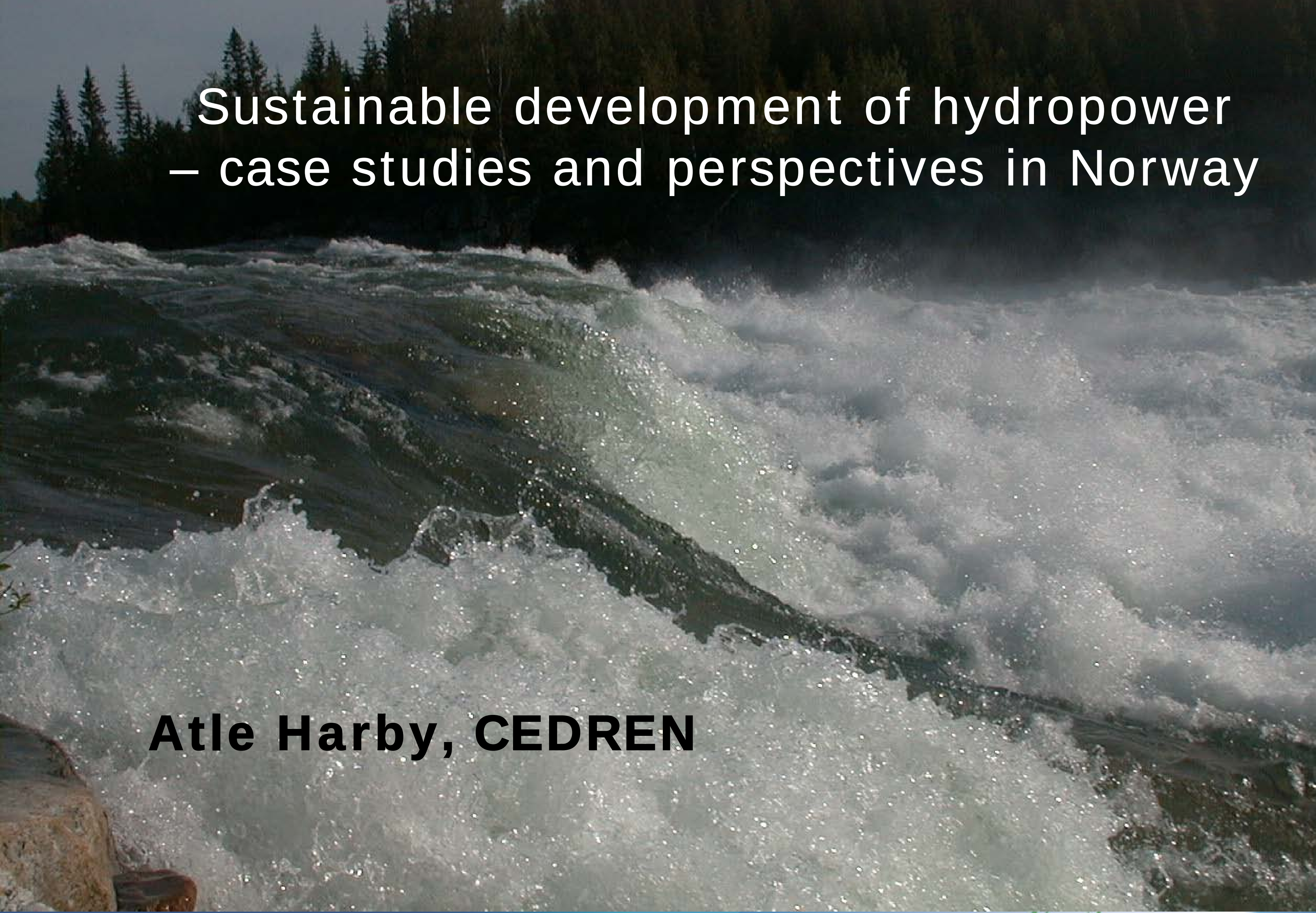
Sustainable development of hydropower – case studies and perspectives in Norway



Atle Harby, CEDREN

CEDREN Centre for Environmental Design of Renewable Energy





Centre for environmental design of renewable energy - CEDREN

SINTEF

NTNU
100 skapende år

NINA

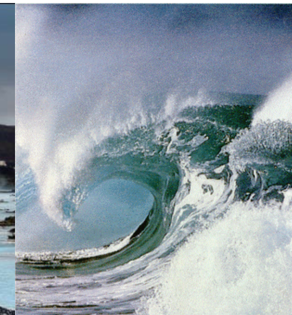
NATURHISTORISK MUSEUM
UNIVERSITETET I OSLO

NIVA

uni Research

Renewable energy respecting nature



CEDREN - Renewable energy respecting nature

- 8 years of research: 2009 - 2016
- 8 large research projects
- 7 Norwegian research partners
- 13 Industry partners and 2 management partners
- Budget: 36 MEuro (8 MEuro in 2012) – financed by the Research Council and the Energy industry
- 16 PhD and 4 Post-doc positions

Funding

The Research Council of Norway

agder energi

BKK

ECO

Eidsiva

EnergiNorge

HYDRO

ICH

Sira-Kvina kraftselskap

Statkraft

Statnett

TrønderEnergi

NVE

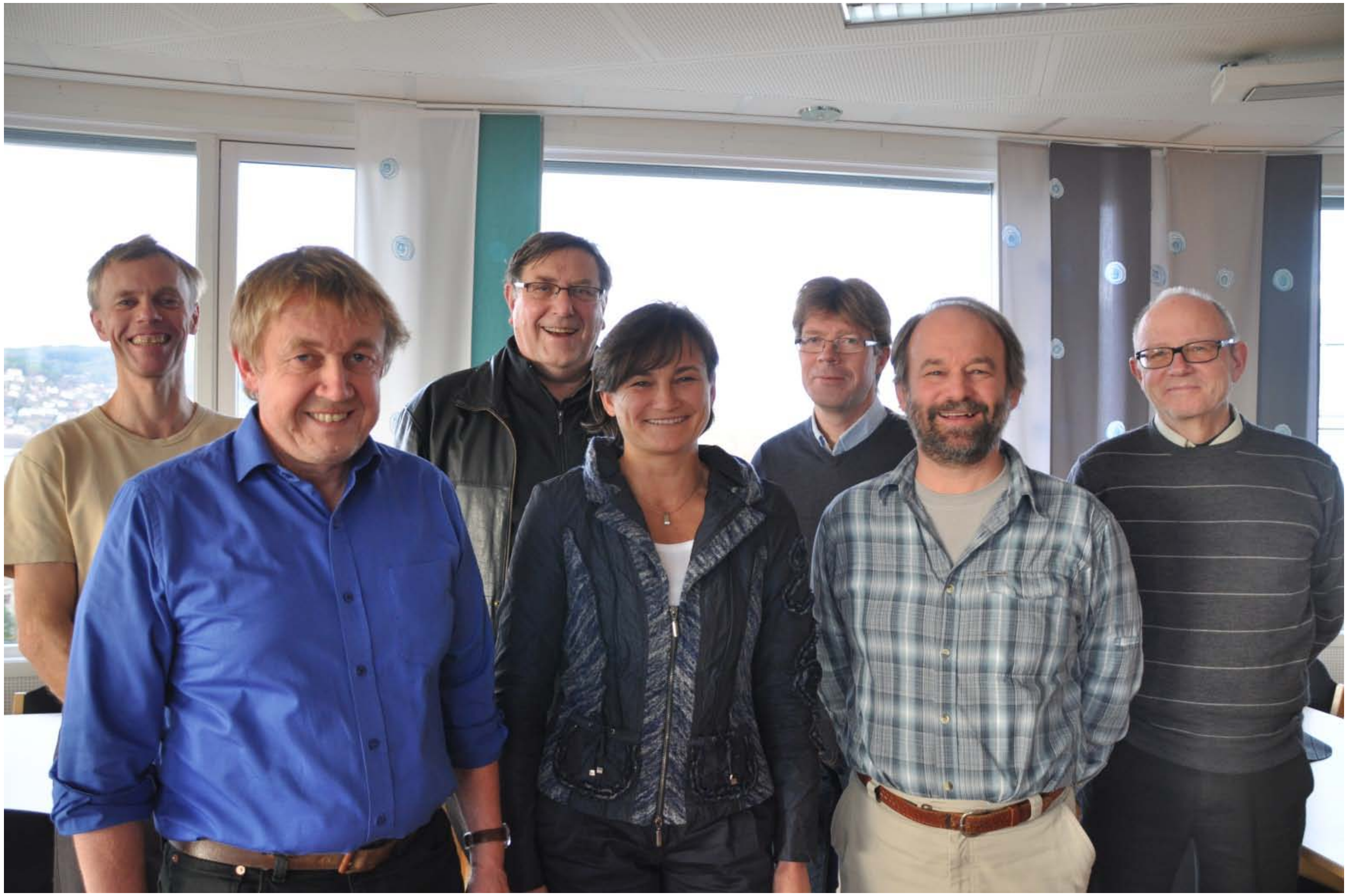
Hafslund

NTE

TROMS KRAFT

PhD and Post doc

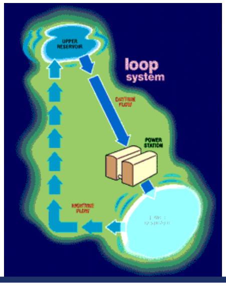
Scientific Committee



Klaus Jorde	Silke Wieprecht	Daniel Boisclair
KJ Consult/SJE	Uni Stuttgart	Univ. Montreal

Main topics

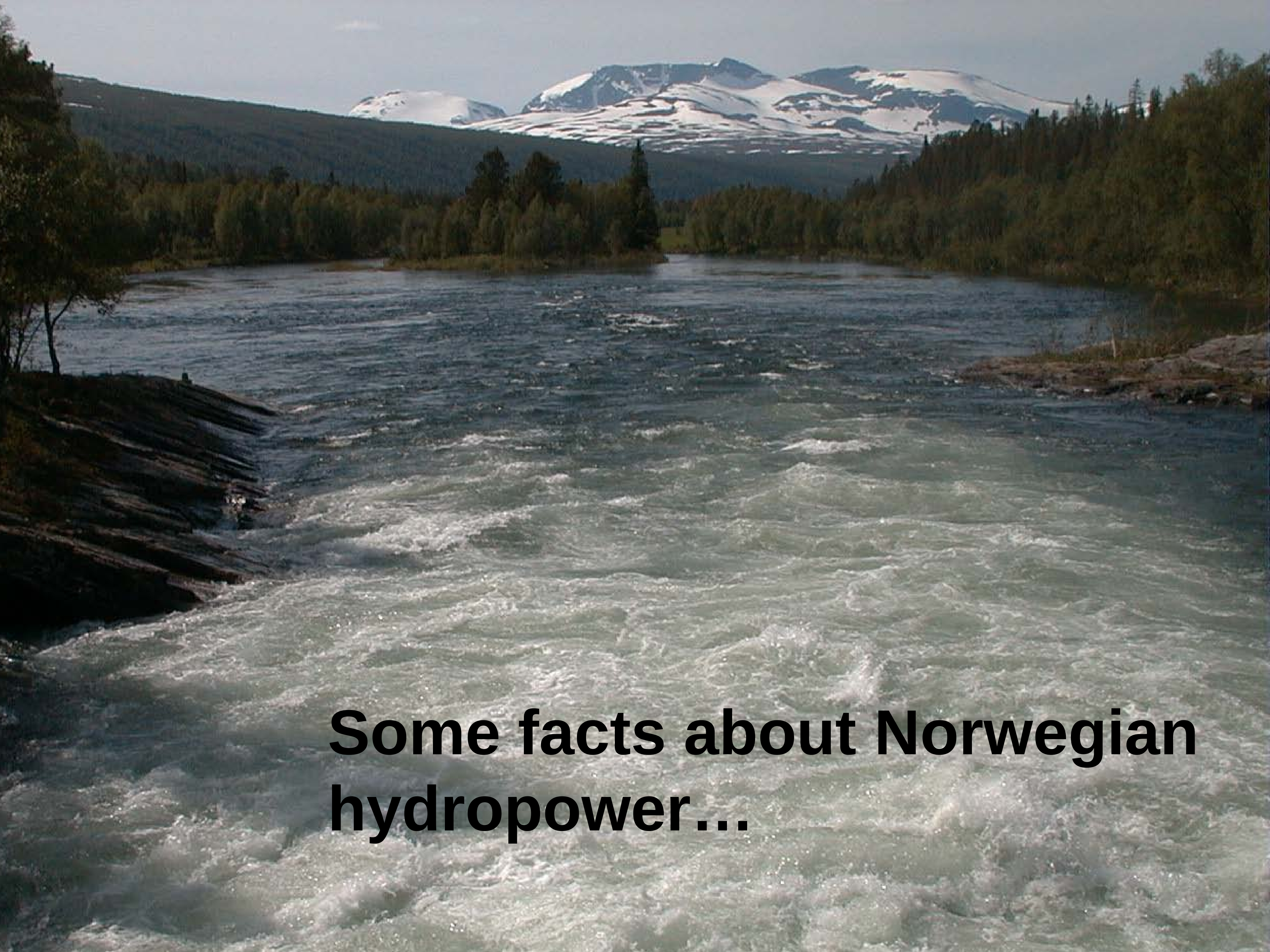
Hydropower technology for the future



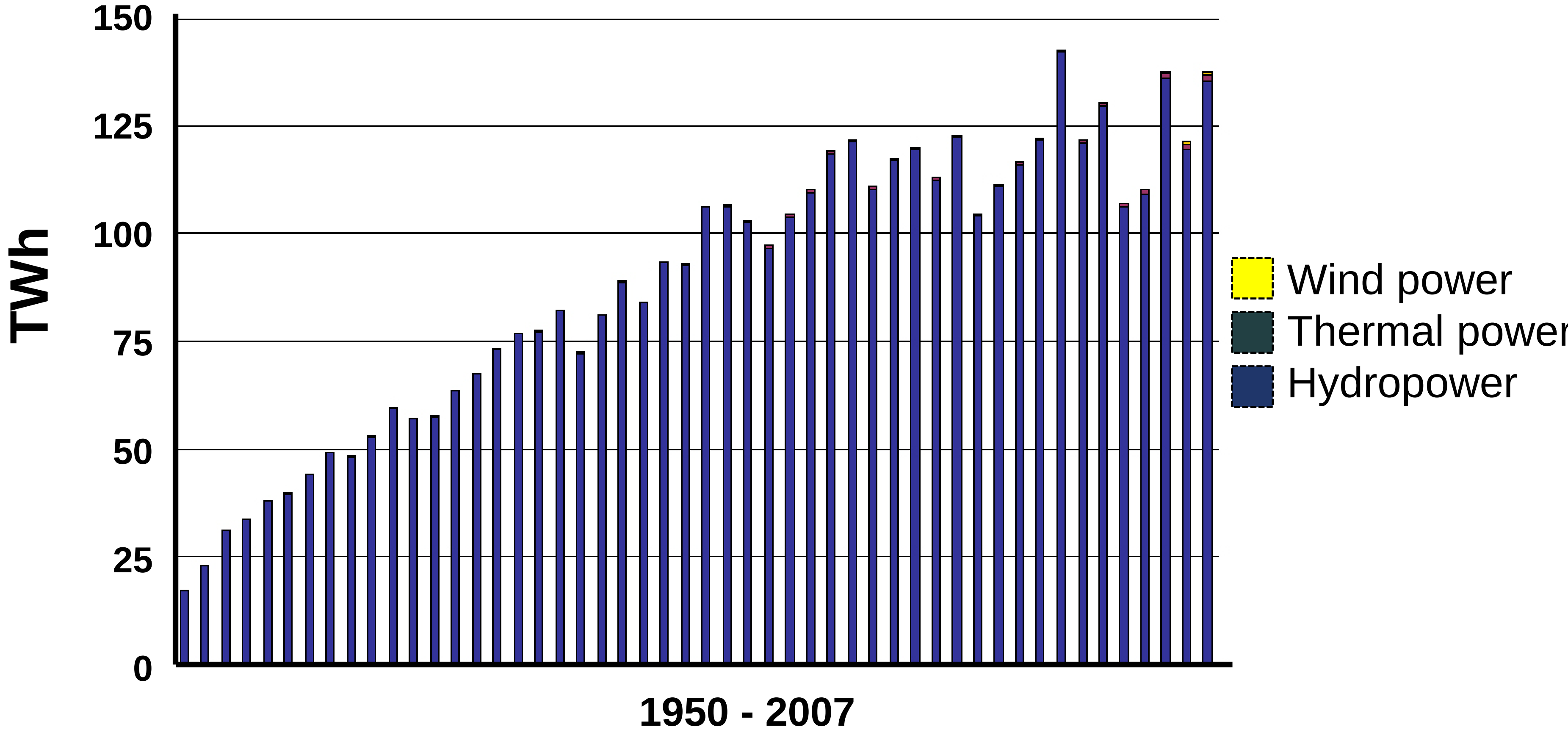
Environmental design of hydropower

Impacts on birds and wildlife from wind turbines and power lines

Reconciling environmental and energy policy concerns


Some facts about Norwegian hydropower…

Electricity production Norway



Source: Norwegian Energy and Water Directorate

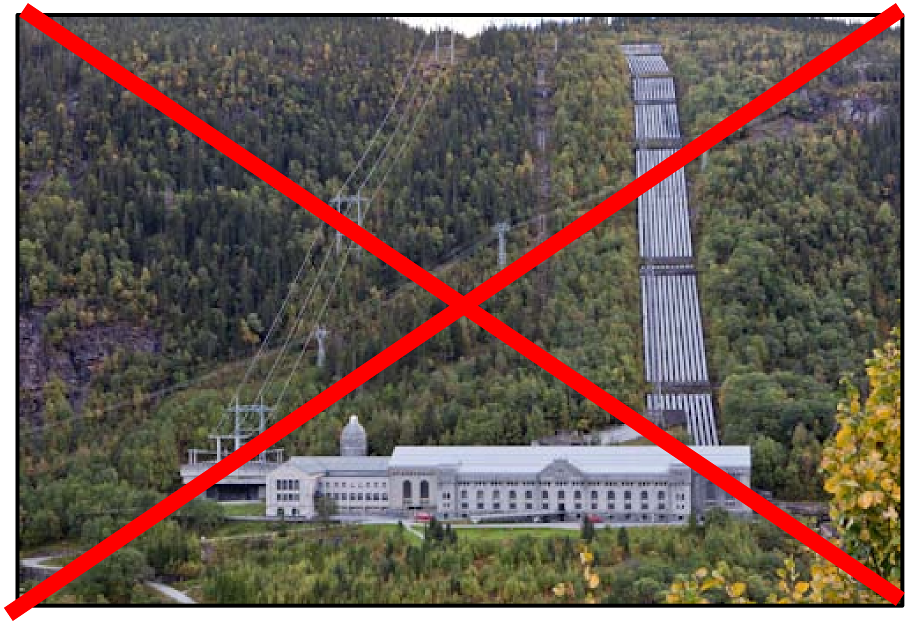
Norwegian hydropower

Natural lakes used as reservoirs

Multi-year reservoirs

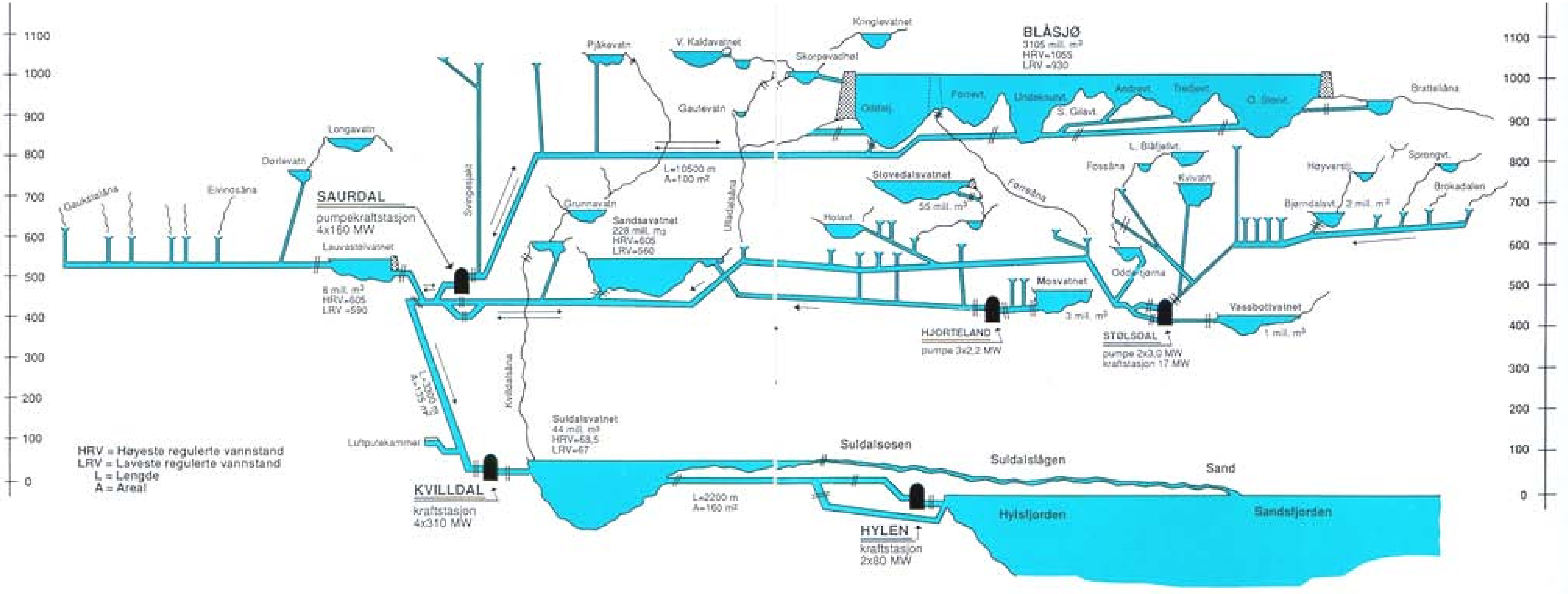
Follsjø reservoir in september

Norwegian hydropower



Solid rocks providing great opportunities to hide penstock and power plants inside the mountains

Storage and waterways

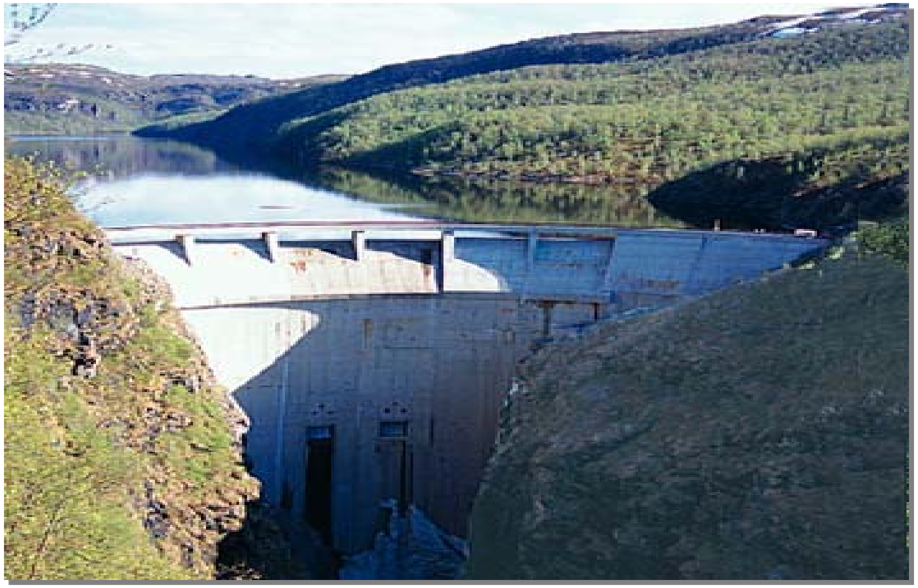


- Complex Storage Scheme:
  - 1 Major reservoir, contains water for multi year production (in case of dry year(s))
  - 34 intakes of streams plus 24 smaller reservoirs that are channeled in to the system
  - 3 Major Power plants (all underground), and 2 pumping stations

The Blåsjø-reservoir

Dams

- Migration barrier
- Loss of connectivity
- Less access
- Loss of biodiversity

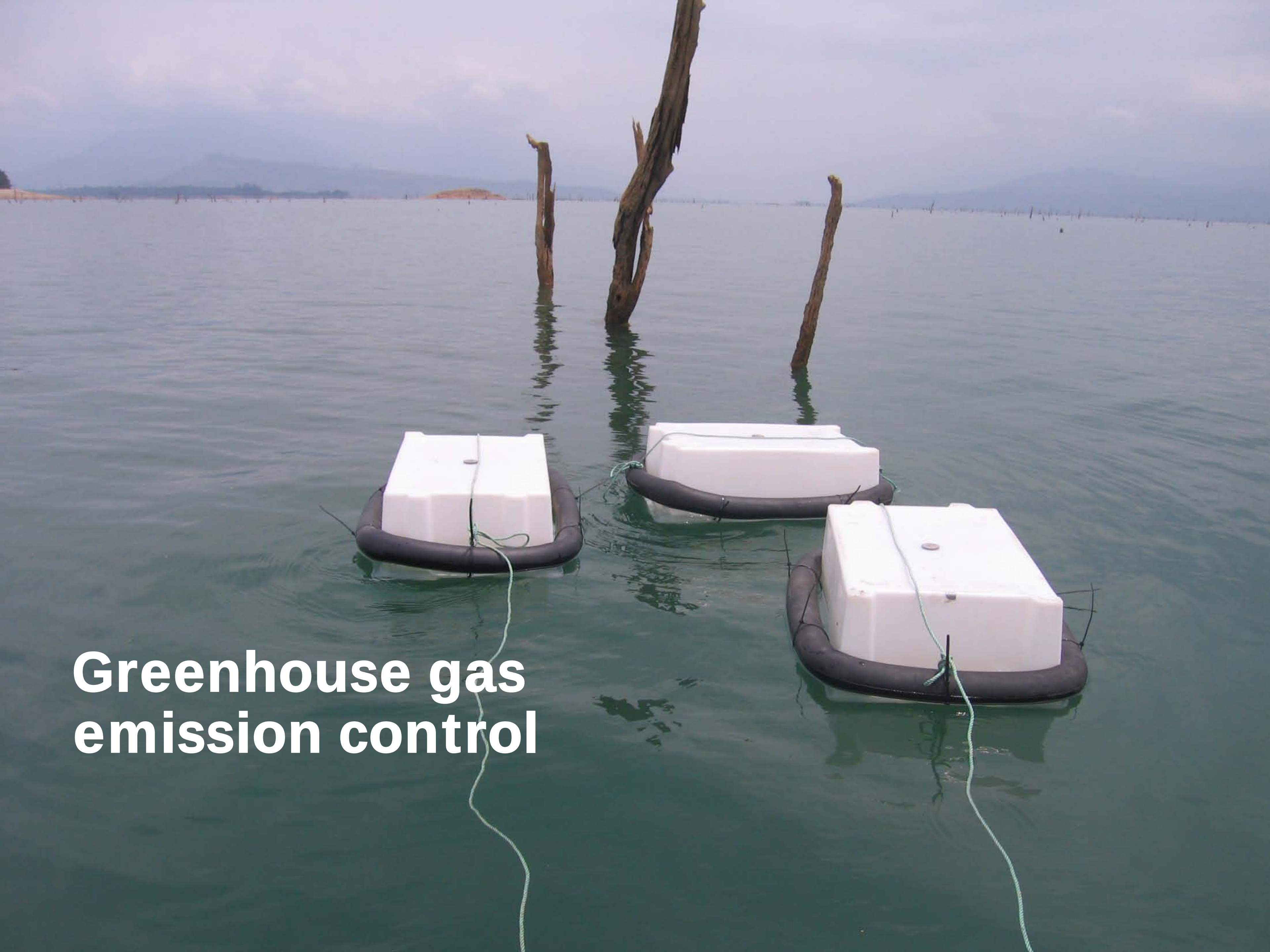



Degraded habitat in bypassed sections

Change in downstream flow regime

Landscape effect
Impacts on wildlife

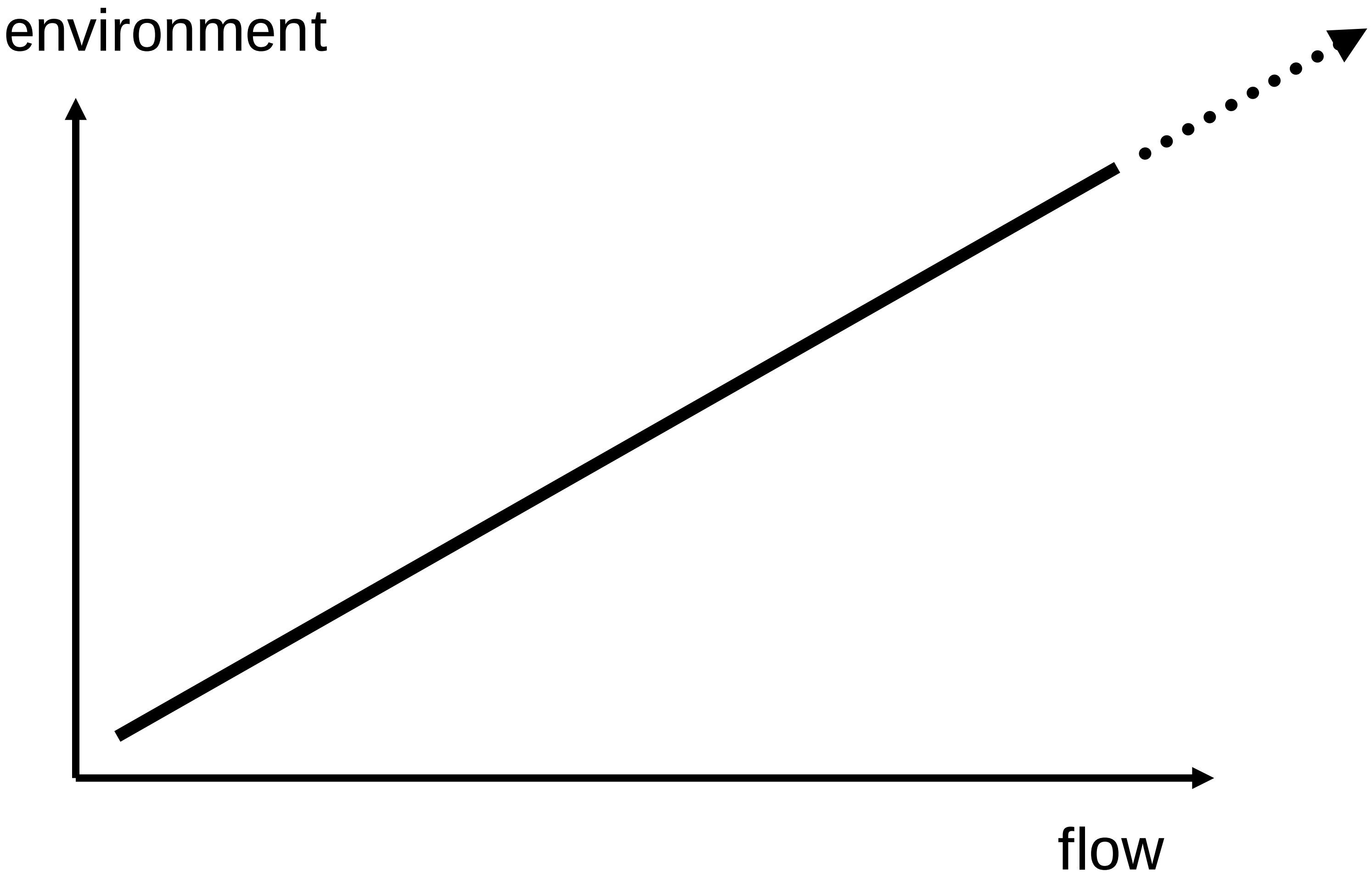
Foto: NINA


Greenhouse gas
emission control

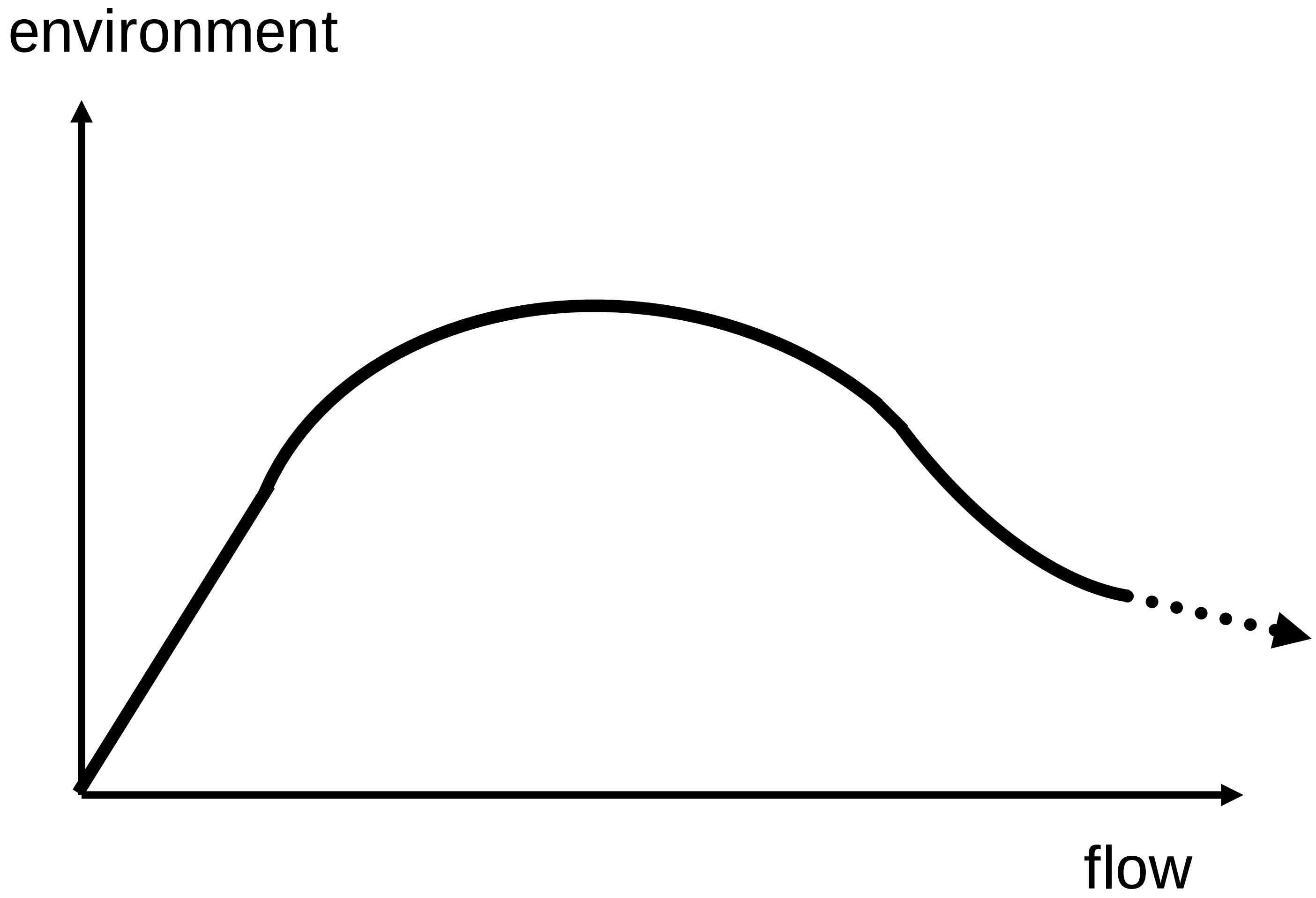

Resettlement


How to mitigate all
this?

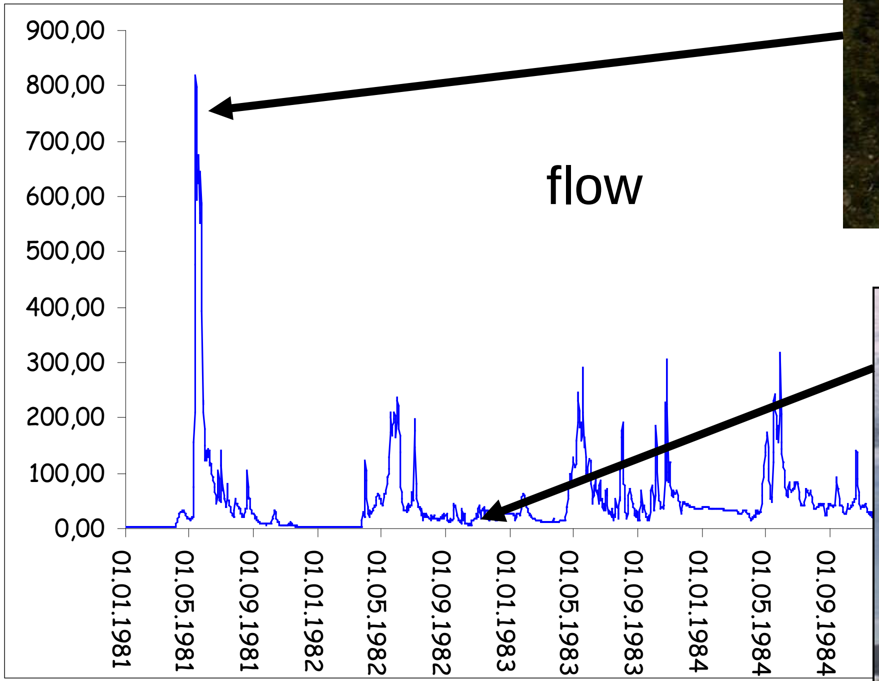
Flow and the environment



Flow and the environment



Variation important!



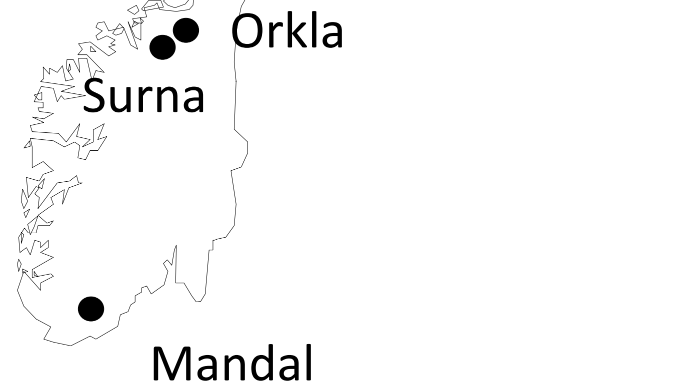
Legislation for new hydropower projects

1. Public announcement about the project
2. Developer propose investigations for environmental impact assessment (EIA)
3. Public hearing
4. The Water and Energy Directorate (NVE) decides investigations for EIA
5. The EIA including mitigation is carried out, costs paid by the developer
6. The license to operate with obligations is given by NVE, but in many cases appealed against
7. → Ends up in the Ministry or in the Parliament
8. License to operate – or not: A political decision

Norwegian legislation

- Until 1970s: Environmental issues not important
- Environmental impacts assessments for new schemes and re-licencing
  - Mostly expert opinion to settle compensation flows
  - Trial periods – often high and low minimum flows
  - ”Common low flow” for small schemes
- Freshets and dynamic flow releases now being introduced
  - Voluntary used in some regulated rivers
  - Proposed in re-licencing

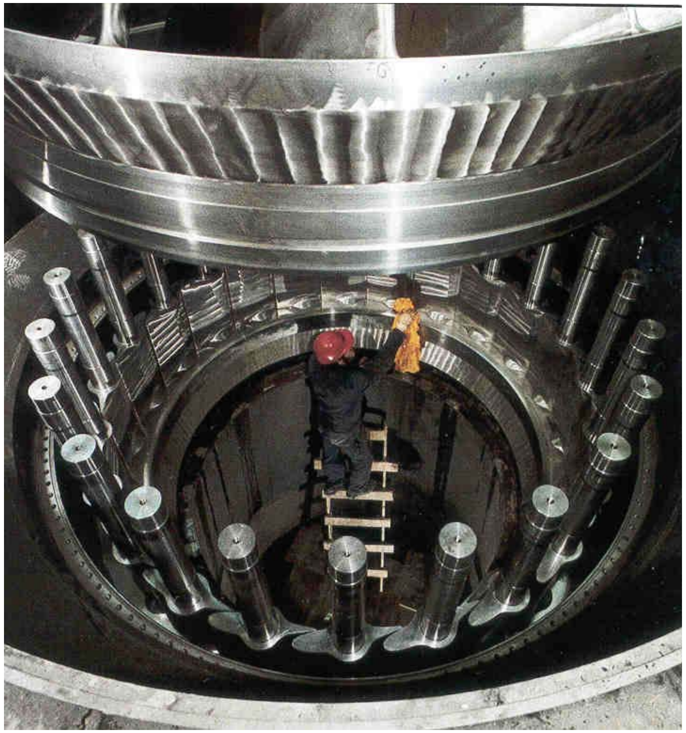
Case studies in Norway



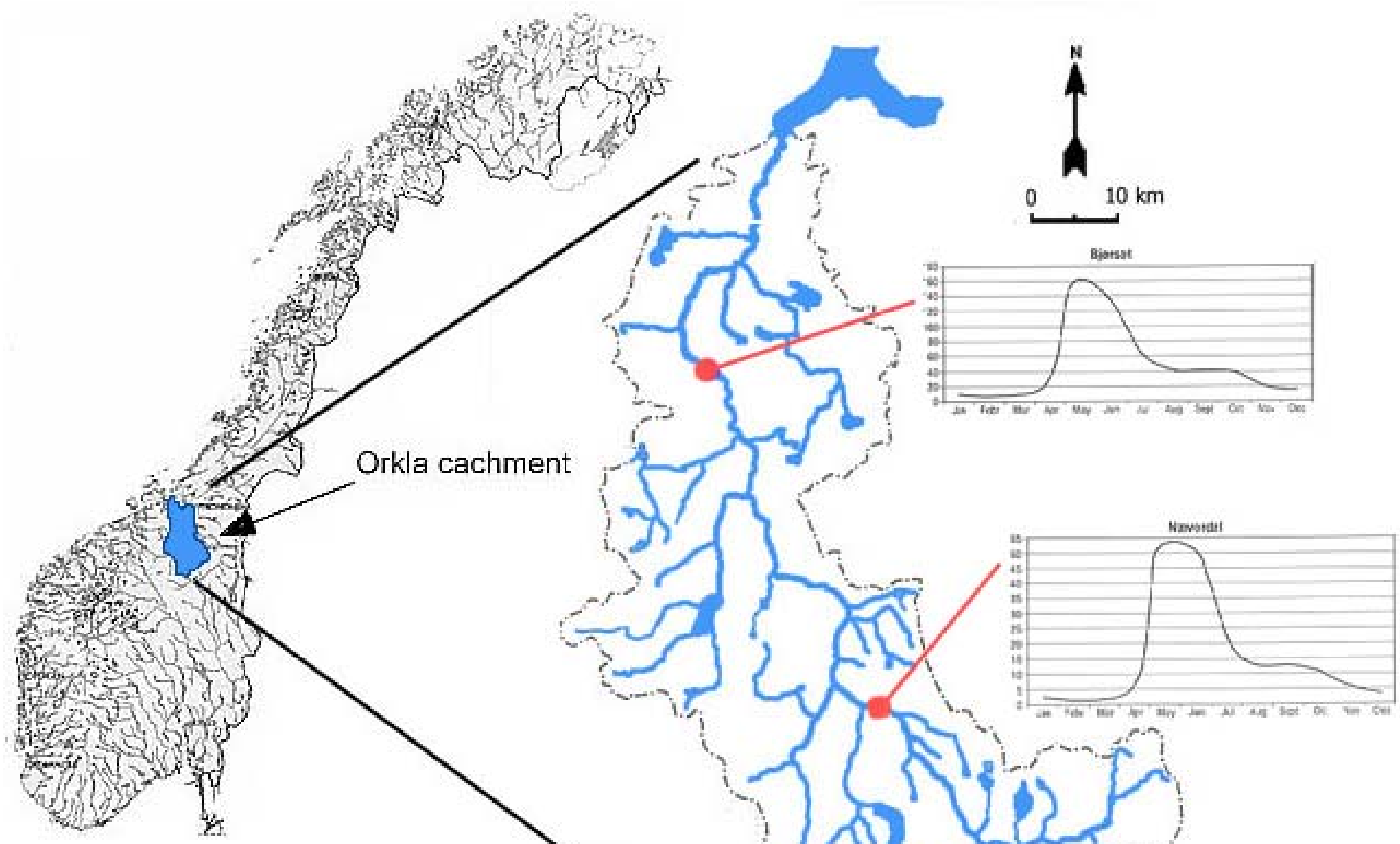
The Orkla river

Prof. Ånund Killingtveit

NTNU and CEDREN

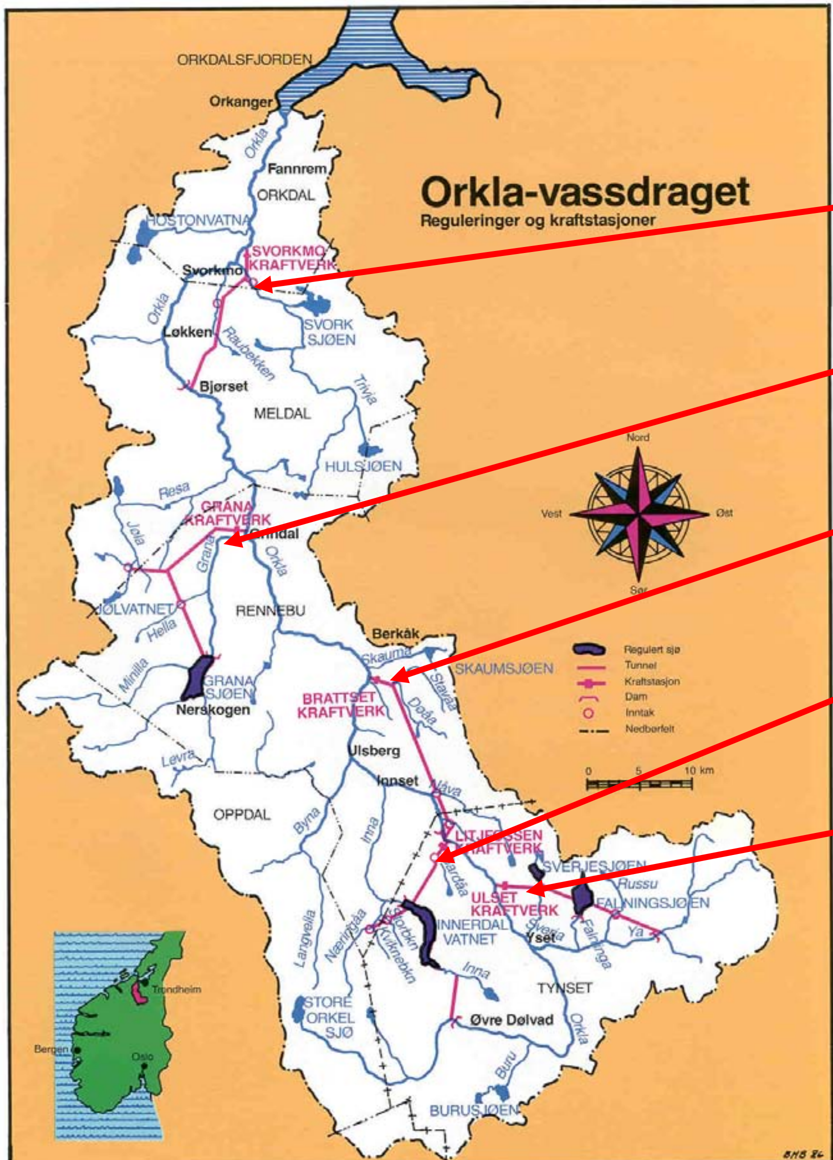


Orkla - Hydrology and climate



Precipitation	500 – 2000 mm/år
Catchment area	3000 km^2
Average runoff	Q=71 m^3/s

Hydropower system in Orkla – an overview



<u>Power plants</u>

Svorkmo

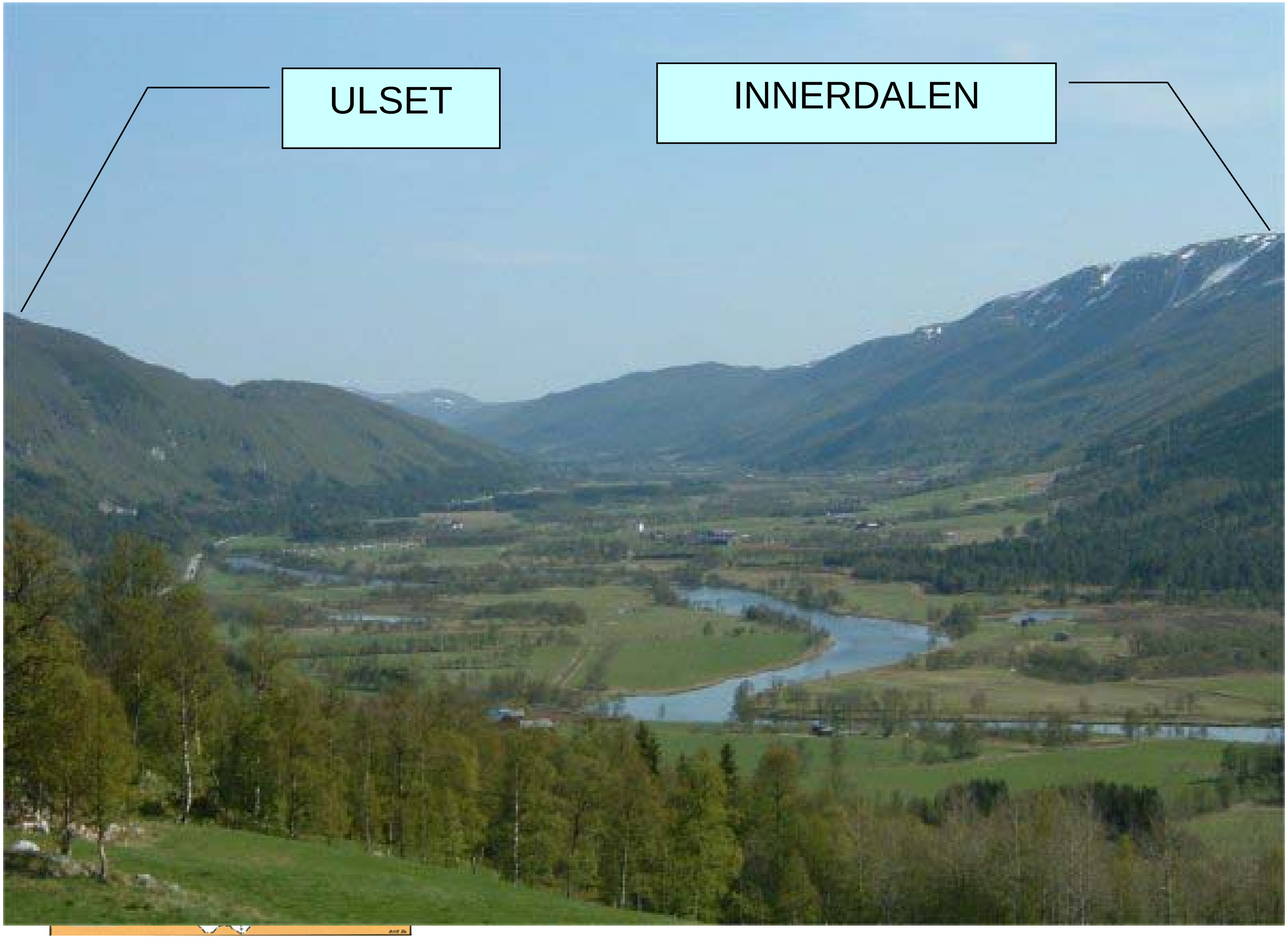
Grana

Brattset

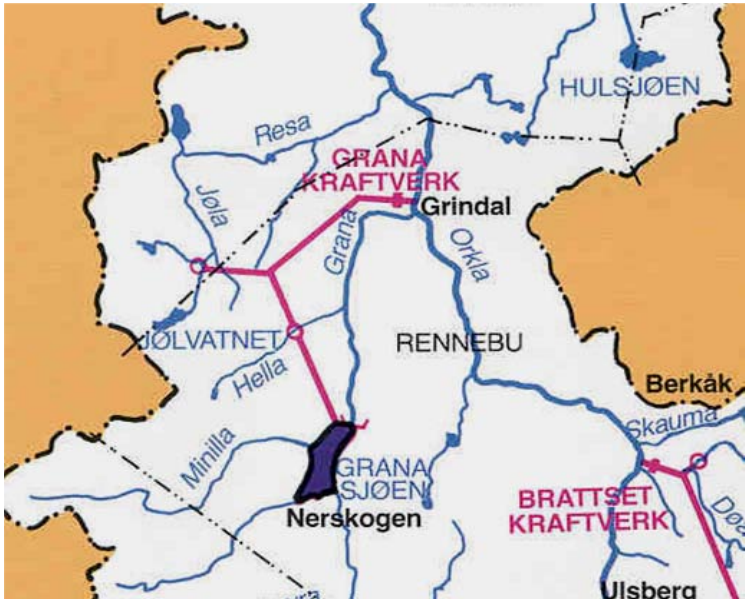
Litjfossen

Ulset

A topography for hydropower development

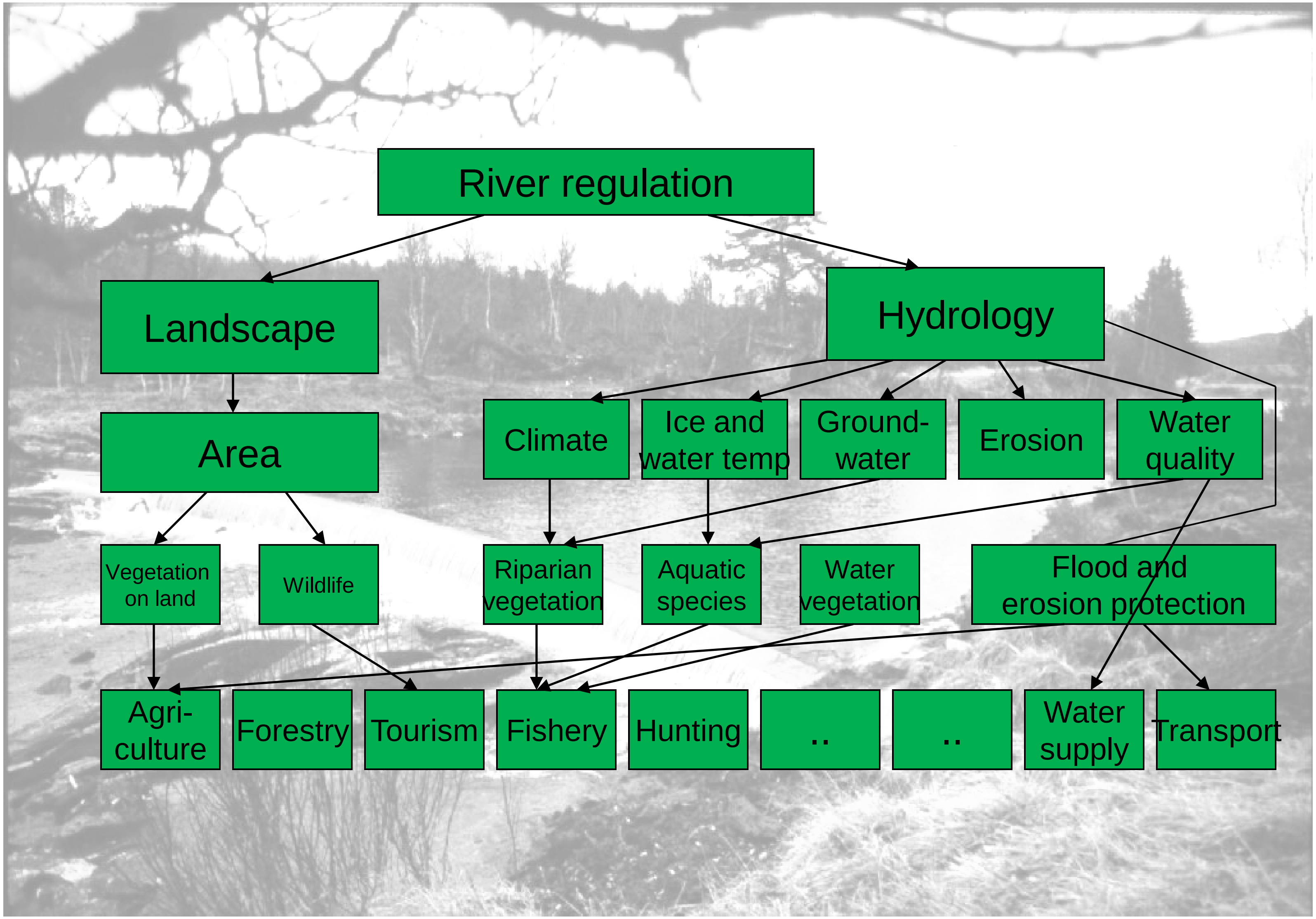


Grana power plant

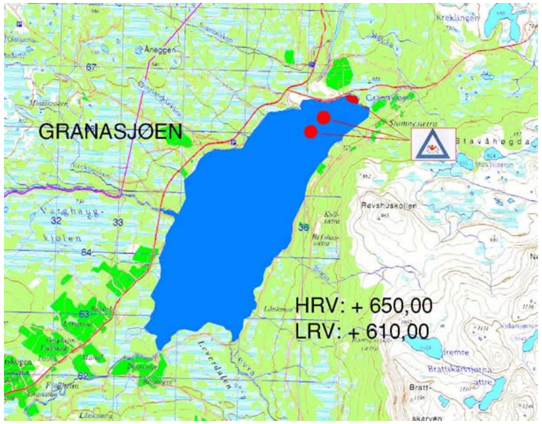


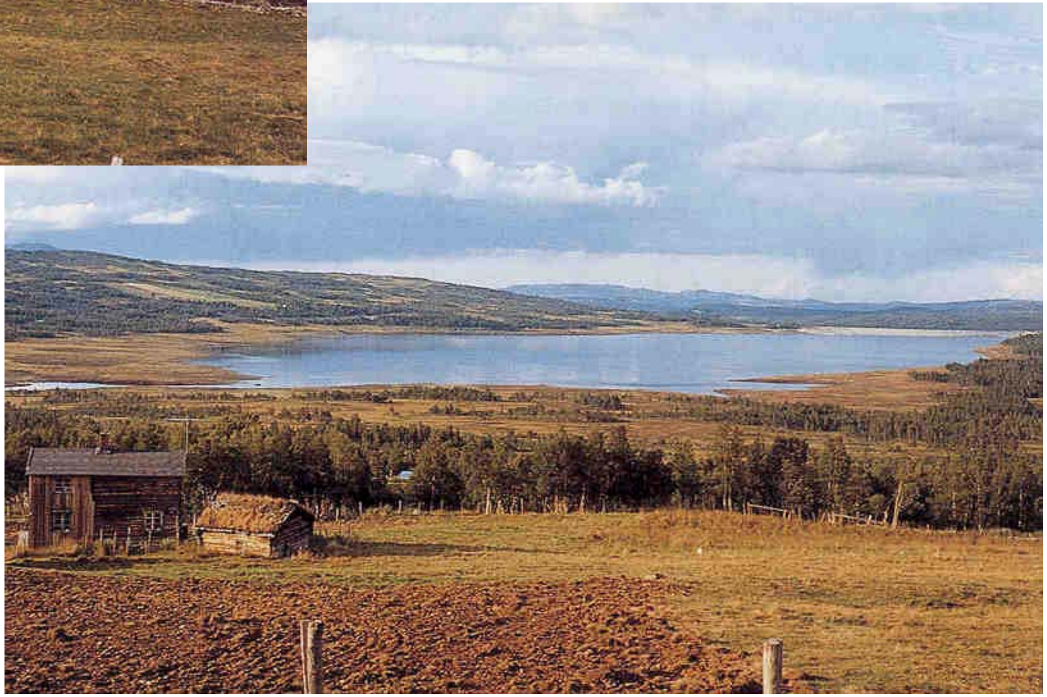
<u>Grana</u>
462 m,
75 MW,
280 GWh/yr

Hydropower and the environment



Environmental effects – Grana reservoir



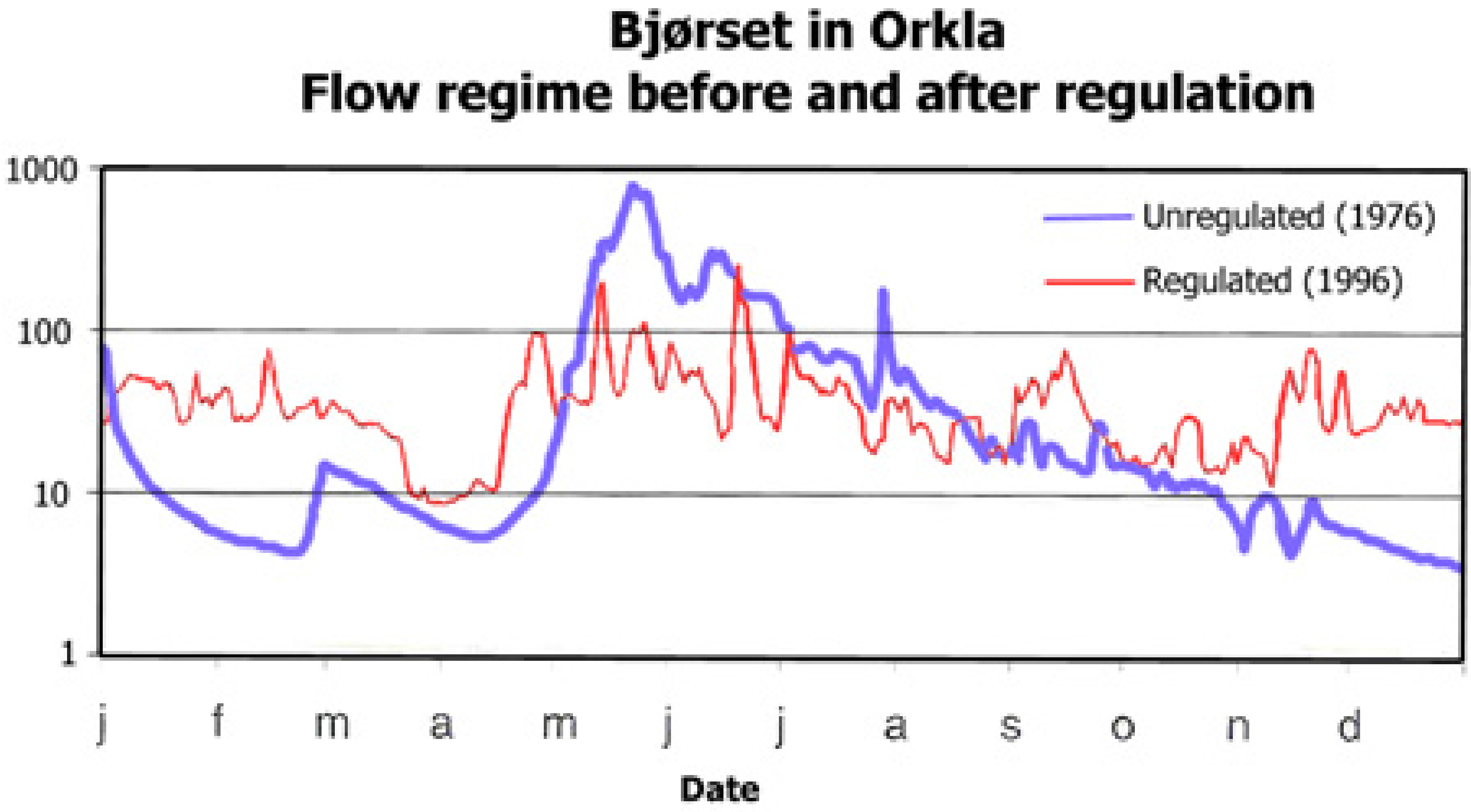


Environmental effects - Innerdalen

Damming the scenic Innerdalen valley was the most controversial part of the Orkla scheme

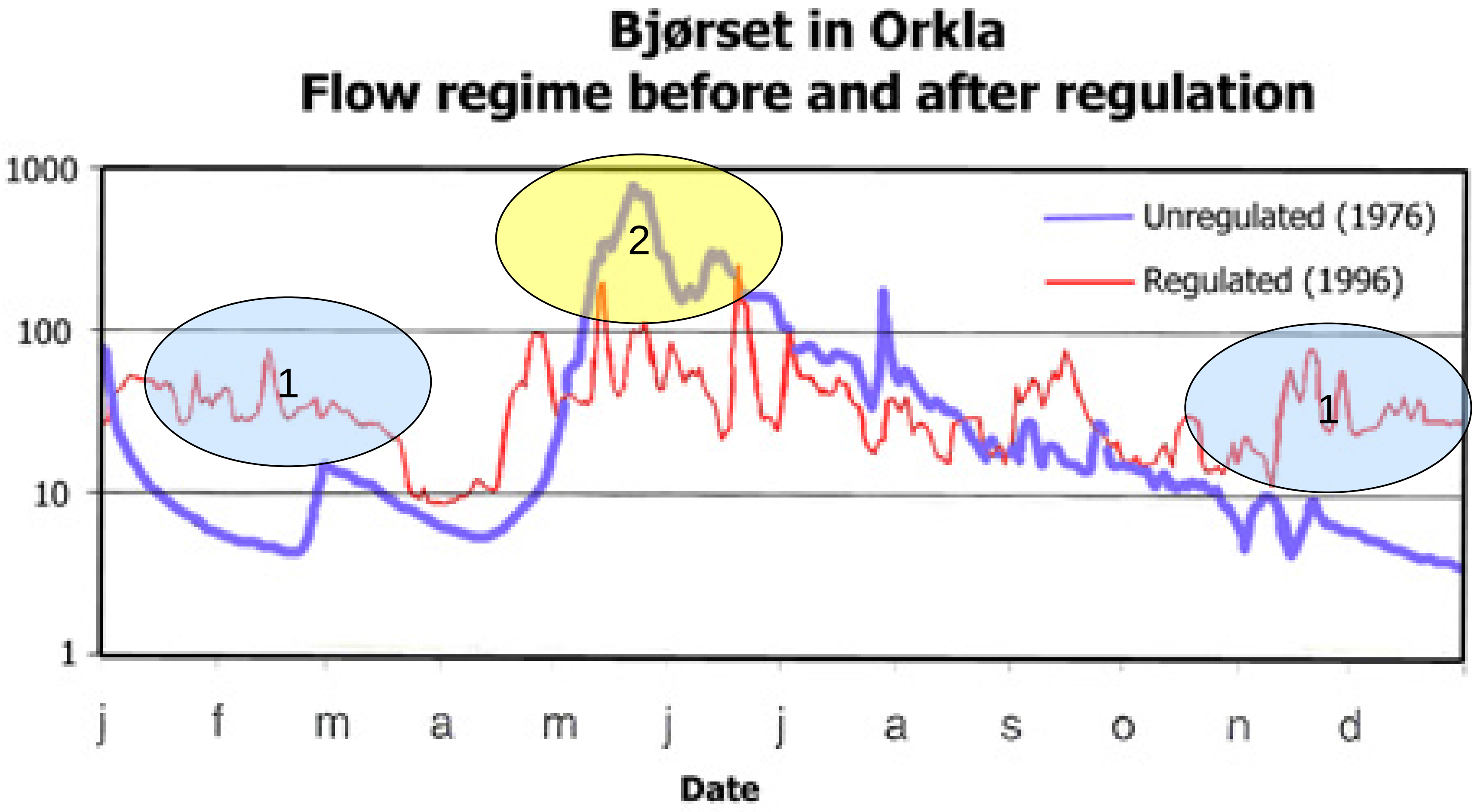
Environmental resistance - Innerdalen

Environmental effects – Changes in flow

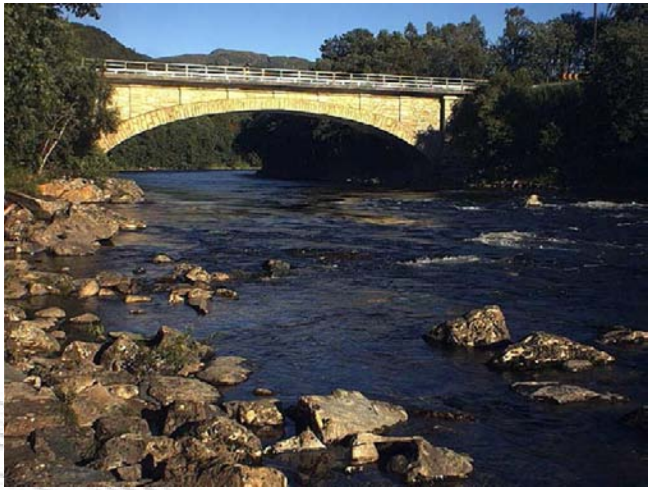


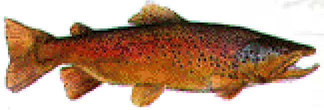
1) Increased winter flows

2) Reduced spring and summer flows



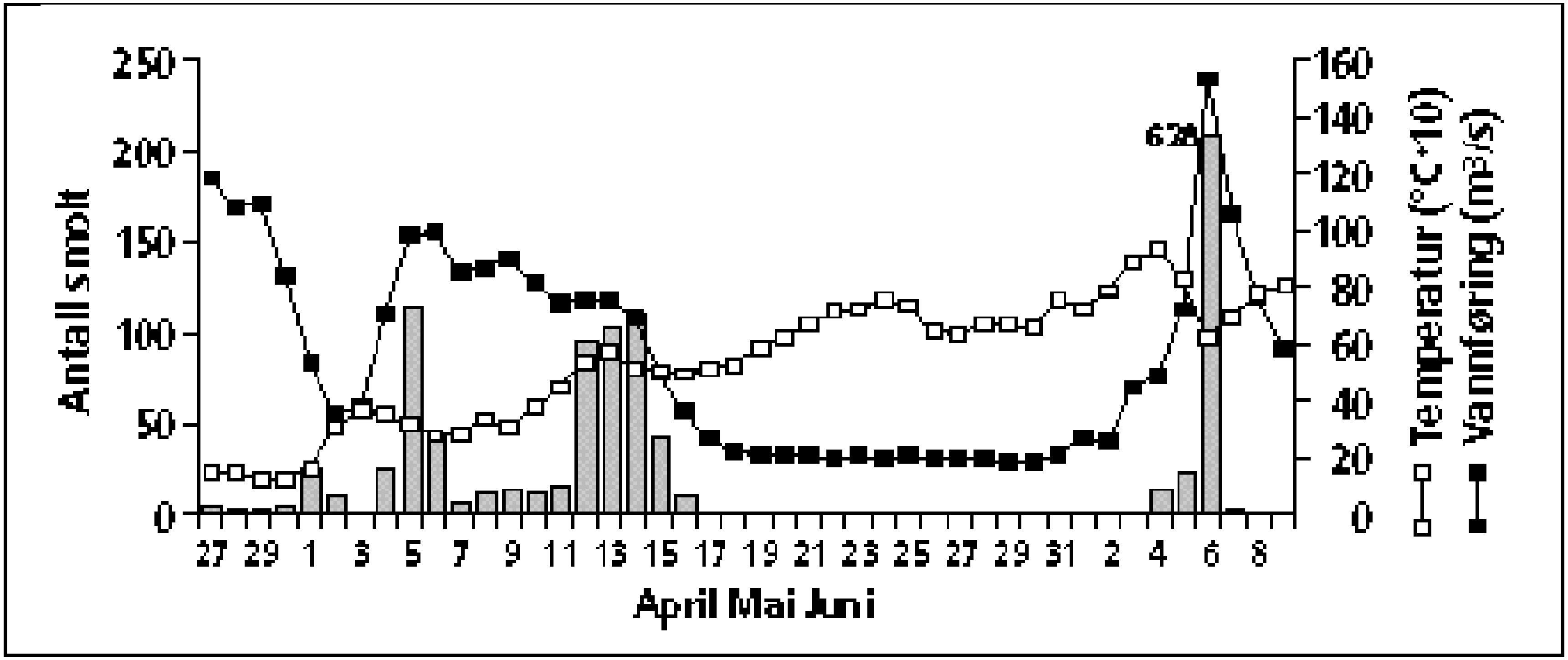
Environmental effects – Salmon fishing



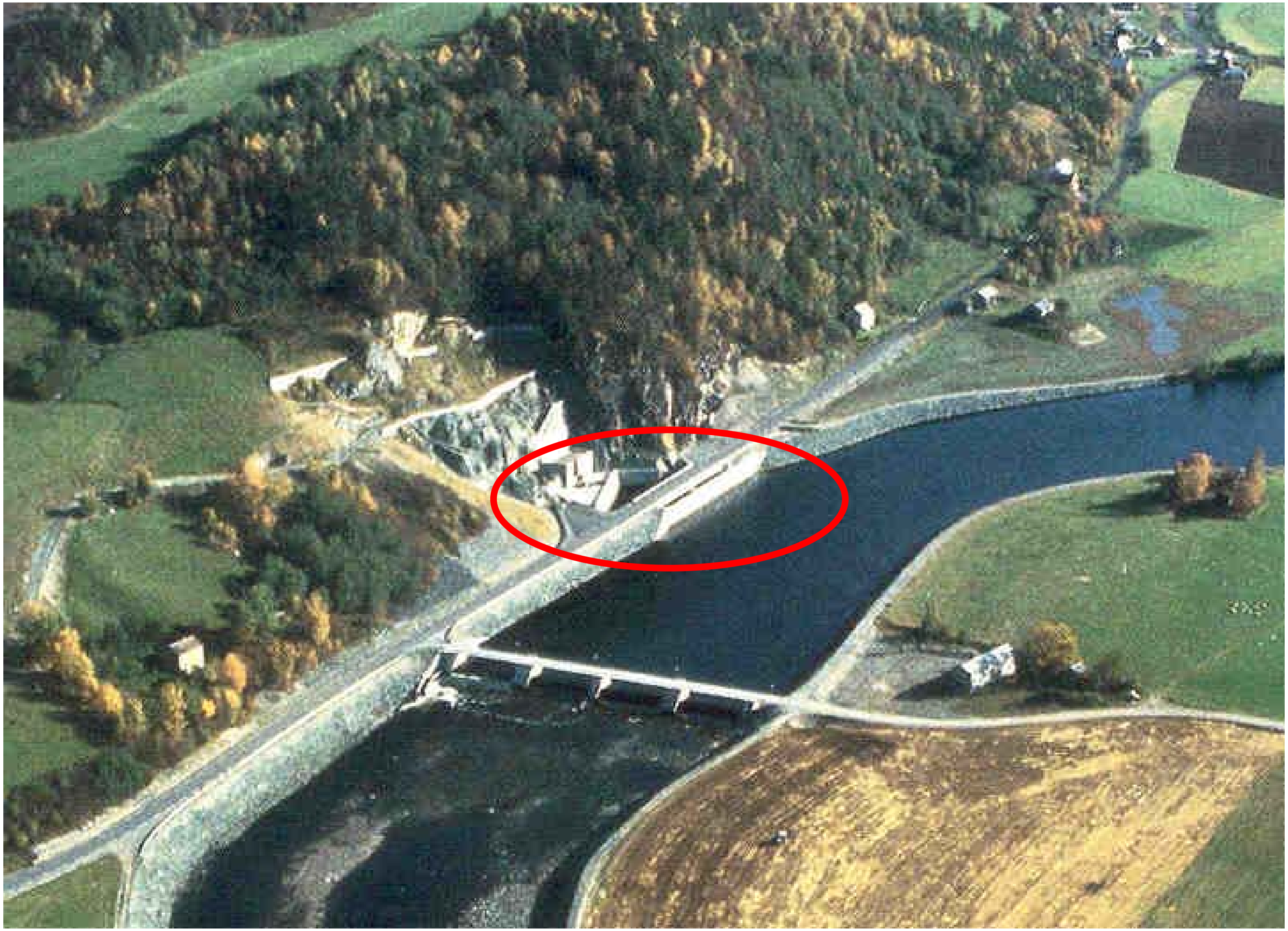


Environmental effects – Downstream smolt migration

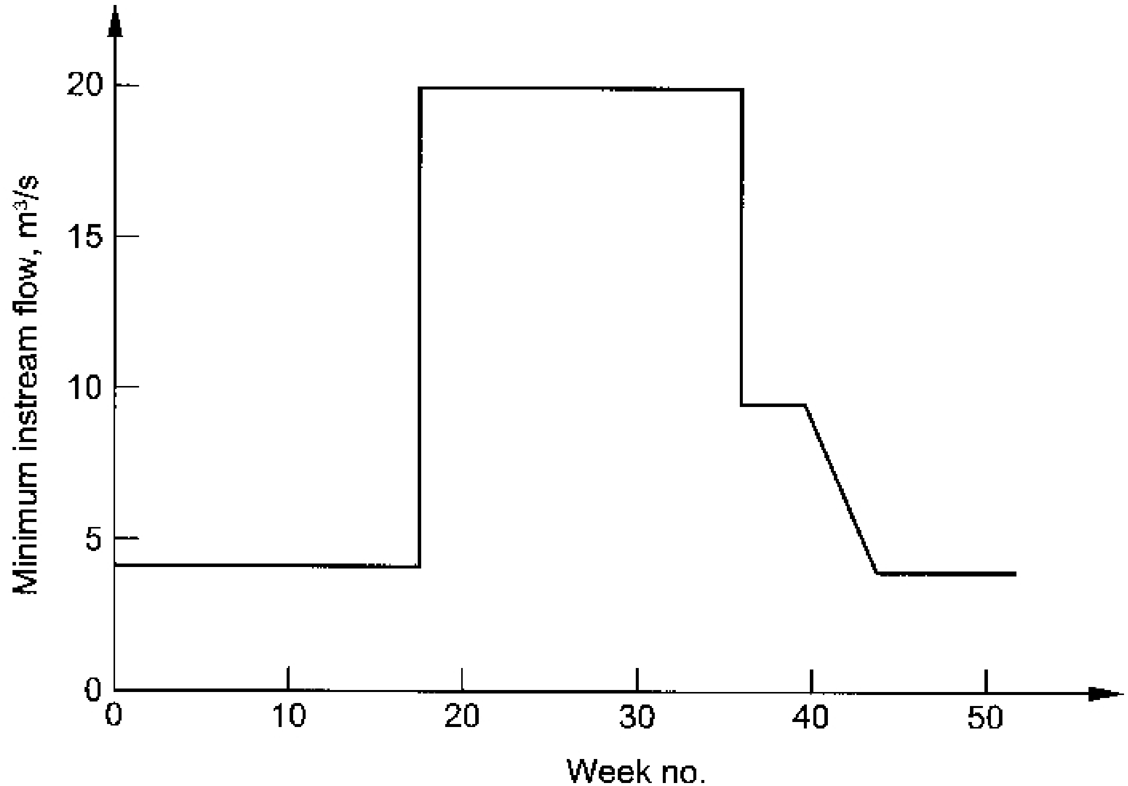
Salmon smolt (2-3 years old) leaves the river and swim out in open sea to feed. It is important to secure that migrating smolt (see figure below) does not enter into tunnel and turbines.
This requires special design of intake at Bjørset and *timing* of flow.



Environmental effects – Salmon fishing

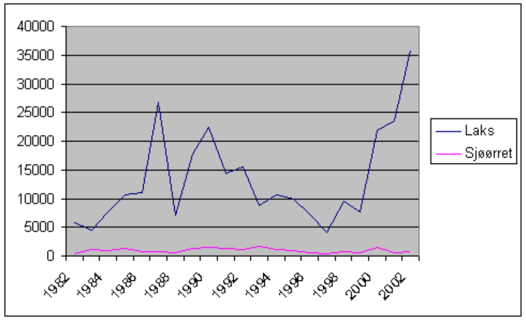


Bjørset Dam – Minimum flow release



Improved fishing and increased salmon stock

- Due to increased good habitat available in winter
- Outweighs the effect of lower summer temperature



Fishing in Orkla has actually improved …

NINA

fakta

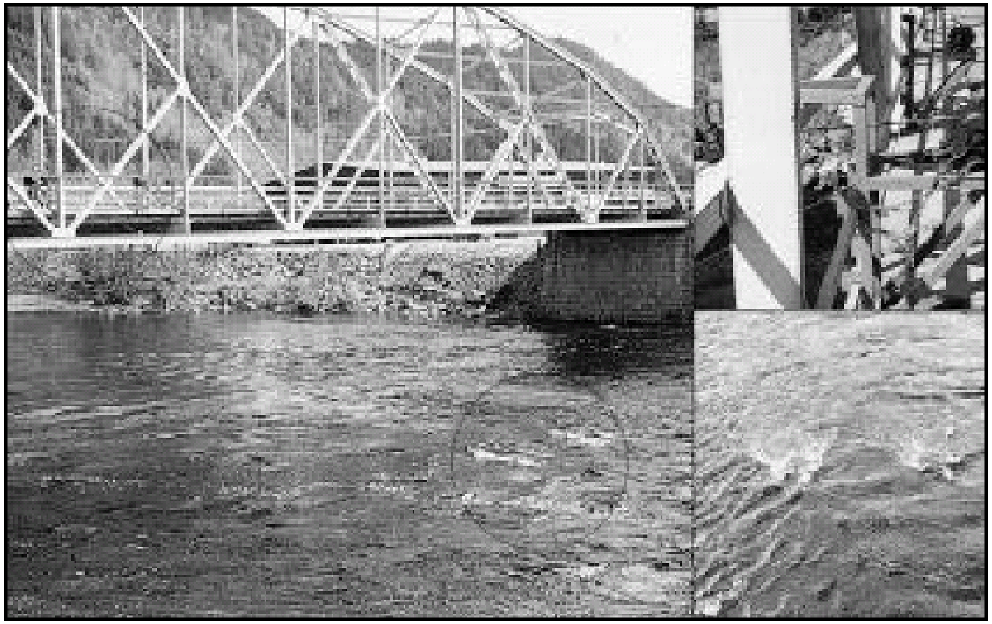
NINA er et ledende kompetansesenter i økologi som utfører langsiktig forsknings- og utredningsarbeid for miljømyndighetene og andre. NINA har ca. 165 ansatte (1993). Hovedsetet er i Trondheim, men vi har også ansatte i Oslo, Ås, Lillehammer, Sandnes, Bergen og Tromsø.

fakta-ark gir populariserte sammendrag av publikasjoner fra NINA.

Nr. 12 — 1990

Økt smoltproduksjon i Orkla etter reguleringen

Det antas at smoltproduksjonen i Orkla har økt etter reguleringen. I gjennomsnitt var produksjonen 37 prosent høyere etter reguleringen, dersom man antar at 1983



Cost of instream flow and operational restrictions

Flow restrictions and reservoir restrictions lead to less efficient operation and loss of power production and also production at a less favourable time and price

<u>Cost estimates (pr 1992):</u>

- Granasjøen: 38 Mill. NOK

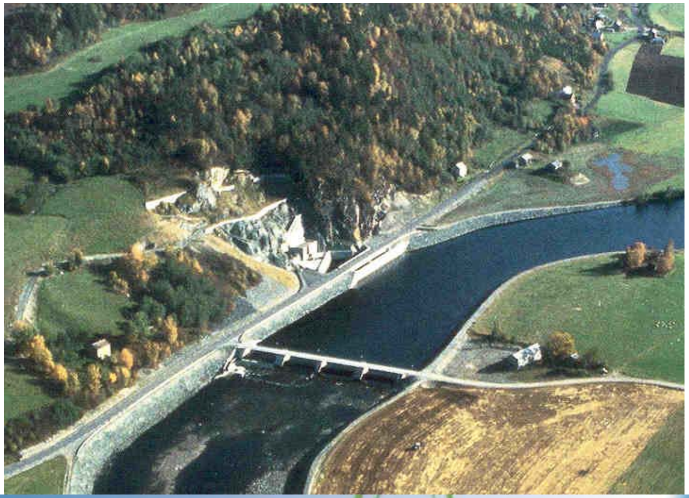
350 MNOK

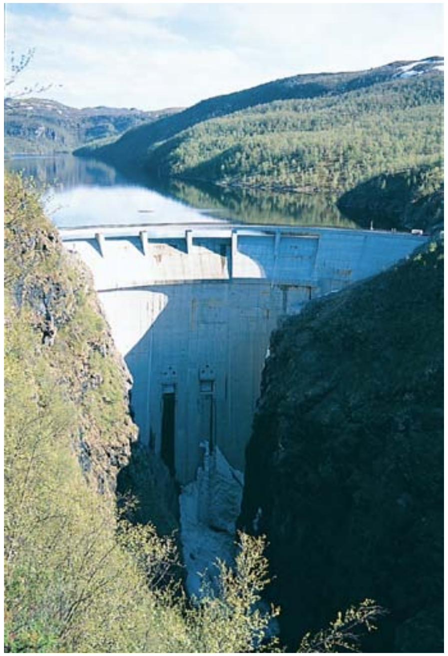
- Minimum flow
  Bjørset dam: 230 Mill NOK
  All other: 70 Mill. NOK

- Intakes and outlets: 4 Mill. NOK

- Fish ladder etc at Bjørset: 5 Mill. NOK

- Compensation costs: 2 Mill NOK

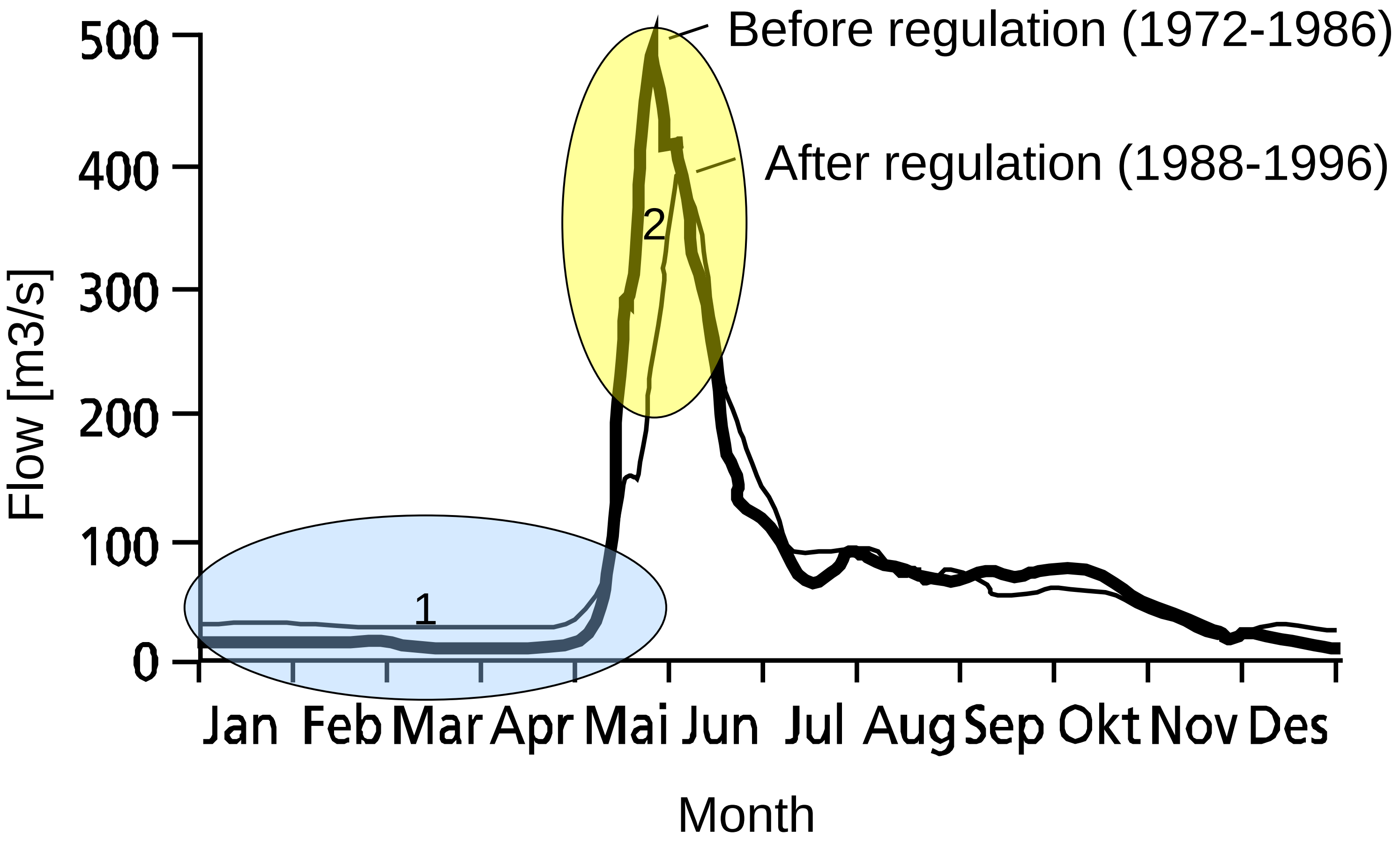




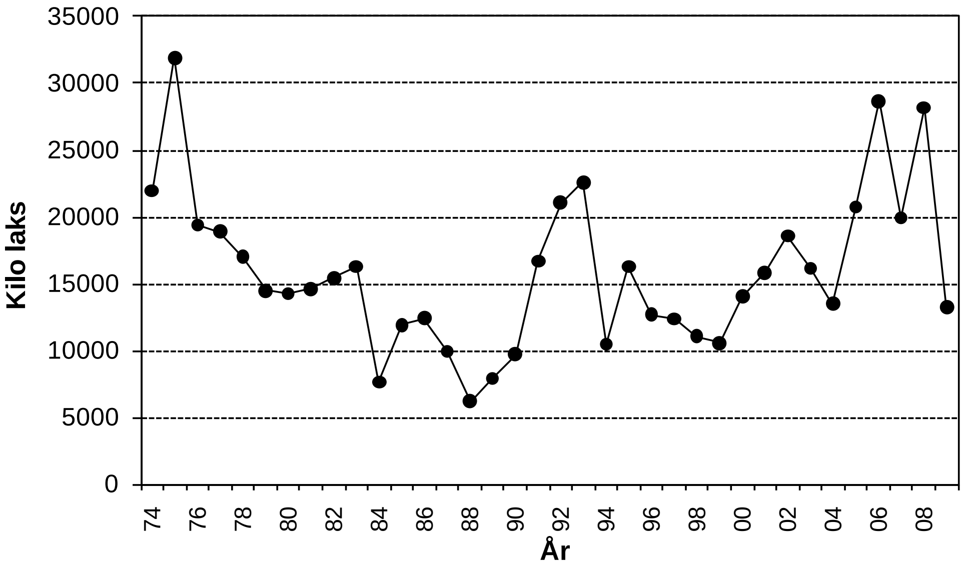
Alta river

Ola Ugedal, Torbjørn Forseth, Tor Næsje

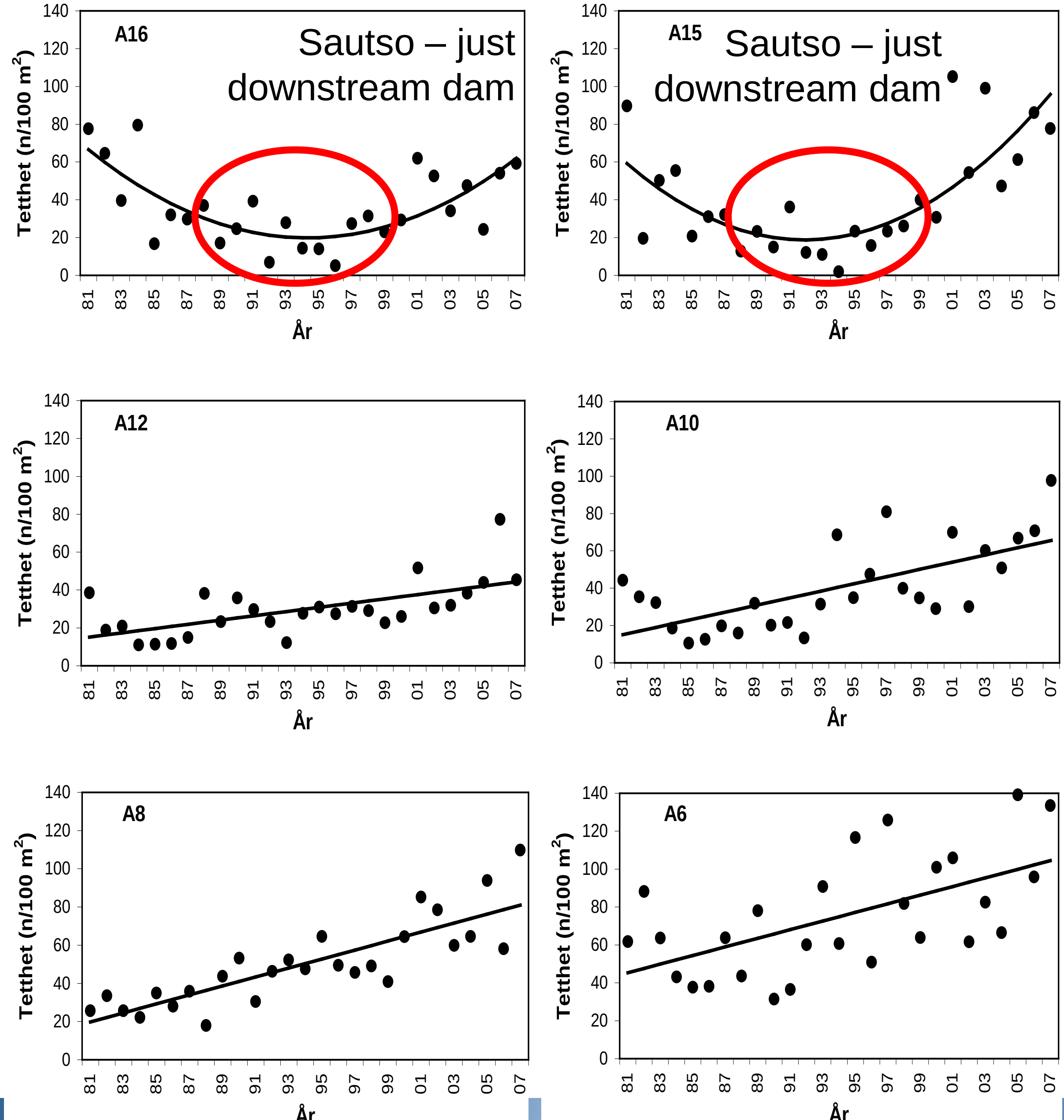
Change in flow



Increased catches



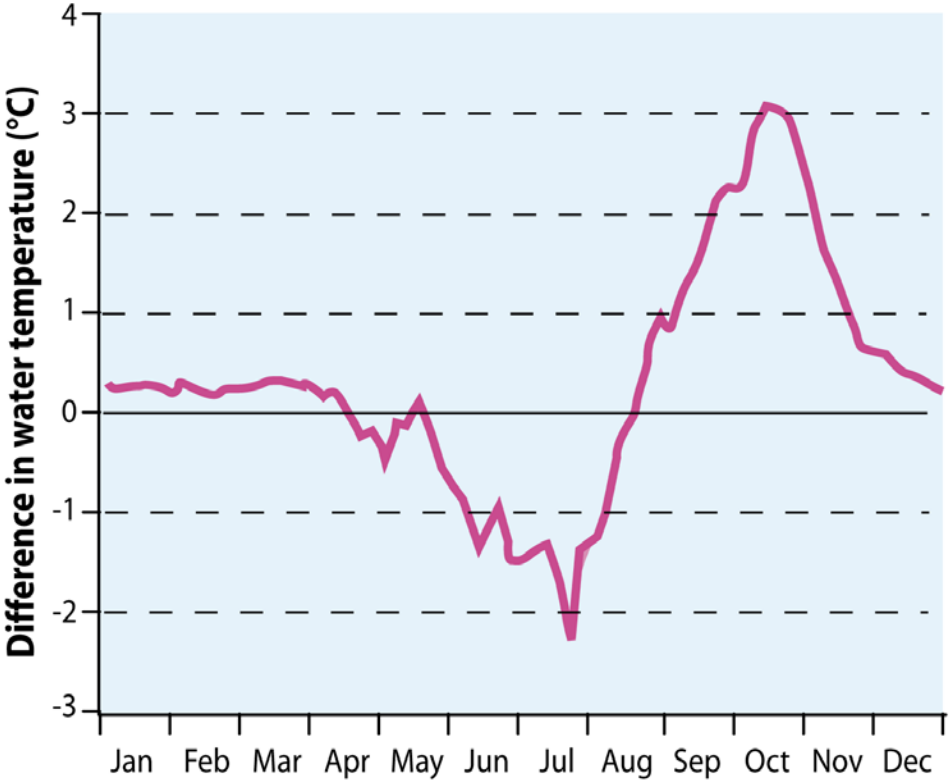
Salmon parr



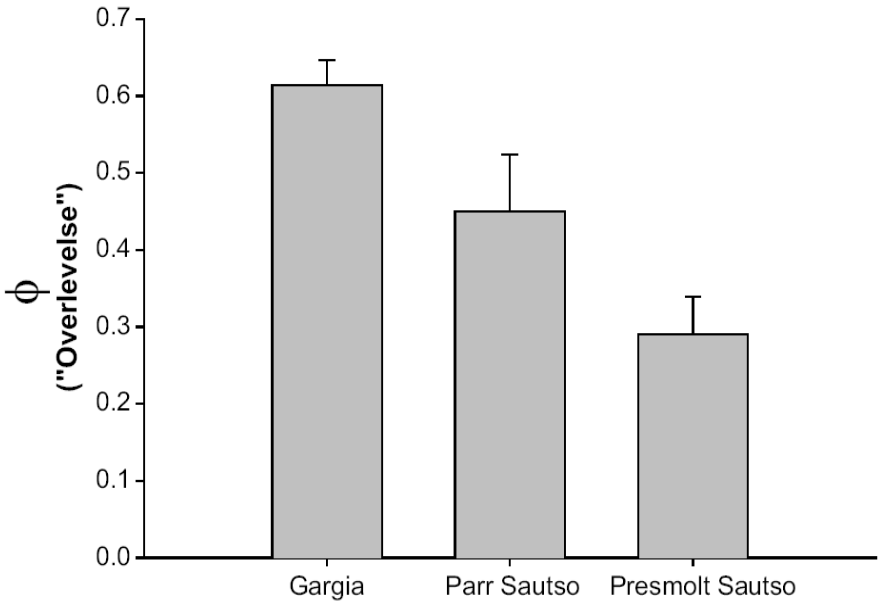
Electrofishing control stations since 1981

→ Increased density

Change in water temperature in Sautso (just downstream reservoir)

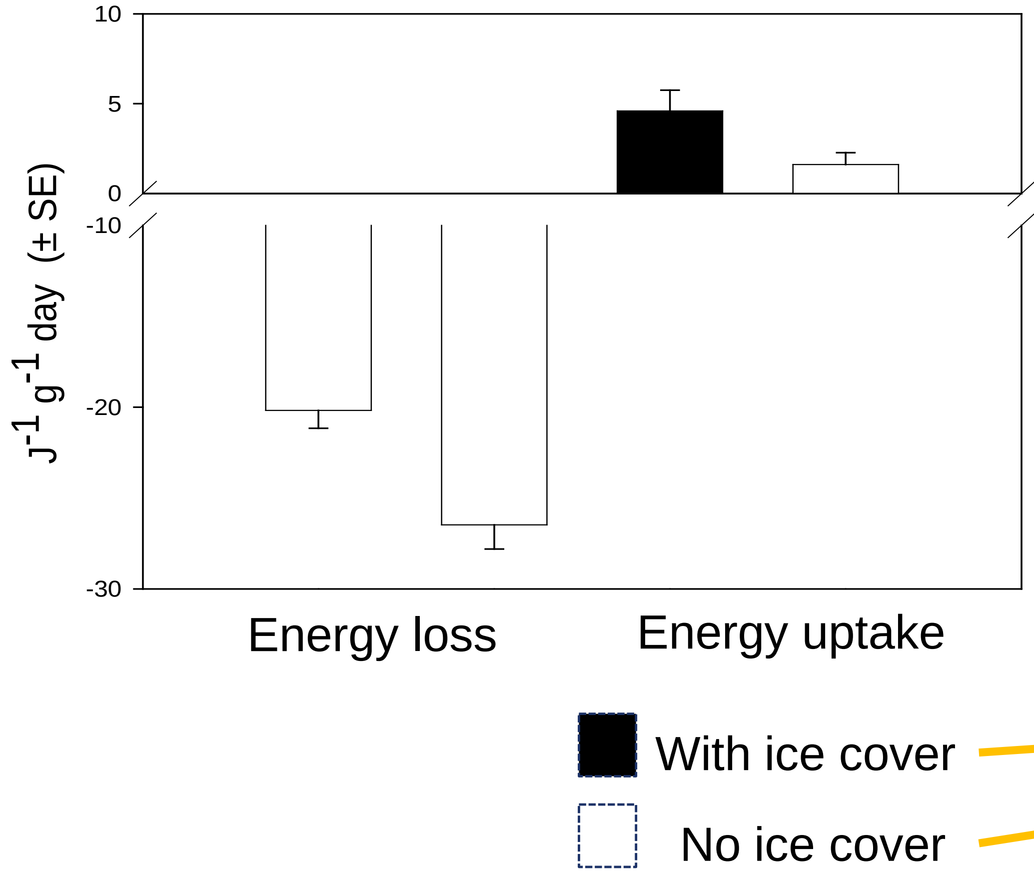


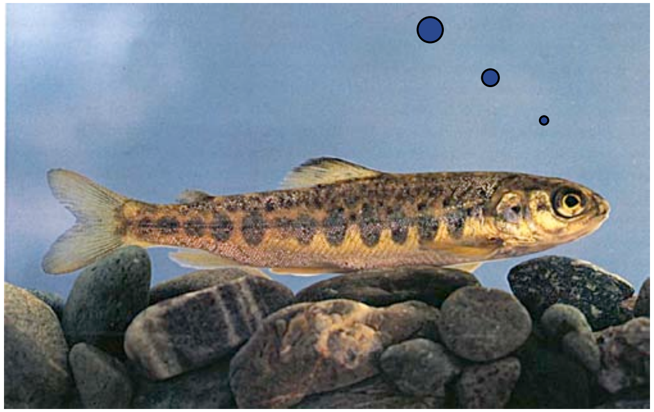
Increased mortality in winter in areas without surface ice cover (PIT-marking study)

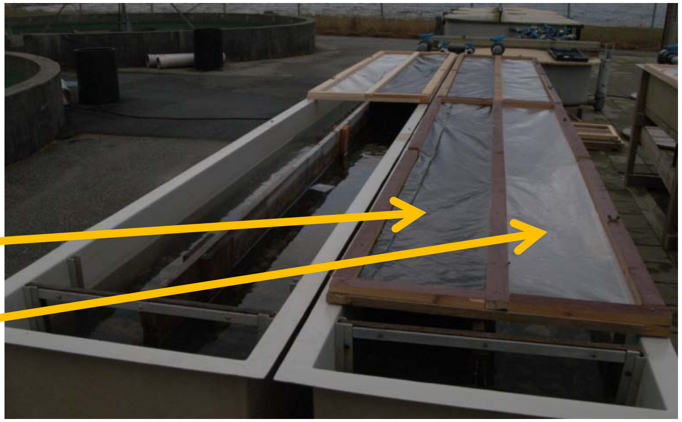


Reduced ice cover leads to spending more energy

$$P = C - R - F - U$$

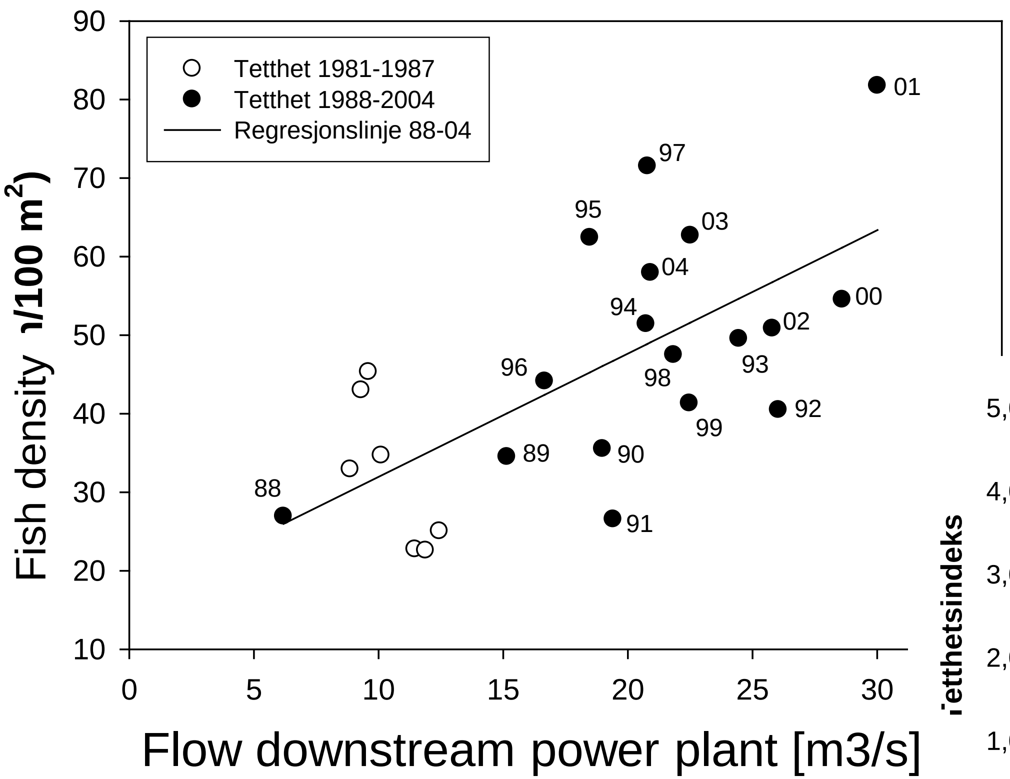


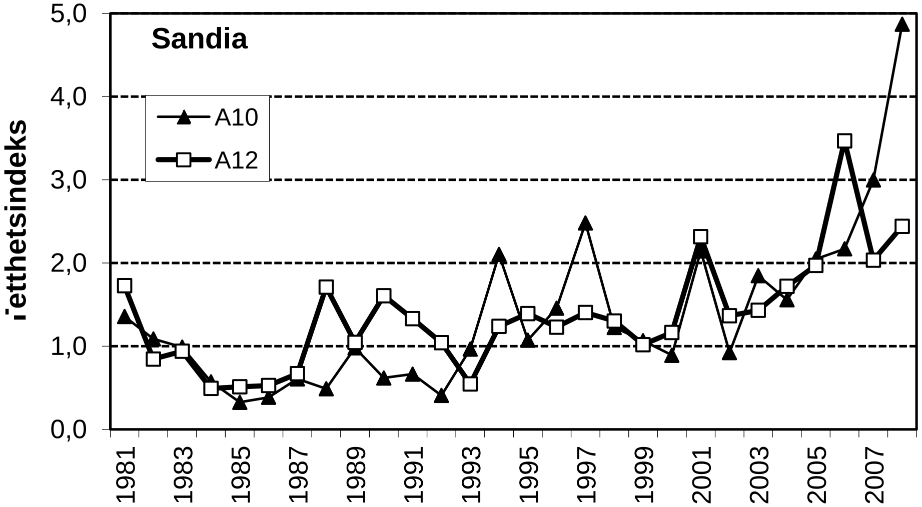




Rapid changes in flow → stranding risk

Stable and relatively high flow in winter wanted!

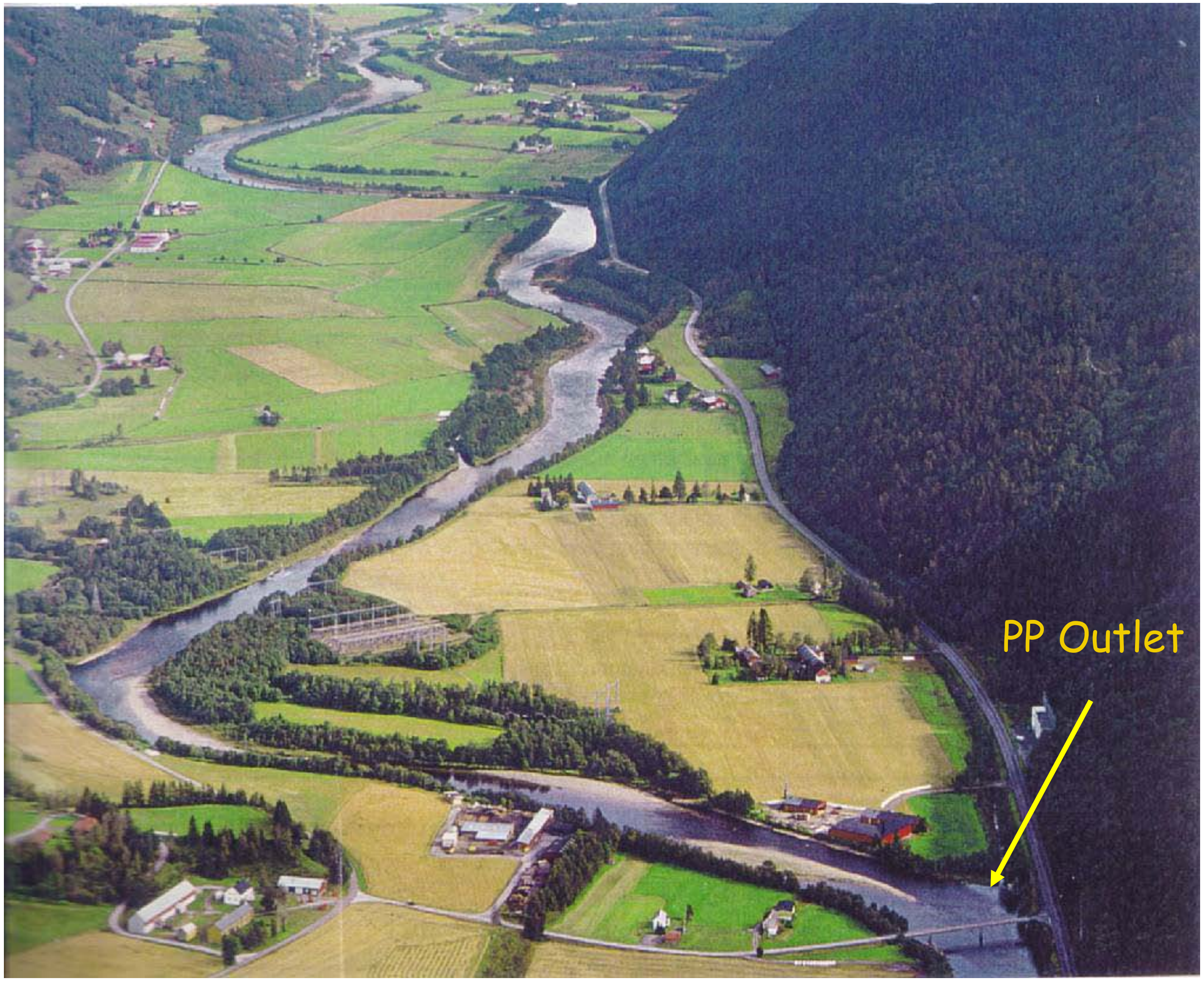




Catch and release fishing

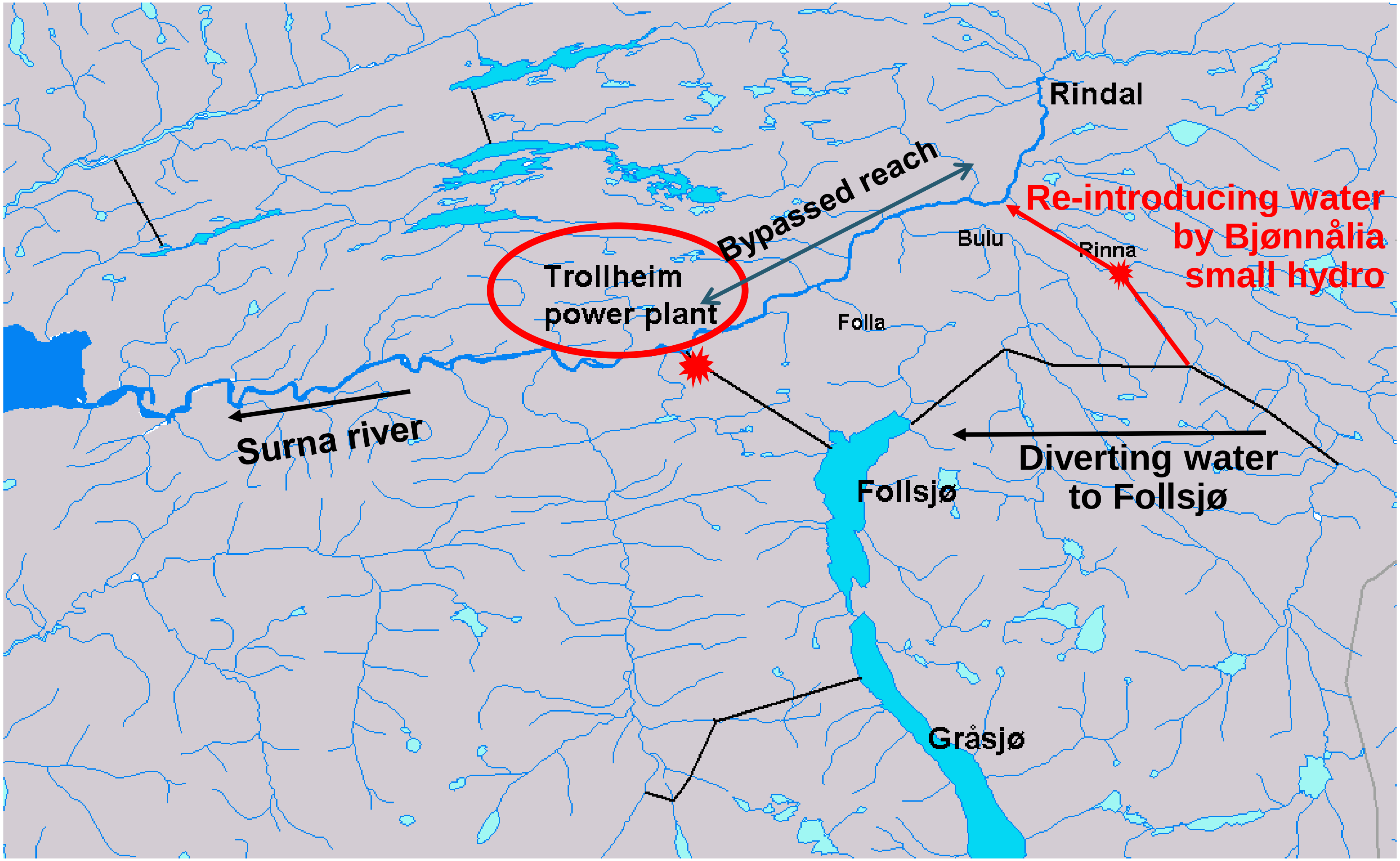
Surna river and hydro system

Bypassed reach (50 % flow reduction)



Håkon Sundt, Jo Halleraker, Knut Alfredsen, Atle Harby

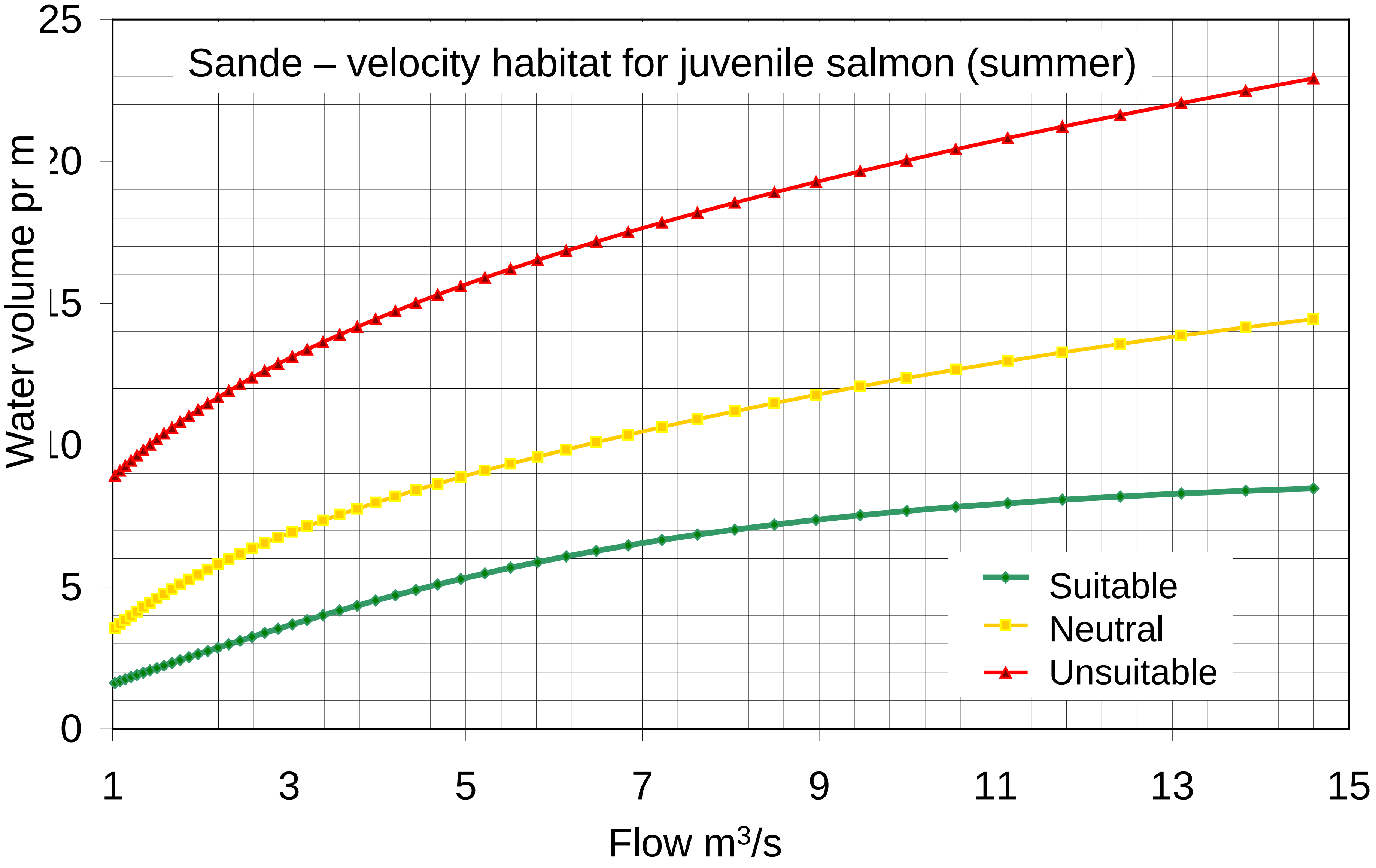
Surna river and hydro system



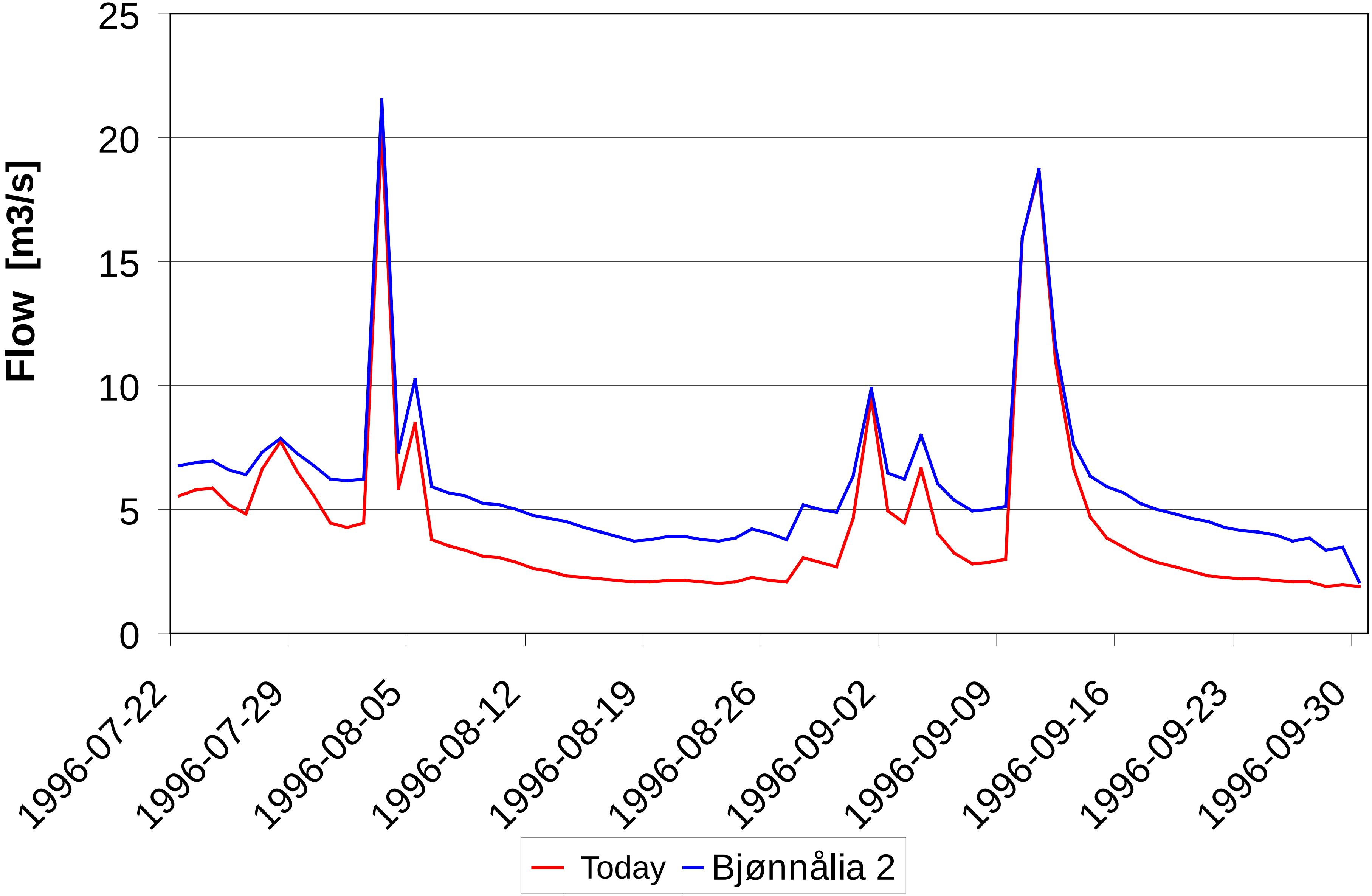

The Surna river

Bypassed reach - Sande

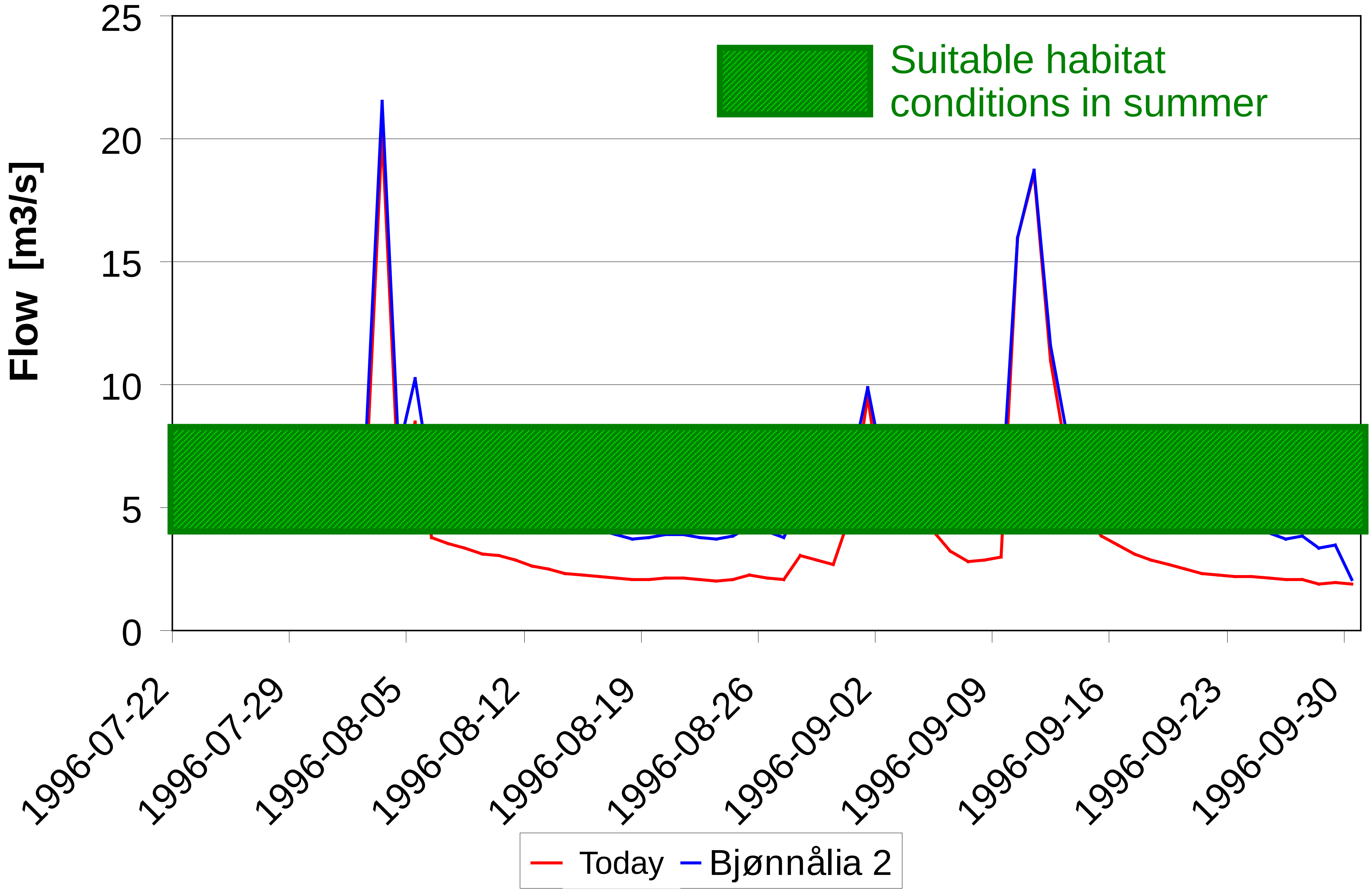

Bypassed reach -
Harang


Sande – velocity habitat for juvenile salmon (summer)
Water volume pr m
25
20
15
10
5
0
1
3
5
7
9
11
13
15
Flow m3/s
Suitable
Neutral
Unsuitable

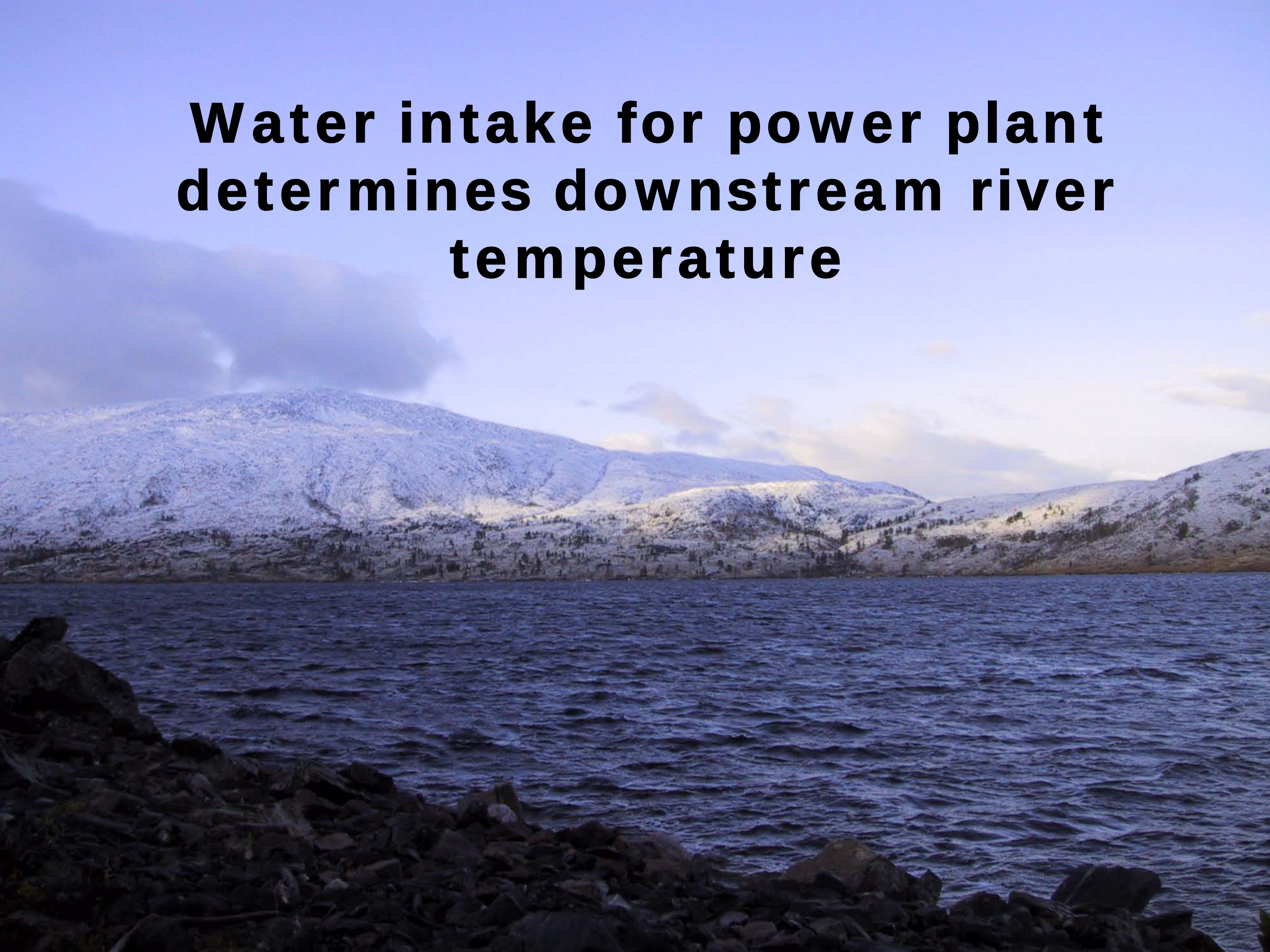
Example 22 June – 30 September 1996



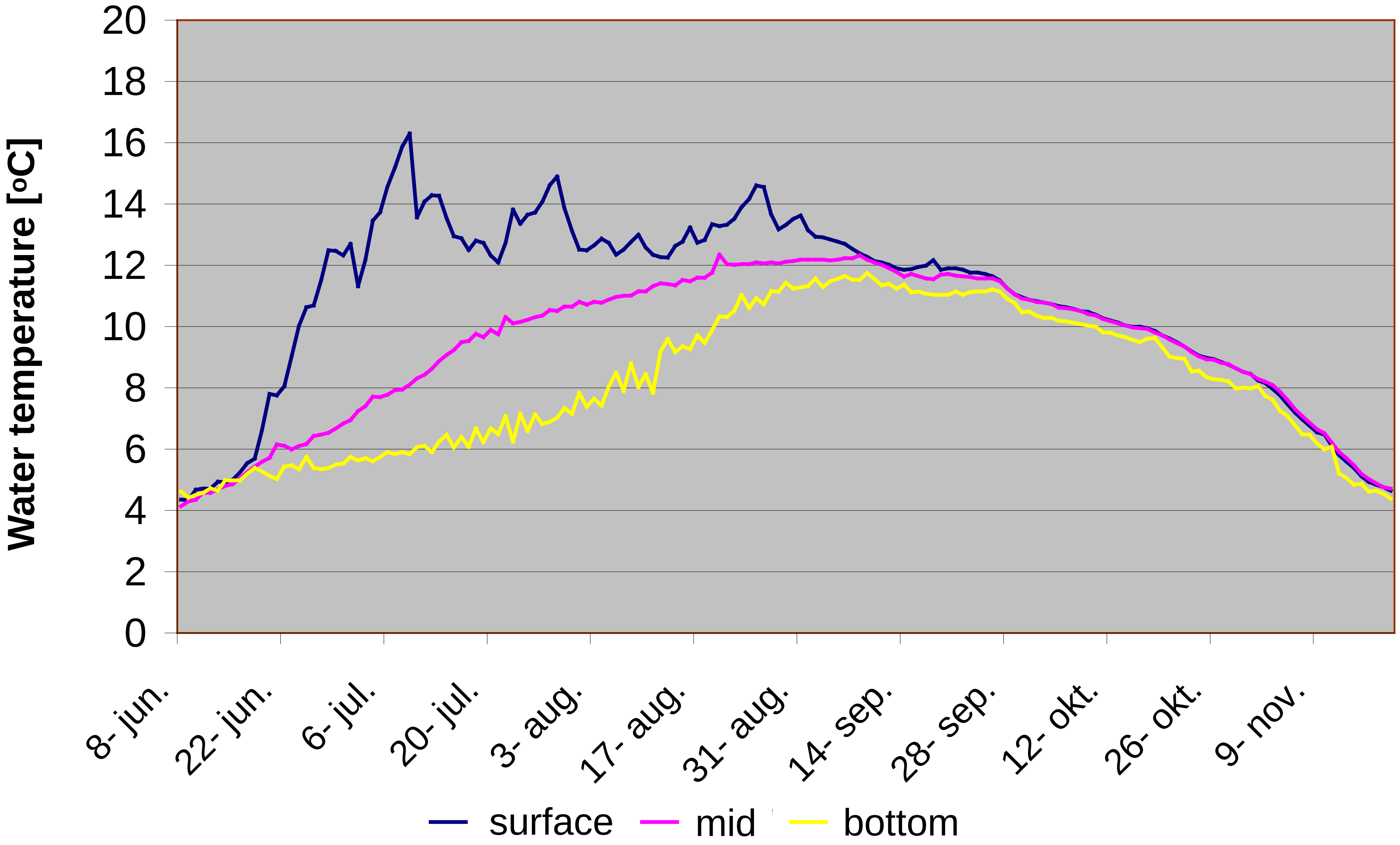
Example 22 June – 30 September 1996



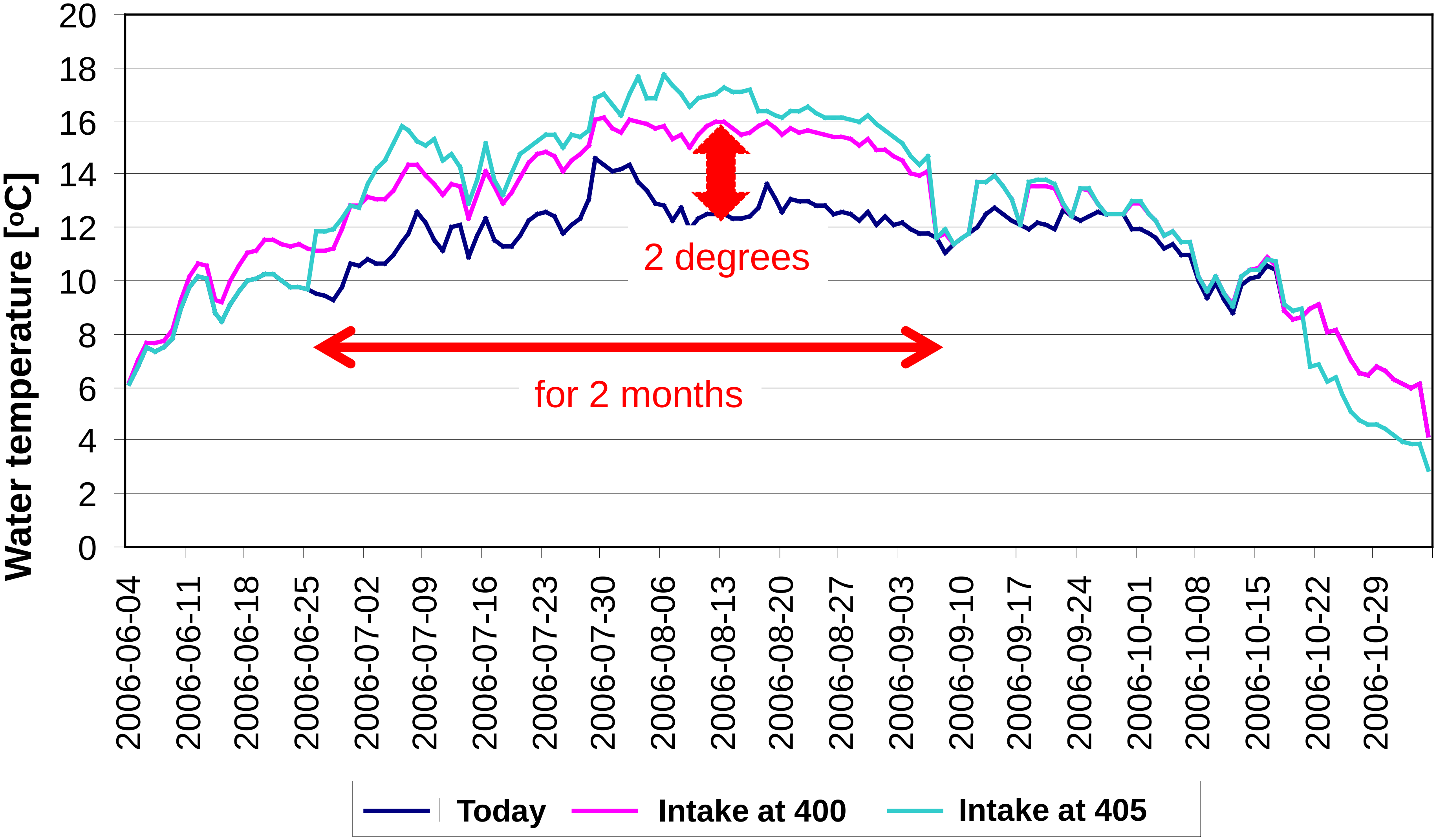
Water intake for power plant determines downstream river temperature



Measured temperatures 2001

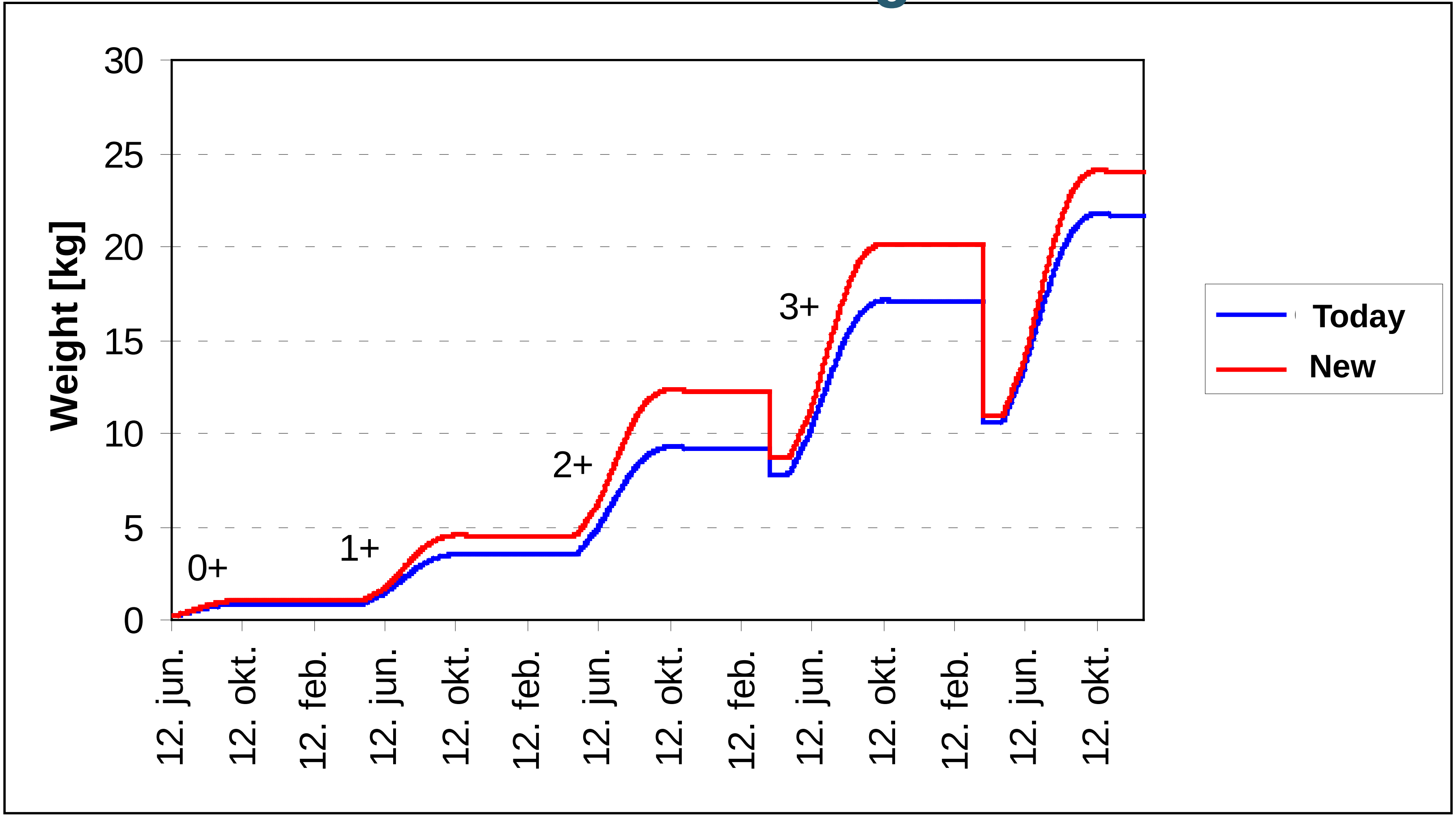


Water temperature in Surna downstream Trollheim power plant



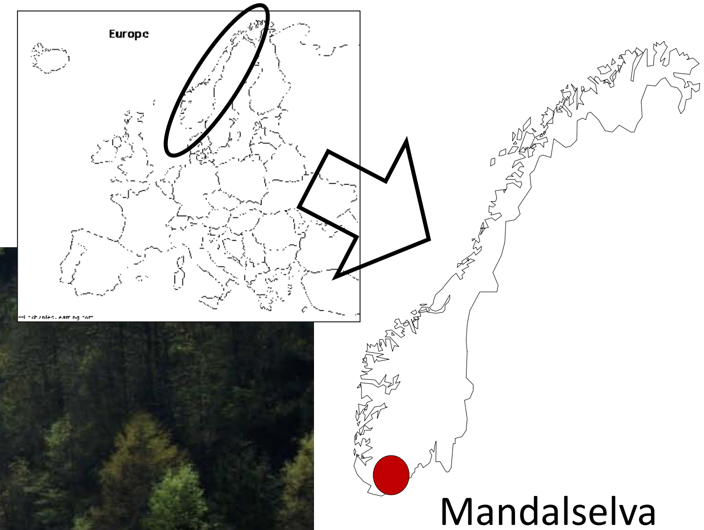
Lower intake is closed when upper intake available

Simulated fish growth



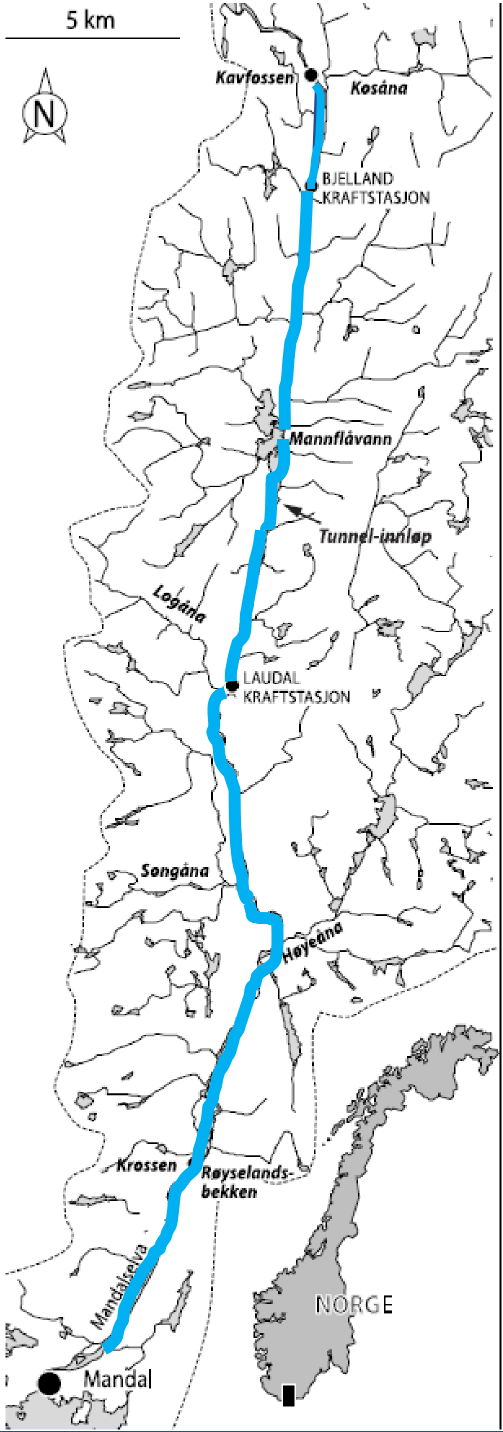
Mean smolt age reduced 0,16 – 0,36 years
Smolt production increased 12 – 18 per cent

Smolt migration
River Mandal



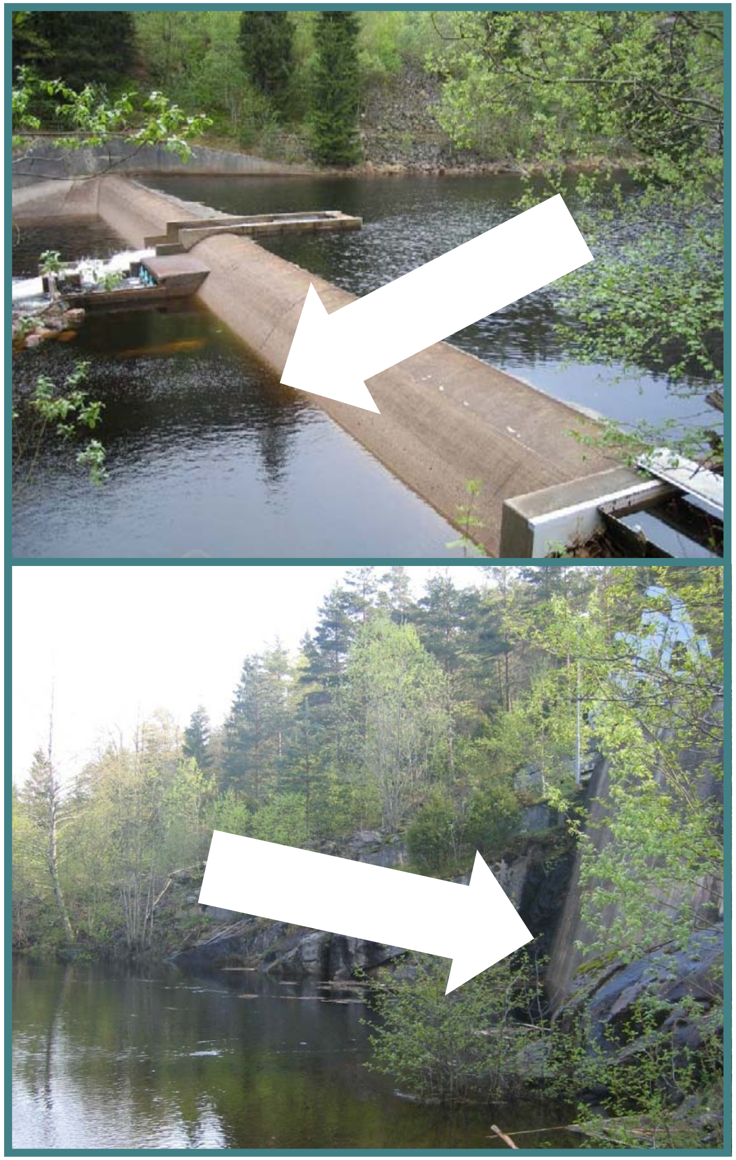
Torbjørn Forseth, Hans-Petter Fjeldstad, Ingebrigt Uglem
Knut Alfredsen & Thibault Boissy

The Mandal River



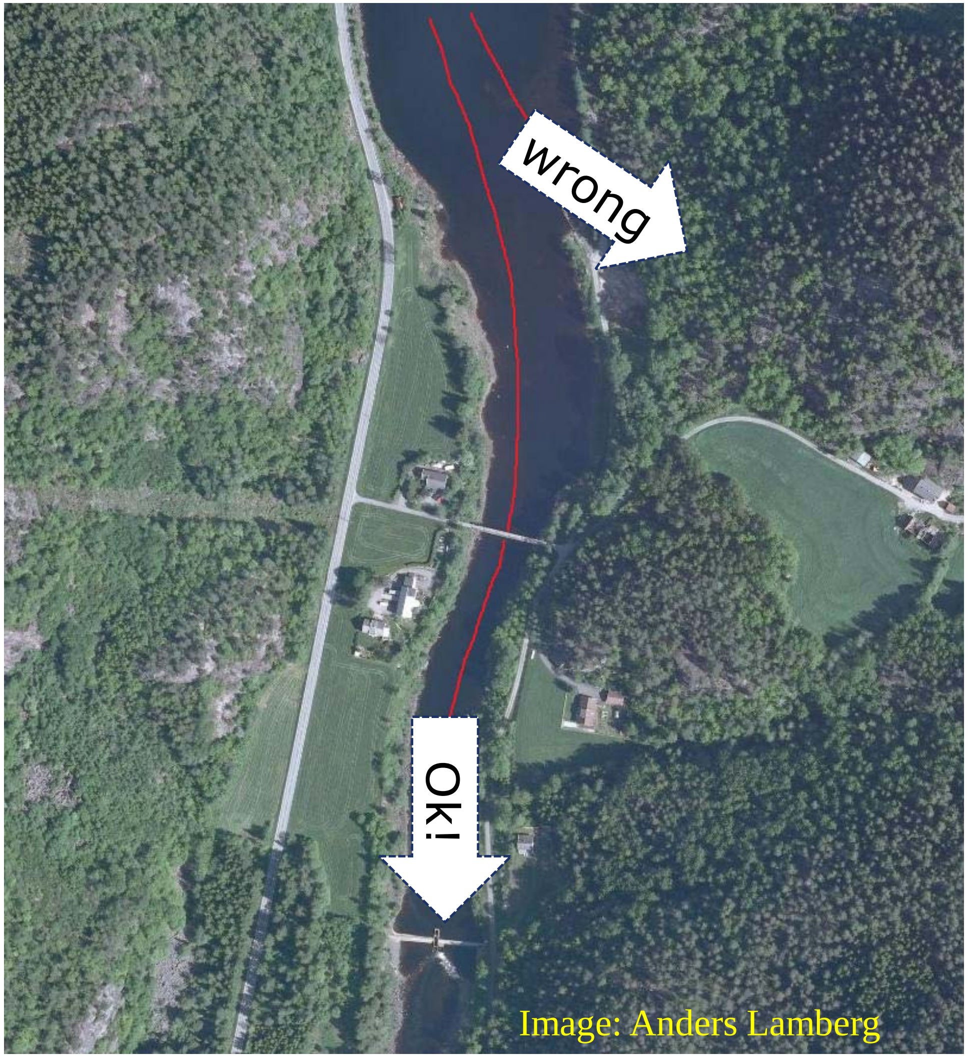
Challenge:

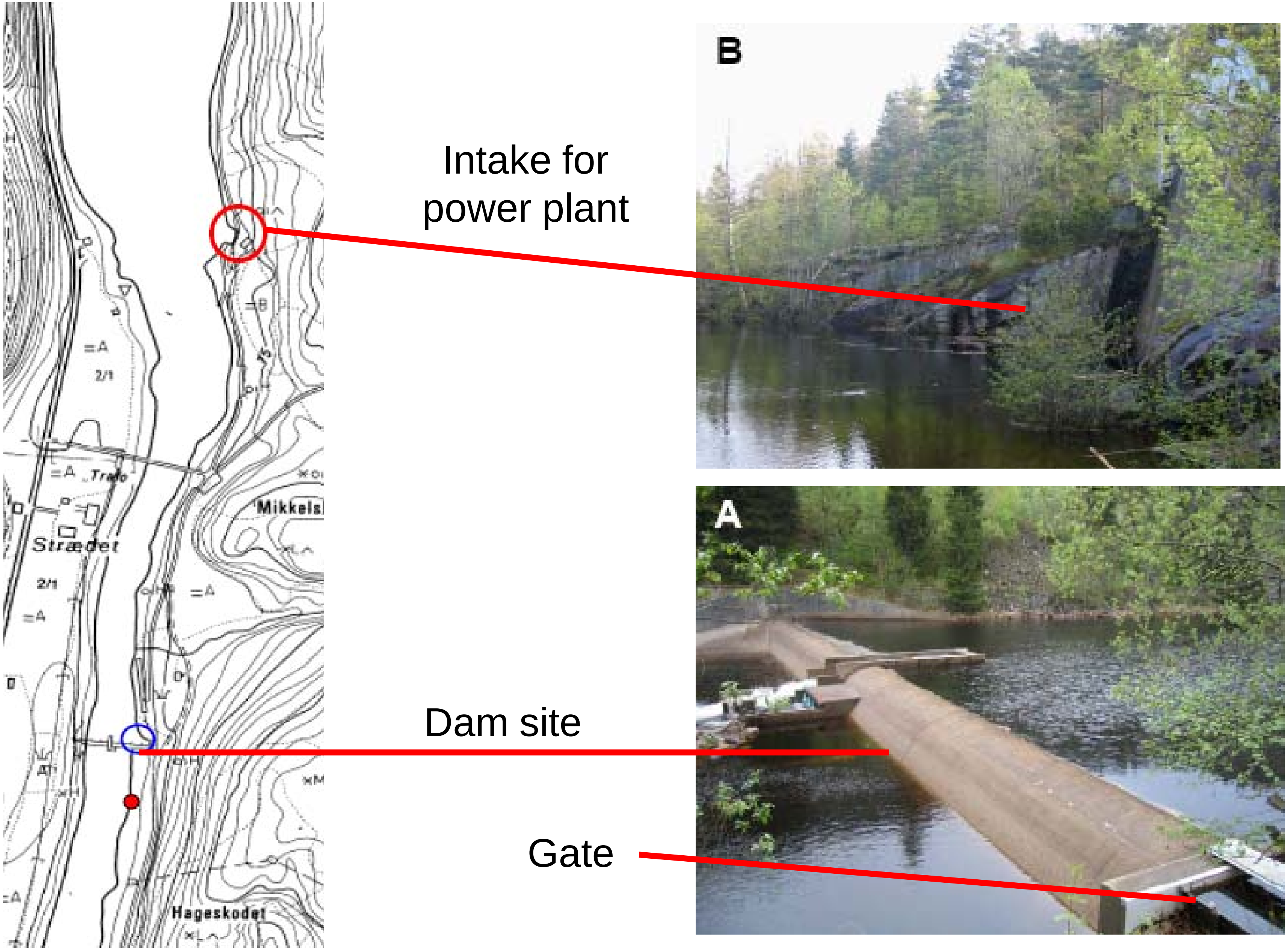
- Safe road:
  2003: 10%
  Goal: 90%



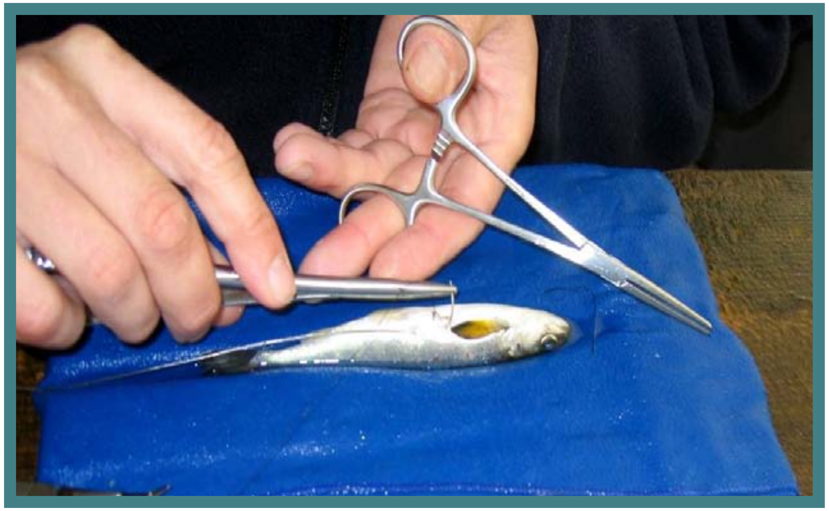
- Wrong route:

When do the smolts arrive and which route do they chose?

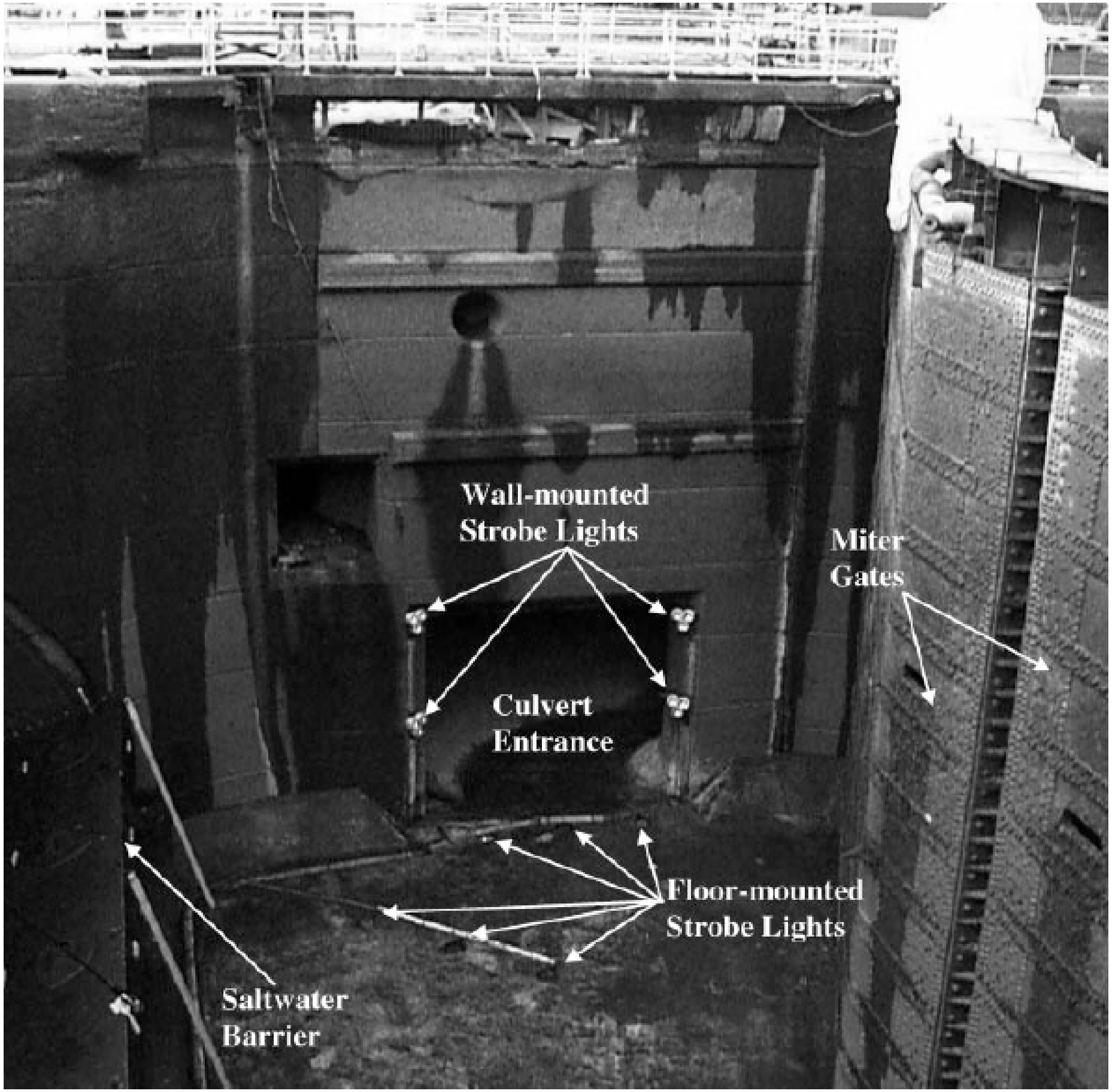



Intake for
power plant
B
Dam site
A
Gate
Trafo
Mikkels
Strædet
Hageskodet

Telemetry: 250 smolts (2003, 2004 and 2008)

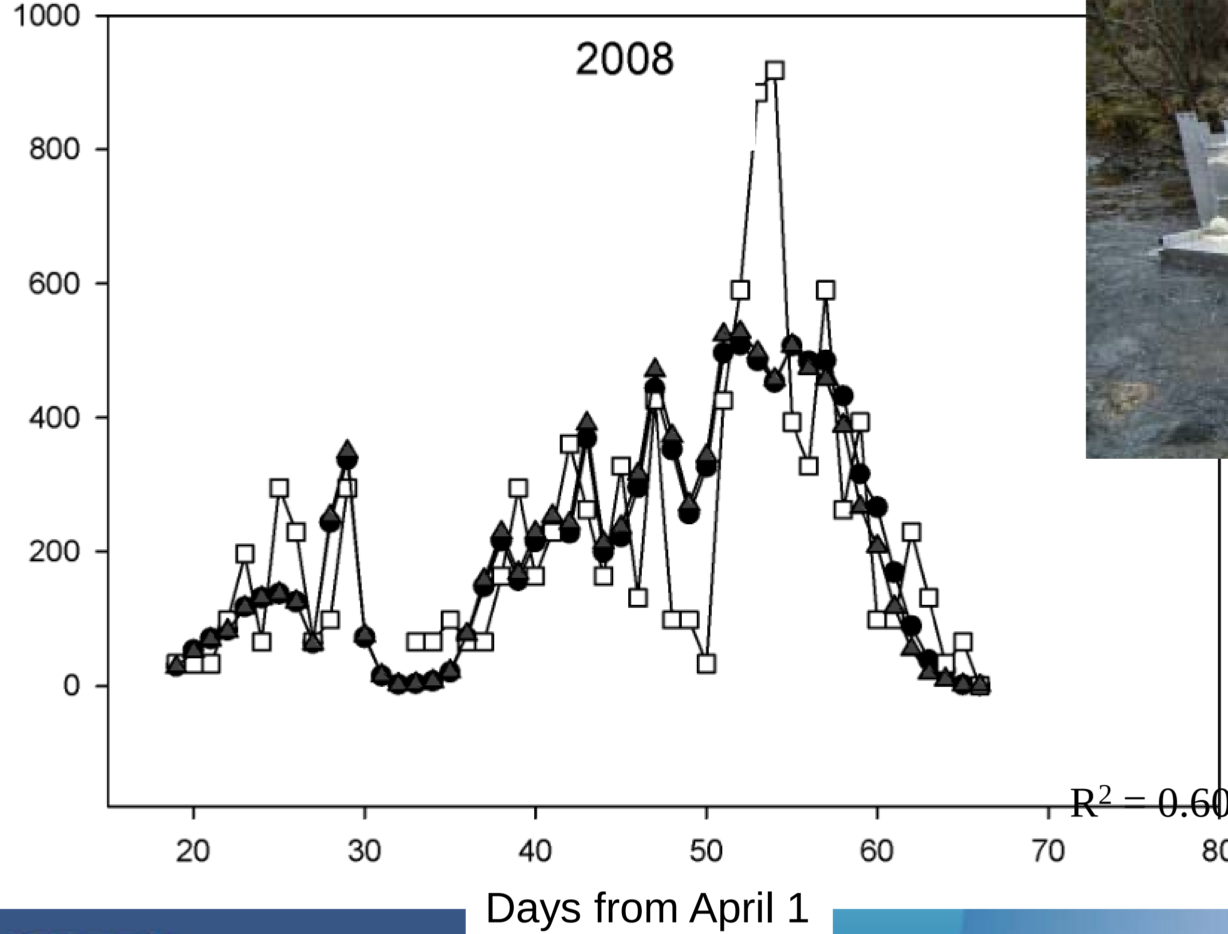


Impacts of strobe lights



Smolt timing model

$$\ln(Smolts) = \ln(MeanSmoltNumber) + Const + \beta_1 \times Tempsum + \beta_2 \times Temp + \beta_3 \times Tempdiff + \beta_4 \times Discharge + \beta_5 \times Dischargediff + \beta_6 \times \ln(Discharge) + \beta_7 \times \ln(Temp) + \beta_8 \times Days$$



Fjeldstad et al., 2012

Predictions from route model

Likelihood for bypass migration

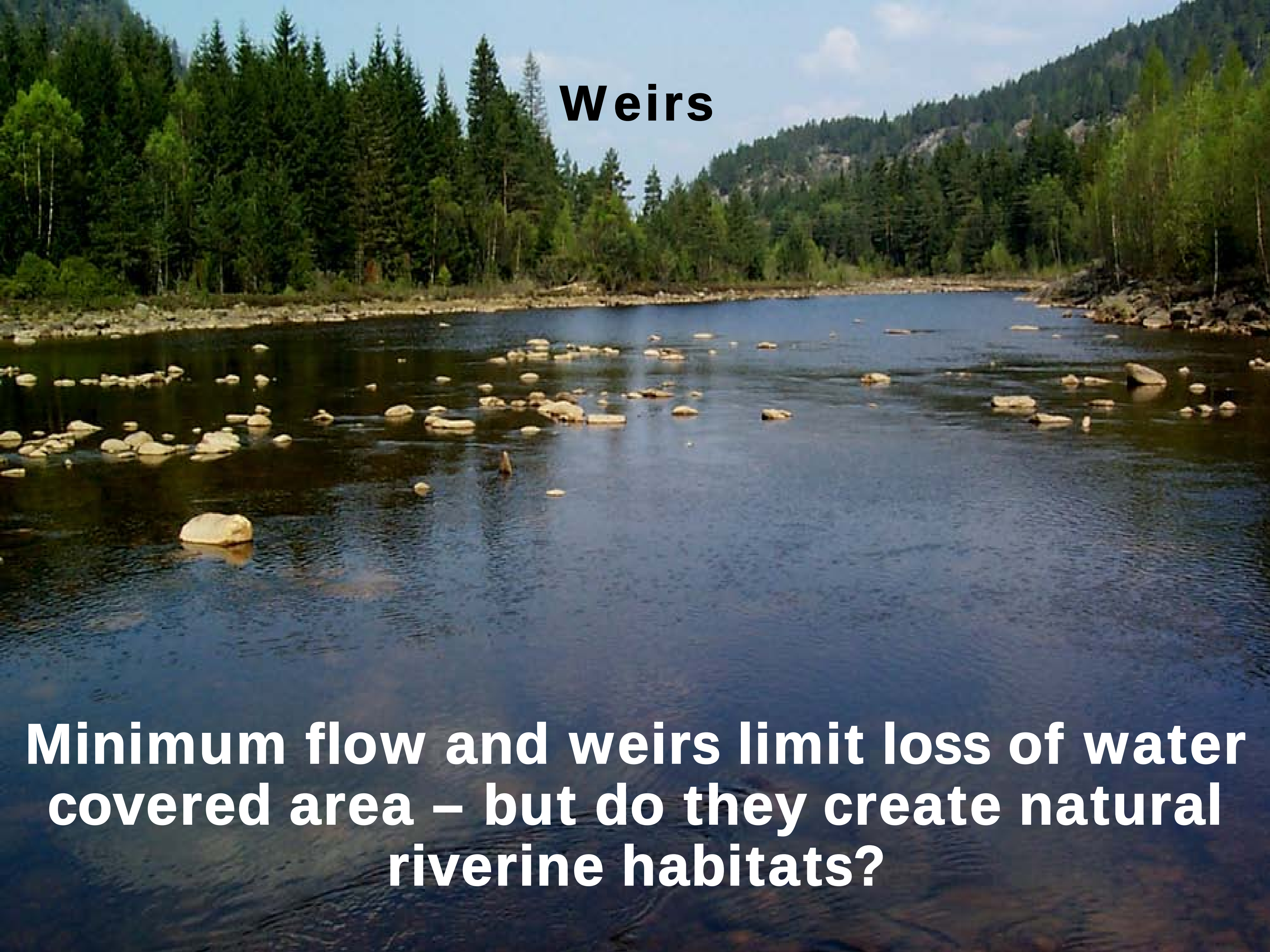
Proportion of total discharge in bypass (%)		Total discharge ($m^3 s^{-1}$)											
		20	30	40	50	60	70	80	90	100	110	120	130
	10	70	63	55	47	39	31	25	19	14	*11*	*8*	*6*
	20	76	70	63	55	46	38	31	24	19	*14*	*11*	*8*
	30	82	76	70	62	54	46	38	31	24	*19*	*14*	*11*
	40	86	81	76	69	62	54	46	38	30	*24*	*18*	*14*
	50	89	86	81	76	69	62	54	45	37	*30*	*24*	*18*
	60	92	89	86	81	75	69	61	53	45	*37*	*30*	*23*
	70	94	92	89	85	81	75	68	*61*	*53*	*45*	*37*	*29*
	80	96	94	92	89	85	81	*75*	*68*	*61*	*53*	*44*	*36*

Fjeldstad et al., 2012


2008:
• 96 fish tagged
• 61 migrated out from lake Mannflåvatn (64 %)
39 fish – 64 %
22 fish – 36 %

Fish stockings

- highly variable effect on the population
- recently promising results when stocking eggs


Weirs
Minimum flow and weirs limit loss of water covered area – but do they create natural riverine habitats?


Mitigation by constructing habitat in combination with compensation flows
CAT
CAT
320C
CAT


Weirs, diverters, artificial pools and riffles, substrate changes, etc
- must be maintained

The Building Block Method

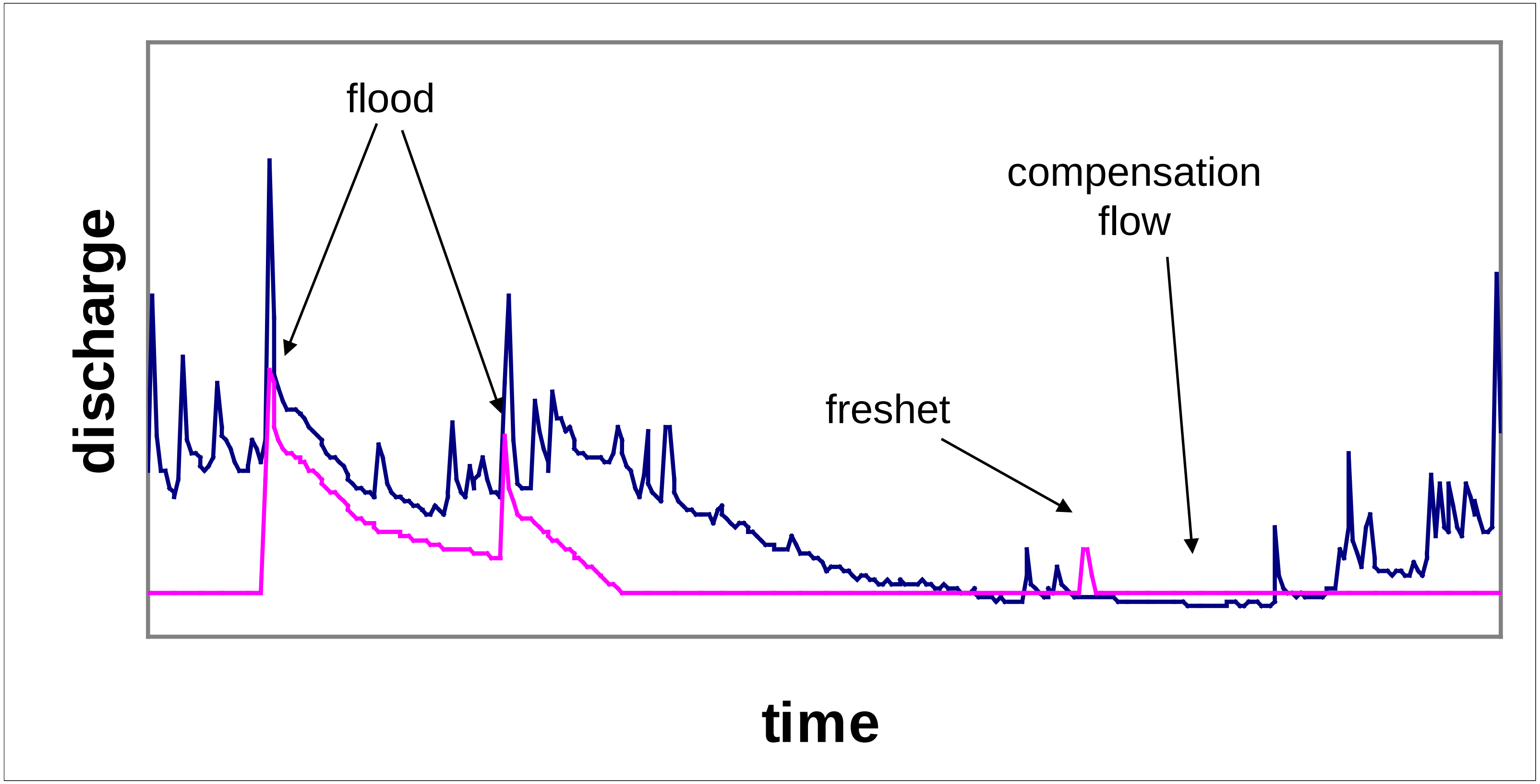


Figure 1. Natural (blue) and regulated (pink) flow regimes downstream of a hypothetical water supply reservoir.

From Acreman et al - Environmental flow releases from impoundments for WFD – draft October 2007

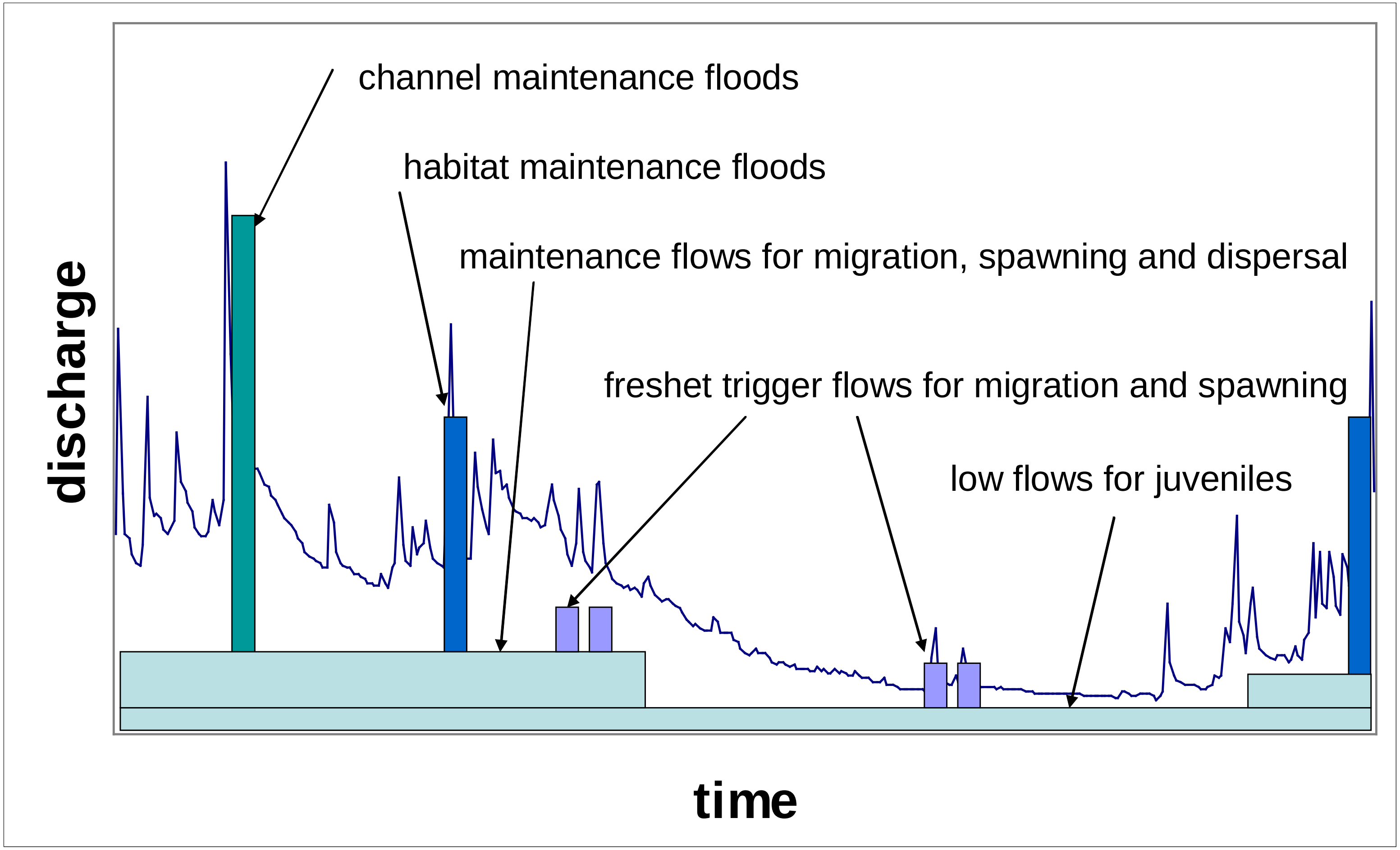
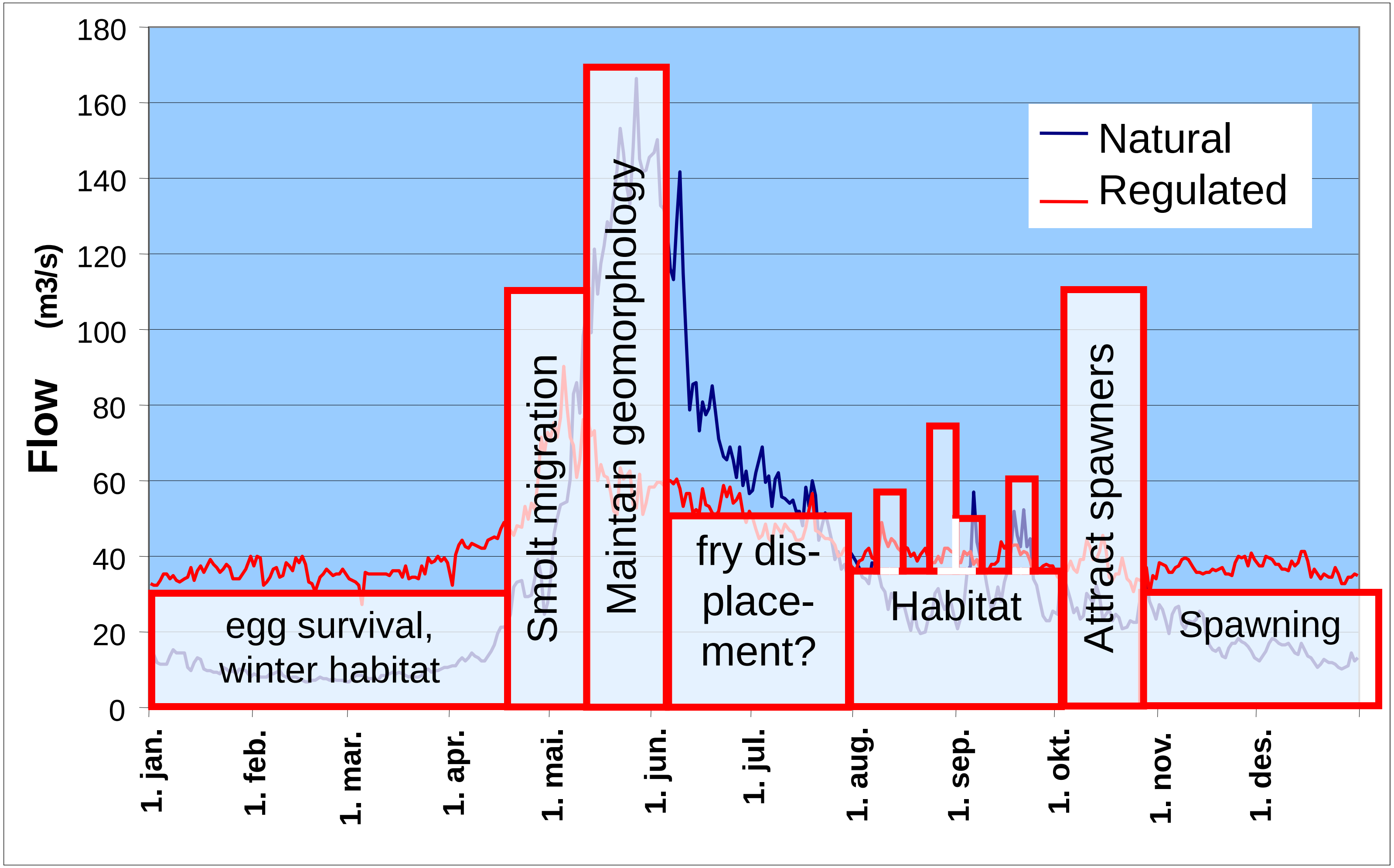


Figure 3 Building block Methodology – conceptual approach

From Acreman et al - Environmental flow releases from impoundments for WFD – draft October 2007

Seasonal requirements



Increased energy demand?

Sustainable?


Lack of undisturbed nature?


Lack of undisturbed nature?
Perfect for hydropower


….thank you for your attention!