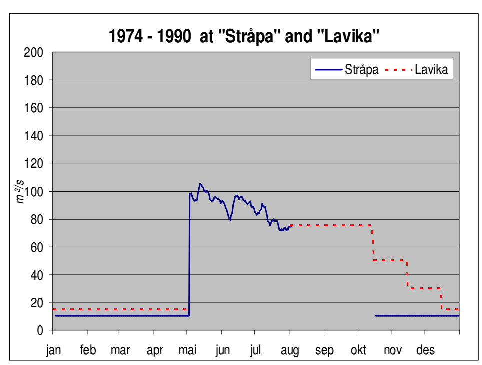

Fig.-9 Features of the 1974-1990 regime
(Graph showing minimum instream requirements, except for May through July where the graph shows actual mean flow through the period of that regime)

In 1990, Statkraft applied for a trial flow regime in order to find solutions to the problems through research in connection with full-scale testing of different flow regimes. An important intention with the trial regulations was to try out different flow regimes in cooperation with local interests, the environmental authorities, the water resources administration and research institutions. The new regime introduced a restriction on speed of flow reduction of 3% per hour. The control point from where the flow was measured was moved from the sea level closer to the outlet of Lake Suldalsvatn ("Stråpa", see map in figure 2) to secure a stable and controllable water flow. Before regulation, damaging spring flows were a common feature of the River Suldalslågen. After regulation, these flows were controlled and the flow regime from 1990 permitted a maximum of 350 m3/sec (Figure 10).

Features of the 1990 regime:

- The control point for water flow moved from "Lavika" to "Stråpa"
- The speed of of the water flow reduction not to exceed 3% per hour and preferably be done over 3 days.
- The main intention of this trial flow regime was to have more flexibility in trying out different flows in combination with research.

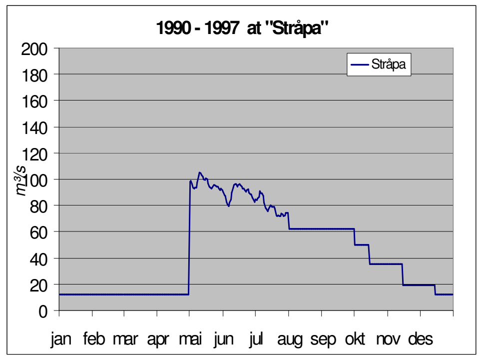

Fig.-10 Features of the 1990 regime
(Graph showing minimum instream requirements, except for May through July where the graph shows actual mean flow through the period of that regime)

In 1998, Statkraft received new trial river regulations, combined with research, for the period 1998-2003. In this period two different hydrological regimes were to be tested to find the hydrological regime that best provides both hydropower and ecology. It is likely that the final manoeuvring regulations will be a combination of known regimes. The regimes are designed to attend to the main impacts described (Figure 11 and 12).

Features of the 1998-2000 regime:

- Reduced amount of water in spring and early summer to raise the water temperature.
- Large one week flood in spring, initiated by natural flood and hence varying in time form year to year. Meant to wash out sediments and algae and help salmon migrate to sea.
- Flow fluctuating weekly between 50-72 m^3/sec in summer to initiate salmon migration to the river.

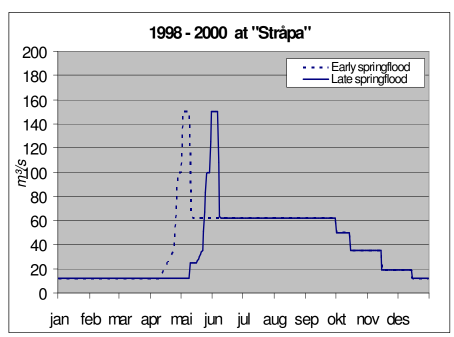

Fig.-11 Features of the 1998-2000 regime
(Graph showing minimum instream requirements)

Features of the 2000-2003 regime:

- Smaller floods in spring to initiate smolt migration, instead of the large spring flood.
- Reduced flow to prevent important sources of food being washed out and to increase temperature.
- Flush flood in autumn to wash out sediments and algae.

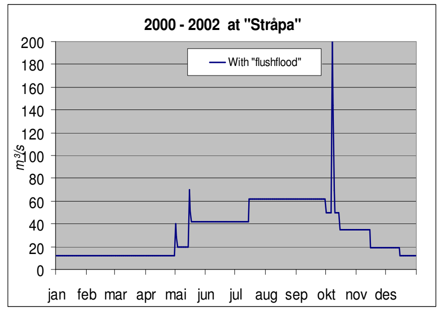

Fig.-12 Features of the 2000-2003 regime
(Graph showing minimum instream requirements)

5. Results of the Mitigation Measures

The trial period of the hydrological regimes ends in 2003. It will take time before all the effects of a change of the hydrological regime will become visible, as the research depends on the salmon life cycle. The researchers have therefore not yet concluded on all topics. However, some effects of the new regulation have been observed:

- The measures to prevent stranding have proved efficient, and stranding of salmon is eliminated.
- Reduced flow in spring and summer has increased the water temperature and the growth of juvenile salmon has increased.
- The flush floods have proved efficient for washing out excess sediments and growth. Short periods of flow at 200 m^3/sec seem to give a similar result as one week of floods at 150 m^3/sec.

Preliminary conclusions have also been drawn concerning fish migration:

- Fluctuations in flow in summer seem to increase migration of mature salmon to the river.
- Smolt migration seems to be initiated by an increase in water flow, not by large floods.

The final conclusions will form the basis for hydrological regimes in new water management regulations. The trial period ends in 2003 and Statkraft aims at applying for definite water management regulations in 2004.

6. Reasons for Success

The reasons for success are strongly associated with the cooperation between Statkraft and local interests, the environmental authorities, the water resources administration and research institutions. Taking local interests and the importance of salmon in the River Suldalslågen seriously has been important to get acceptance.

The fact that the results from research in Suldalslågen can be transferred to other rivers justifies the high costs of the mitigation measures and is an important factor when considering the reasons for success. Also the fact that today's regulations gives an increase in power production, compared with the regulations of1974, justifies the costs of the project. The flexibility shown by all parties has resulted in regulations that satisfy both economic and ecologic considerations.

7. Outside Comments

1) Results of research connected to the project have been published in a series of reports.
2) There have been several articles about the project locally and in national and international media.

3) Posters have been presented.

Acid Rain 2000, Poster sessions.
J. Schjolden and A.B.S. Poléo. **Physiological responses in Atlantic salmon to heavy rain episodes in an acidic tributary to the River Suldalslågen, Western Norway.** University of Oslo, Department of Biology, POBox 1066 Blindern, 0316 Oslo Norway

S.Hytterød, J. Schjolden and A.B.S. Poléo. **Physiological recovery in atlantic salmon from river Suldalslågen stock after exposure to acidic Al-rich Water.** University of Oslo, Department of Biology, POBox 1066 Blindern, 0316 Oslo Norway

A.B.S. Poléo, J. Schjolden and S.Hytterød. **Increased seawater tolerance in atlantic salmon exposed to aluminium and acidic water from a tributary to the river Suldalslågen, western norway: an evidence of acclimation?** University of Oslo, Department of Biology, POBox 1066 Blindern, 0316 Oslo Norway

A.B.S. Poléo[1], C.S. Jensen[2], J. Schjolden[1]. **Impact of water quality on density of juvenile salmonids in selected tributaries to the river Suldalslågen, Western Norway.**
[1]University of Oslo, Department of Biology, POBox 1066 Blindern, 0316 Oslo Norway
[2]Statkraft Engineering AS, POBox 191, 1322 Høvik, Norway

4) There have been professional disagreements on certain subjects. Final conclusions have not yet been reached.

8. Further Information

8.1 References

1) Kaasa, H. 1998. Lakseforsterkningsprosjektet i Suldalslågen, fase II. Sluttrapport 1990-1997. Resultater og konklusjoner. Statkraft Engineering. *Includes 180 detailed references.*
2) Kaasa, H. 1999. Enhancement of an Atlantic salmon population. Recommended measures and their estimated costs. River Suldalslågen, Norway. International workshop on sustainable riverine fish habitat. Victoria, British Colombia 1999.

8.2 Inquiries

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