Application of hydro power scheduling models for environmental design

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Contents

- The Norwegian hydro power system
- Hydro power scheduling models
- The Sira-Kvina hydro power system
- The Atlantic salmon in the Kvina river
- Integrating different environmental requirements in hydro production planning

Norwegian hydropower

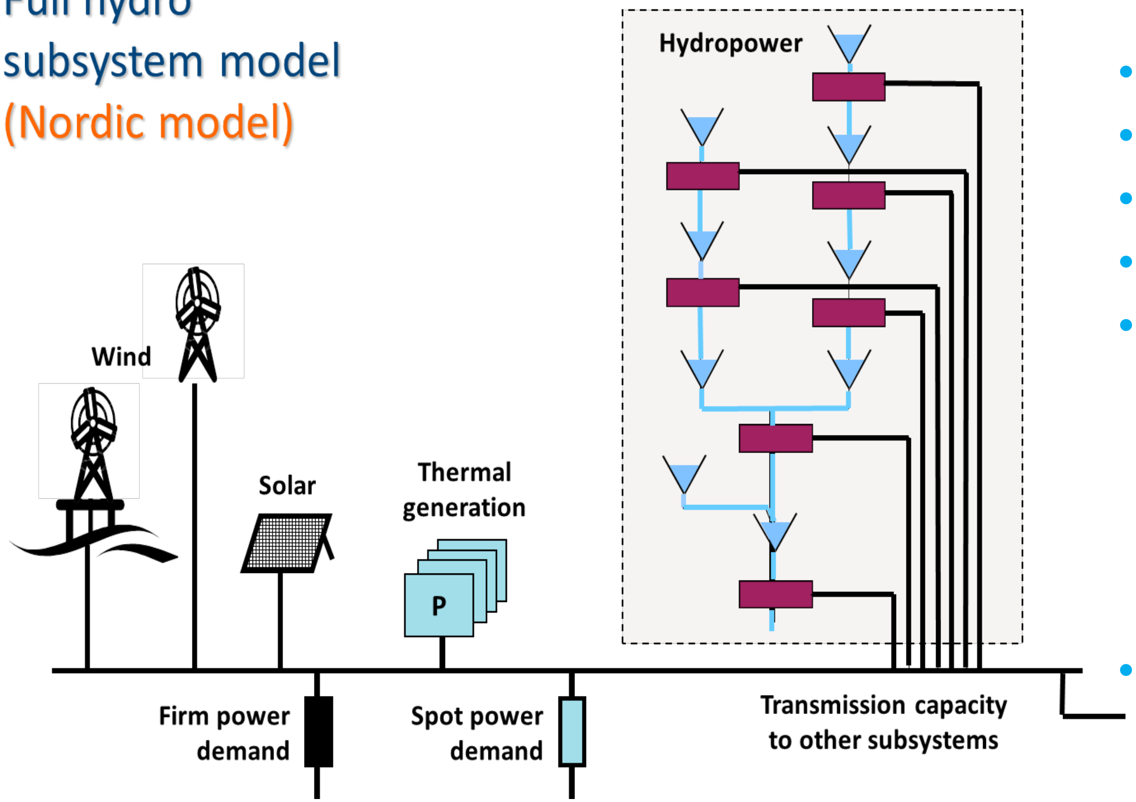
- *Produces 99 % of Norwegian electricity consumption (125 TWh, 1200 plants)*
- *70 % of Norways large rivers are regulated*
- *30 % of Norwegian salmon rivers are regulated*
- *In 2004, 42 % of national fishery yields came from regulated rivers*

Sources: NVE, 2011 &
Anon. 2011. (Status for norske laksebestander i 2011)

EMPS/Samkjøringsmodellen : A stochastic fundamental market model with hydro optimization

- Strategy for aggregate hydro models – Simulates detailed hydro

Full hydro subsystem model (Nordic model)



Features:

- Flexible demand modelling
  - Gradual adaptation to price
  - Optimizing adaptation
- Thermal unit start-up costs
- Reserves
- Wind power
- Parallel processing
- Advances in time resolution
  - Sequential blocks of hours per day
  - Daily inflow
  - Hourly wind power data
  - Daily pumped storage
  - Automatic calibration
- Detailed grid with load flow model
  - EPF/Samlast

The European Multi-area Power Market Simulator EMPS

Current EU model has 55 nodes/96 connections for 37 countries plus offshore nodes

Production units

- 10 thermal power plant types: Nuclear, oil, coal, gas etc
- CCS implemented in coal, gas and biomass
- RES plants deterministic: Biomass, geothermal
- RES plants stochastic: Hydro, wind, solar, wave
- 75 years of wind, solar and hydro resources simulated

Consumption

- Price dependent consumption per year from statistics, projected to a future year (2020-2050)
- 5-8 demand levels per week

Hydro power

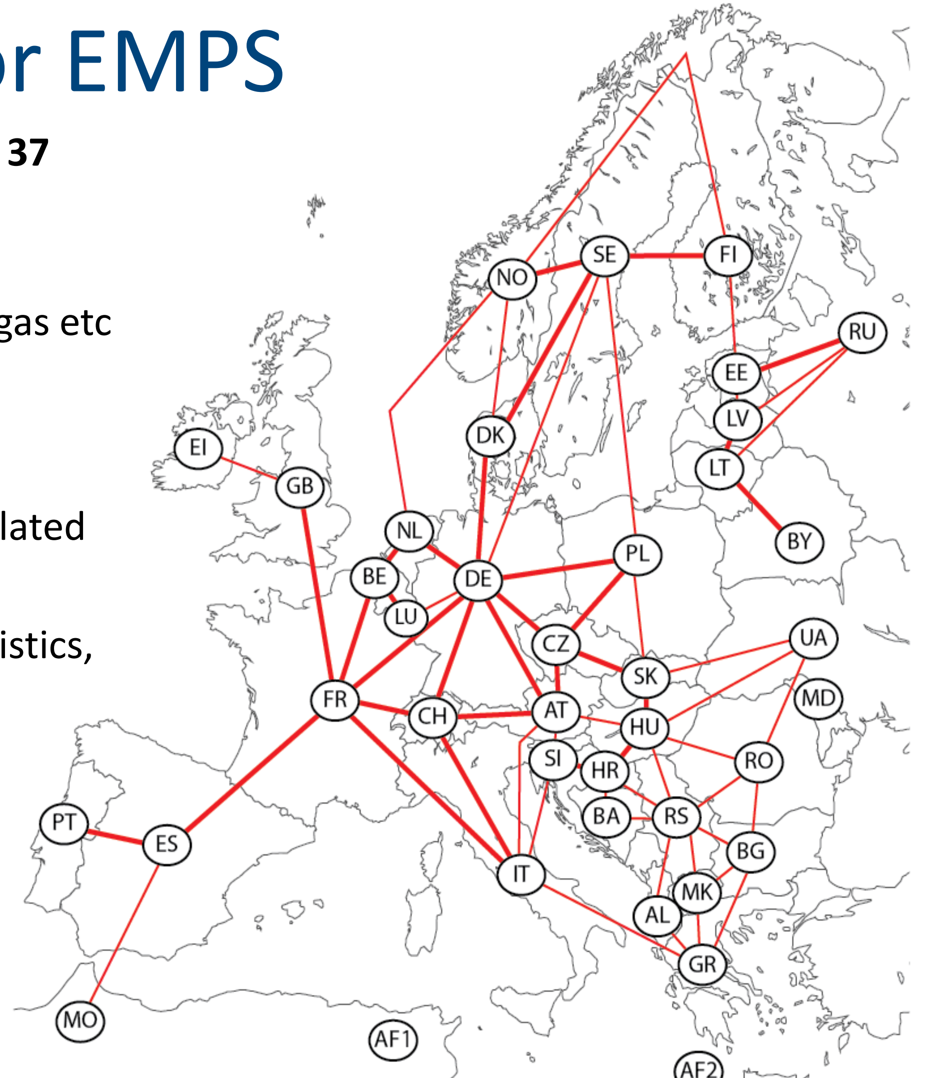
- Reservoir, Run-of-river, Pumped storage

Wind power

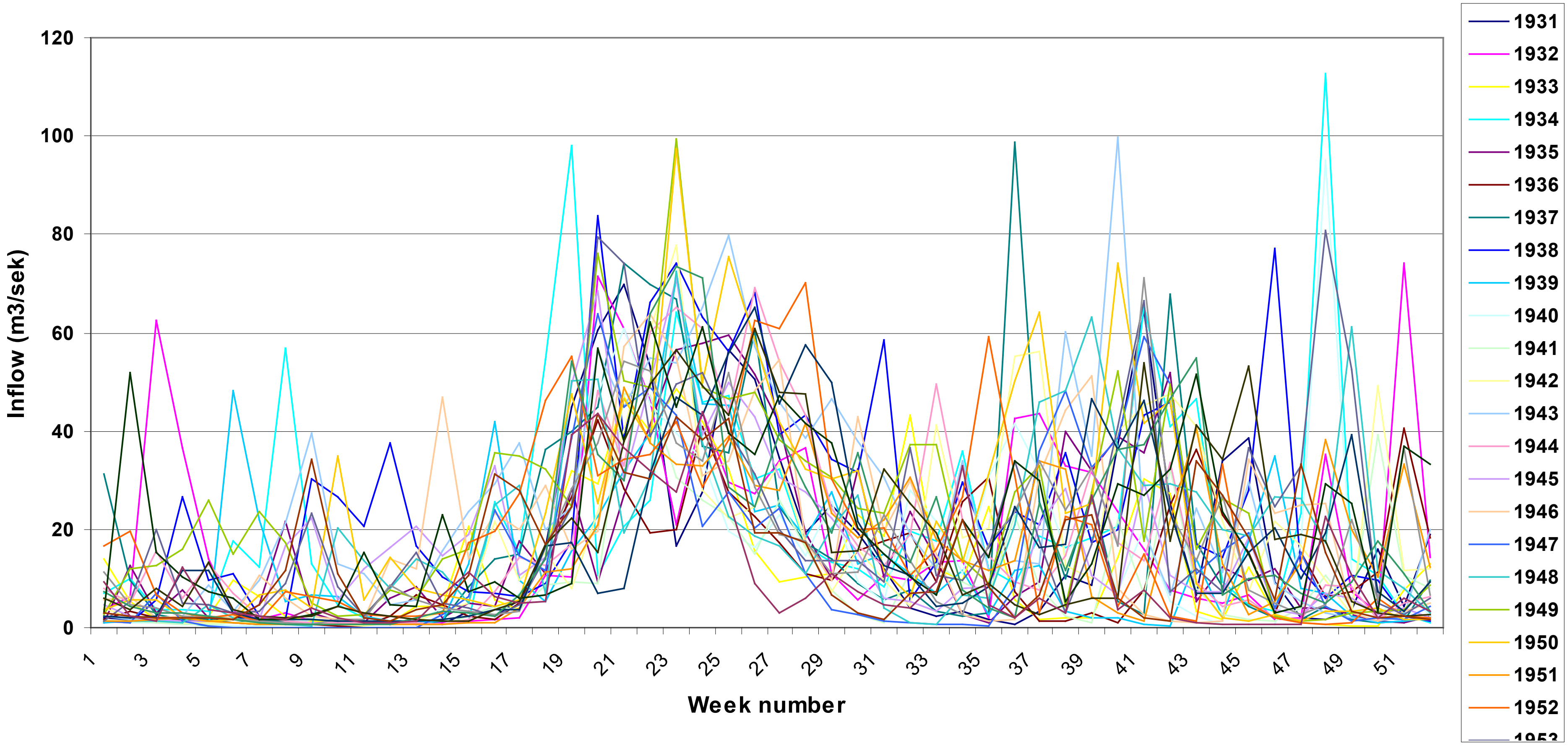
- Divided into onshore and offshore wind farms

Solar power

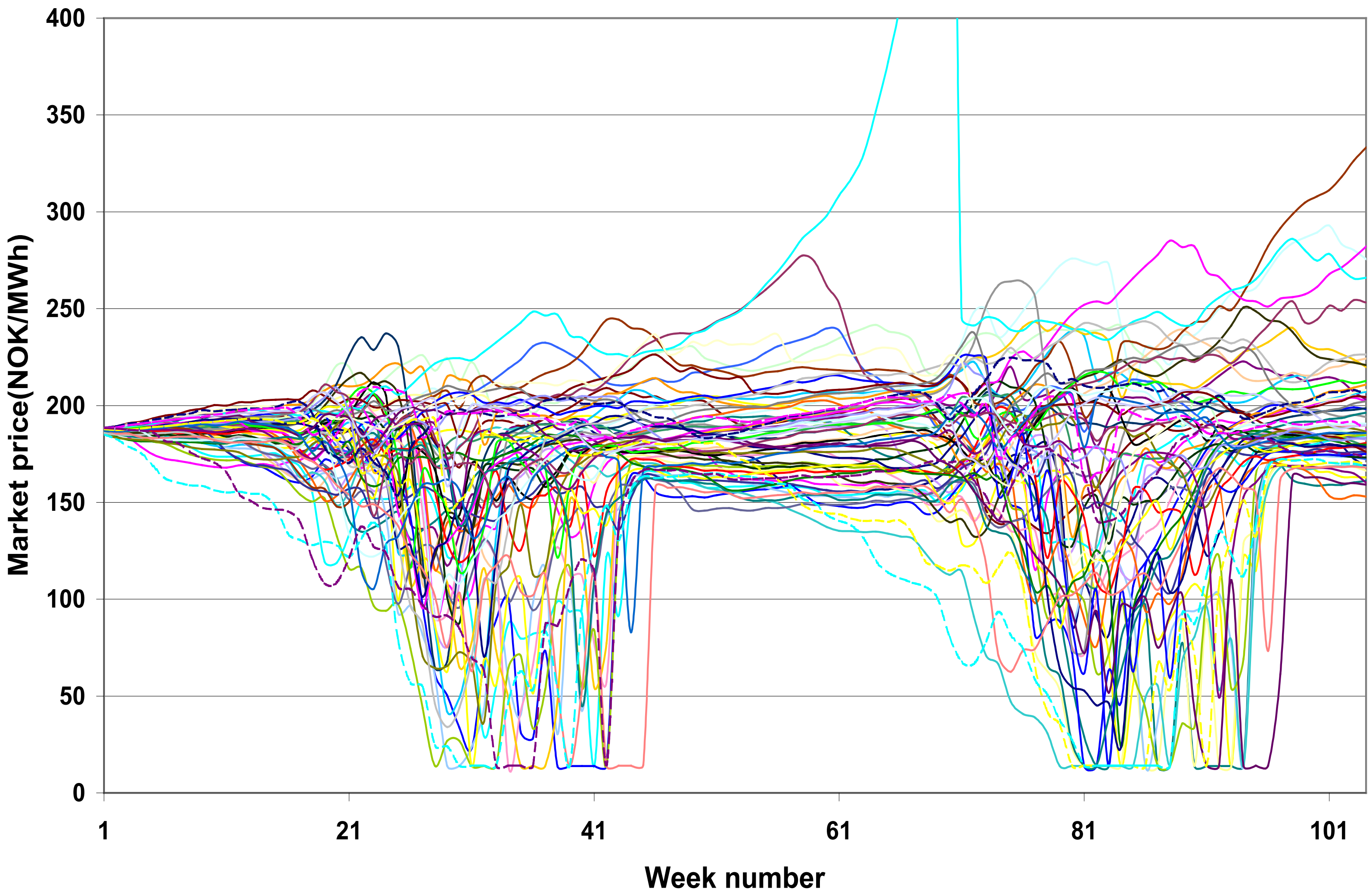
- Aggregated capacity of PV and CSP



Set of inflow scenarios for a given climate



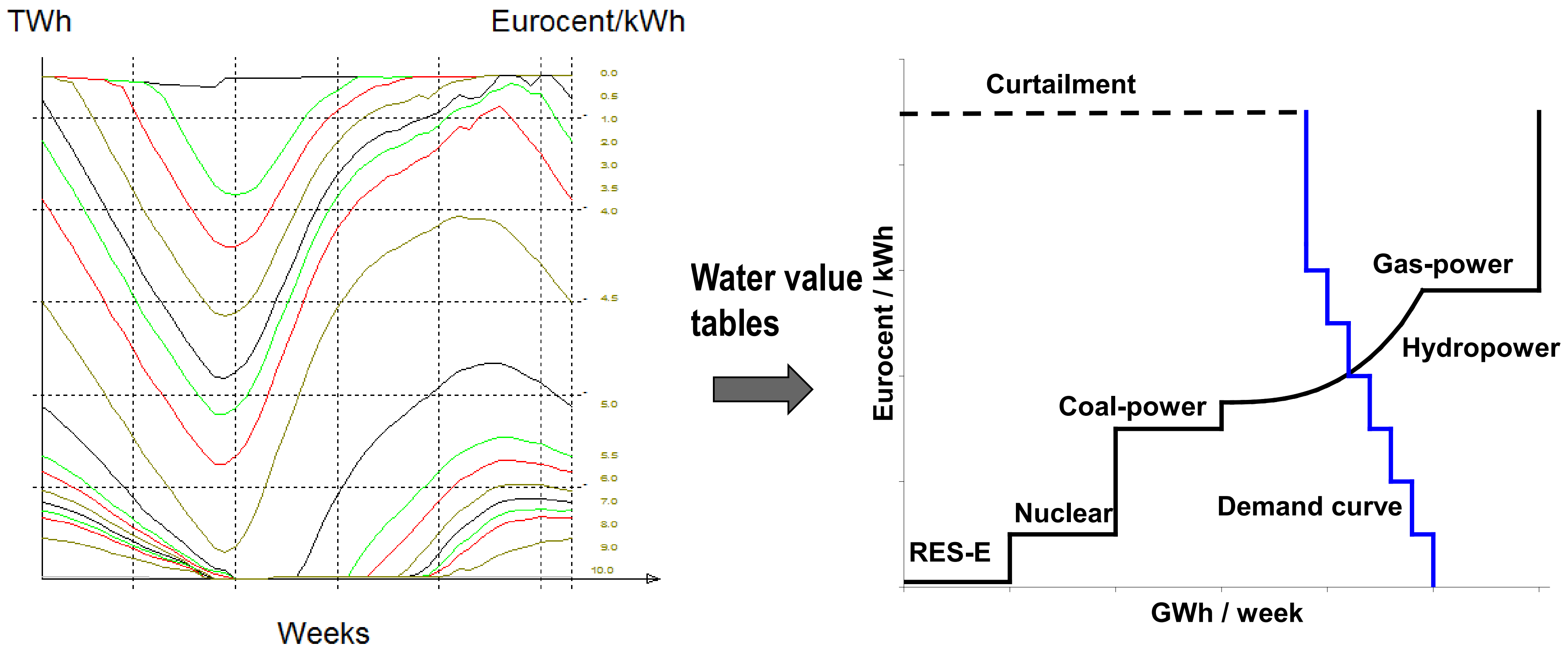
Spot price forecast from the EMPS model



EMPS model: Optimization and simulation

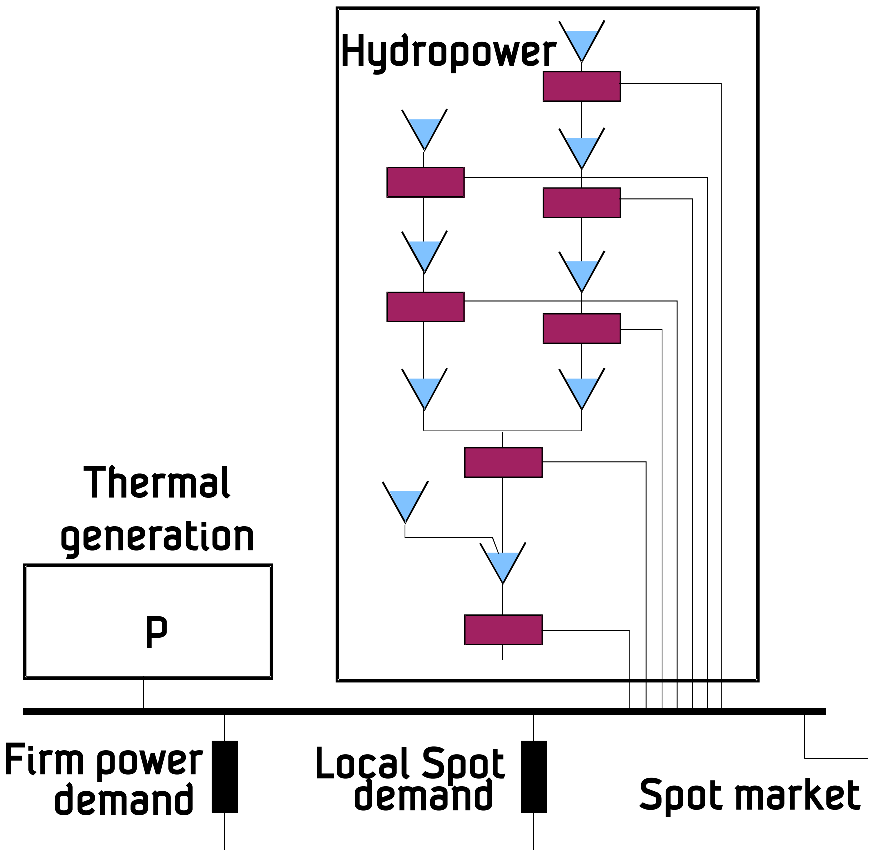
Strategy hydro reservior calculation (SDP)

System/market simulation (LP)



ProdRisk: Local Long and Medium Term Planning

- Exogenous stochastic market prices, endogenous market and combinations



ProdRisk

Stochastic optimal scheduling

- SDDP solution algorithm – Optimization of detailed hydro system
- Supplement to EOPS/Vansimtap
- May include utility functions, futures trading
- Ideal for scheduling generation, maintenance
- Provides endpoint water values for short term scheduling
- Time consuming – Parallel processing used
- Flexible time resloution
- Flexible use of penalties
- Investment analysis

The ProdRisk model

- Optimization model for mid-term scheduling
  - Calculates optimal strategy using detailed hydraulic description
  - Simulates consequences of following that strategy, using available weather (inflow, temperature) and price forecasts
  - Solution technique: A combination of Stochastic Dual Dynamic Programming (SDDP) and Stochastic Dynamic Programming (SDP)
  - Data model basically equivalent to one subsystem in the EMPS model
  - Market price externally given as price forecast
- Some attributes
  - Time resolution: Week or price segments within the week
  - Stochastic inflow and market price
  - Head included in the optimization through coefficients
  - May include dynamic hedging and risk aversion
  - Profit forecasts
  - Provides end-point water values readily used by short-term model

The Atlantic salmon life cycle

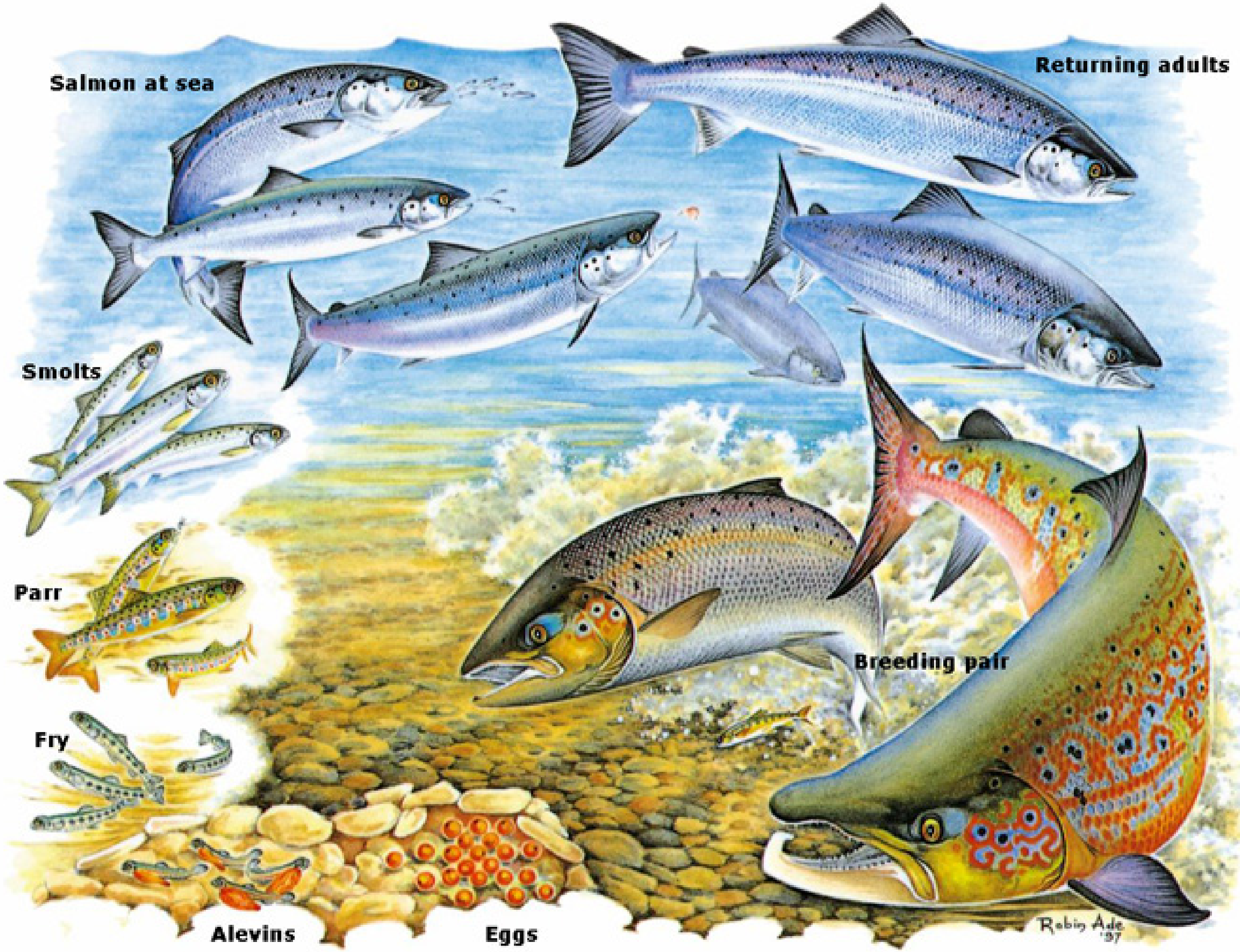


Illustration: NASCO

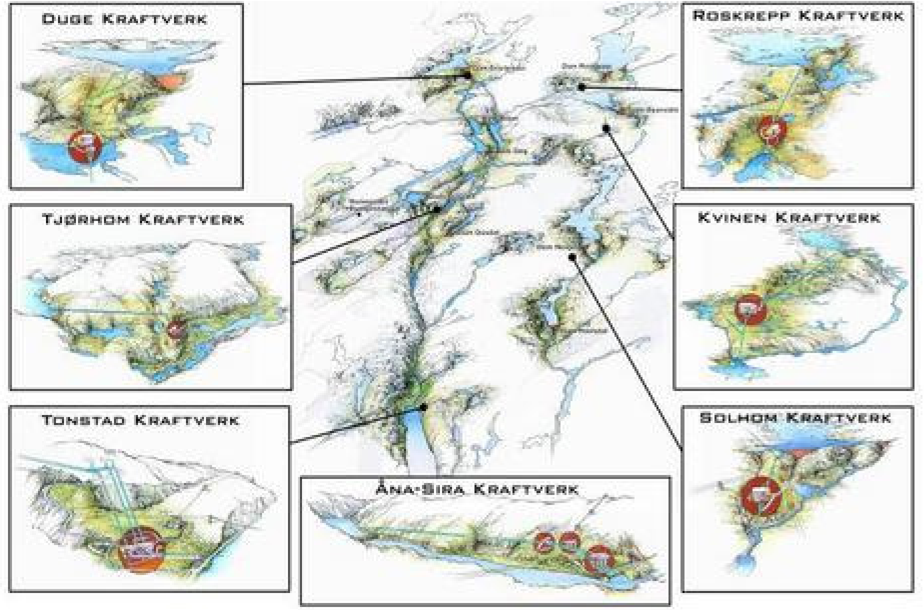
Reduced salmon populations as a result of hydropower regulations

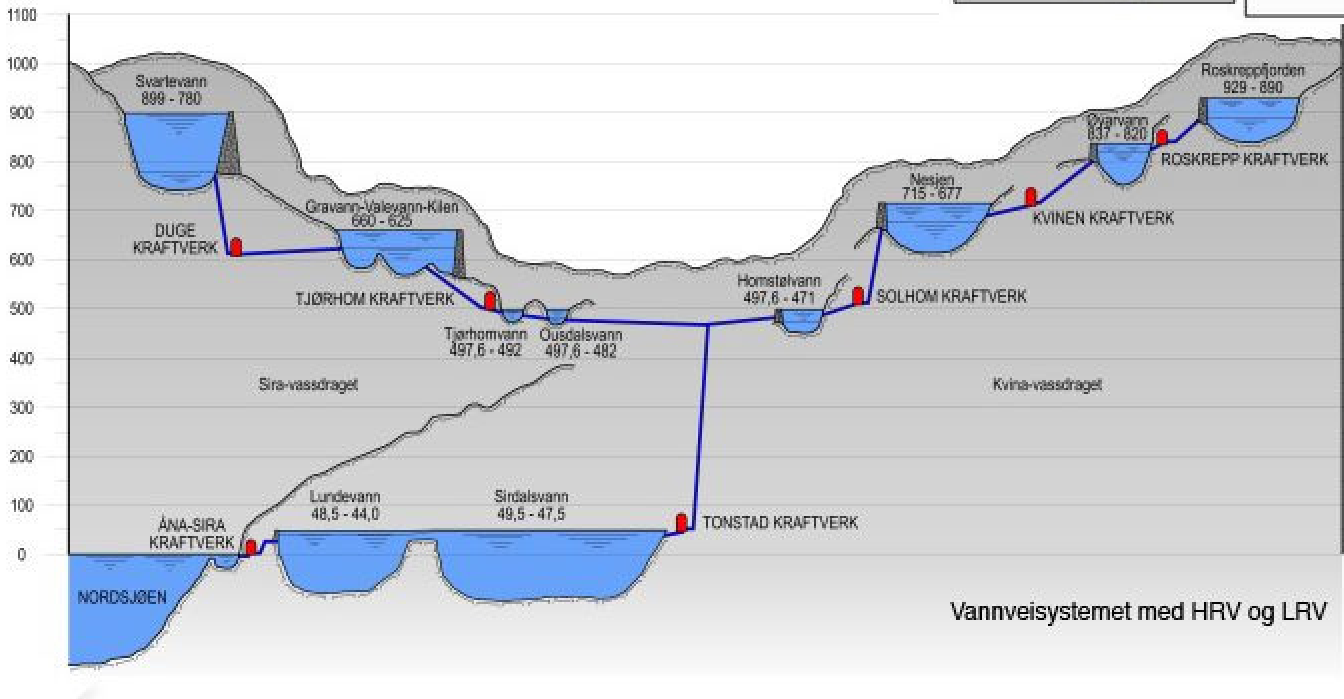
- Most important reason for population reduction in Norwegian rivers (n = 83, 19 % of the salmon rivers of totally 435 populations and negative effects in many others)

Extirpated	**19**
Threatened/vulnerable	**16**
Reduced juvenile densities	**38**
Moderate impacts	**10**
<u>Total</u>	**<u>83</u>**

Norwegian Directorate for Nature Management, 2011

The Sira-Kvina hydro power system





The Sira-Kvina hydro power system

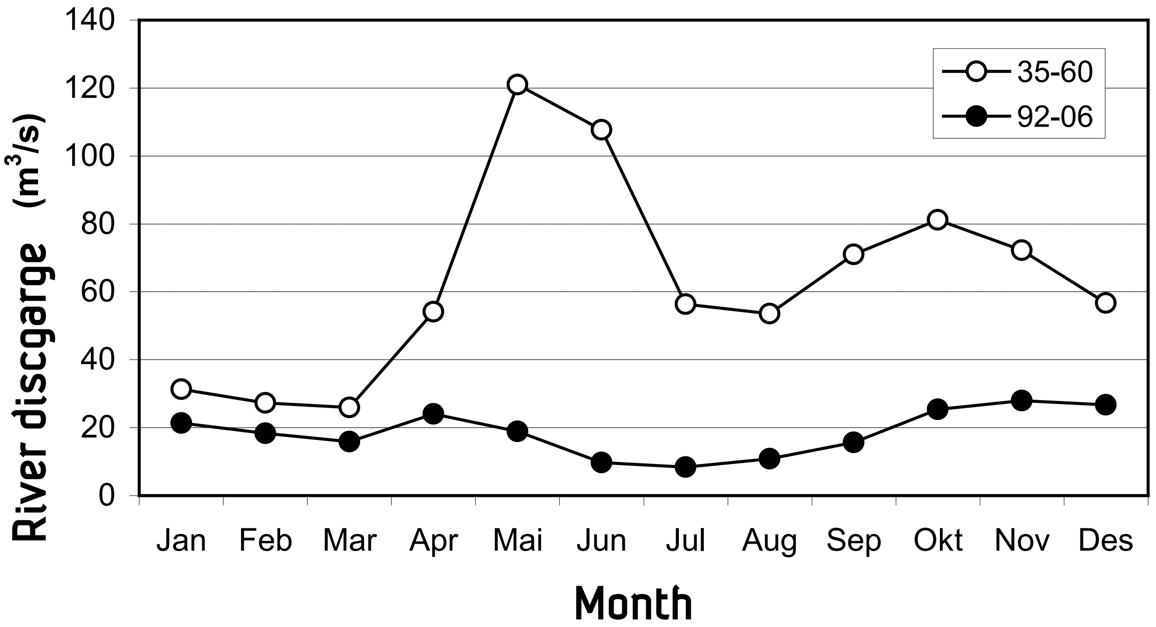
- Operates 7 hydropower plants with respective reservoirs and infrastructure

- Tonstad: A total installed capacity of 960 MW with 4 units, each 160 MW, and one unit at 320 MW, all equipped with francis turbines. Annual production of approximately 3,800 GWh, it is the largest power station in Norway with respect to annual production (per 2006)

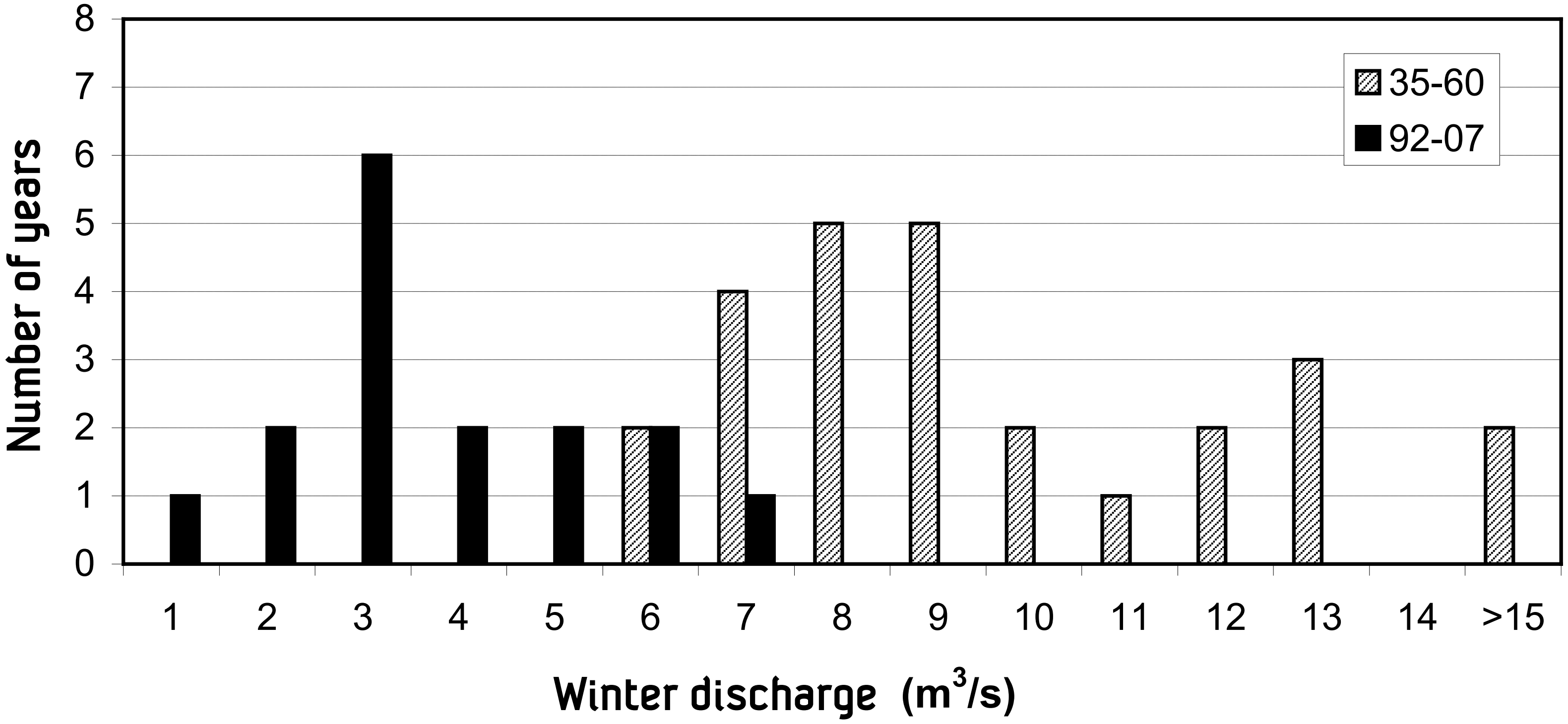
- Total production approx. 6 TWh, total installed capacity of 1760 MW

Present situation

- Almost 70 % of the Kvina runoff is diverted to the Sira catchment
- Run-of-river power plant in the middle of the salmon reach
- Smolt production estimated to be reduced from 36 000 to 16 000 (= loss of 20 000)
- Main causes: reduced winter discharge, degraded juvenile and spawning habitats



Changes in lowest weekly winter discharge



Sustainable hydropower:

- Power production which allows for the existence of a healthy/viable salmon population, acknowledging natural fluctuations

Photo: SINTEF Energy

Photo: Anders Lamberg

Future extension of the Kvina hydro power system

- Diversion of two additional tributary catchments (500-900 masl) to Sira(123 GWh)

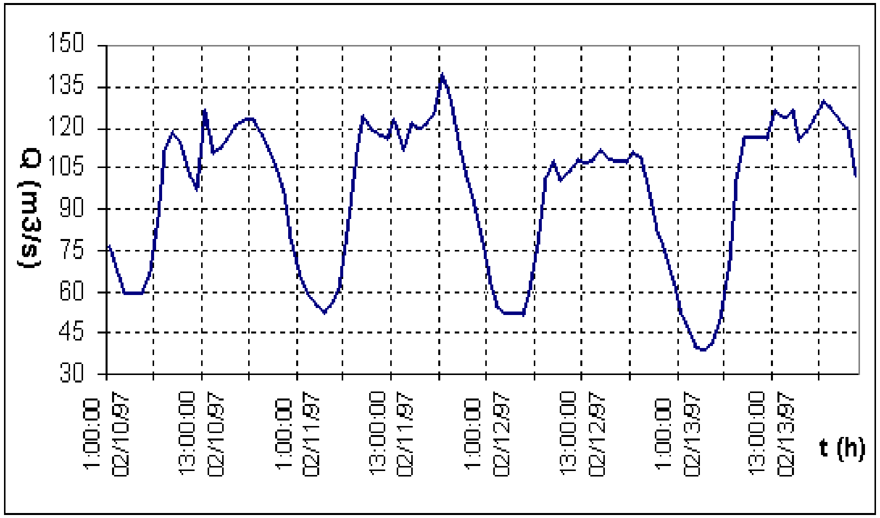
- Increased diversion of water from 69,5 to 74 %

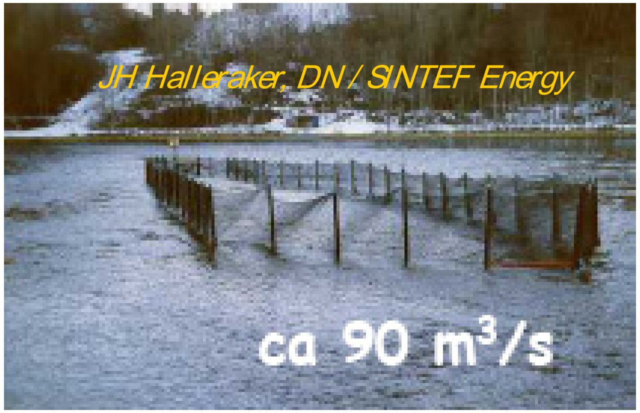
- Allocation of a "water bank" as compensation of diverted runoff according to suggestions from an environmental analysis

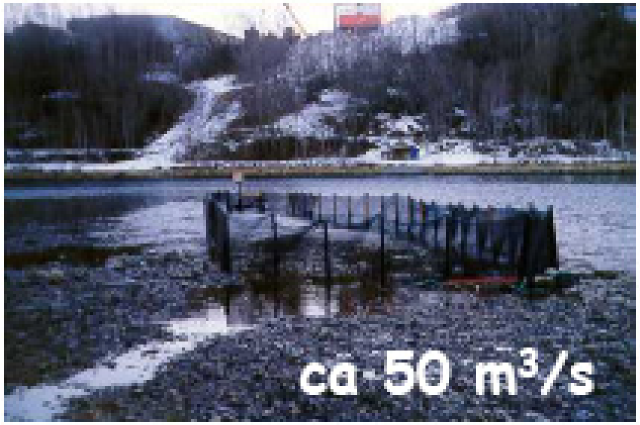
- One new run-of-river power plant at the present migration barrier, including a new fish ladder to extend the anadromous reach. The power plant is designed to produce power from the "water bank"

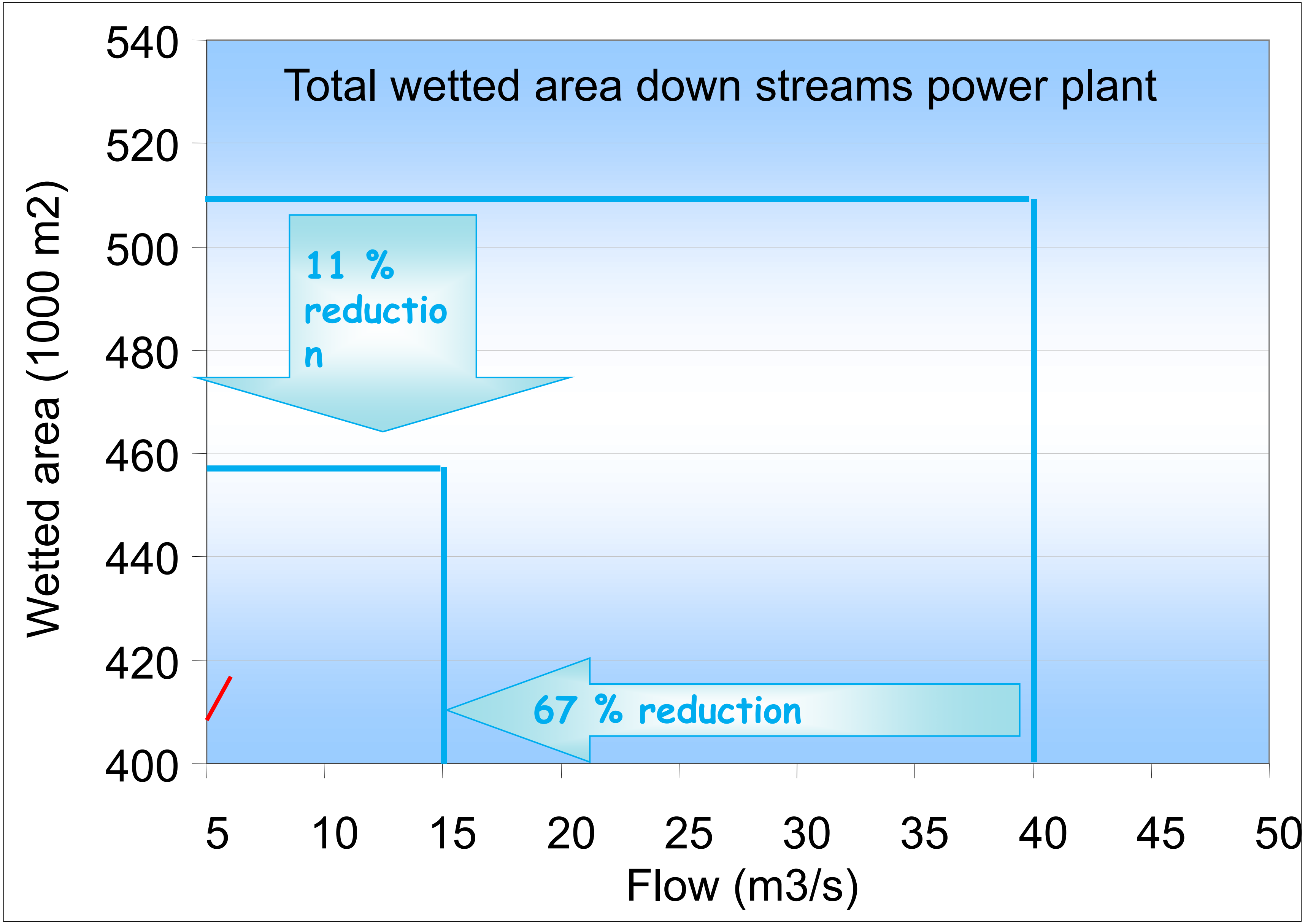
Flow variations

- *Seasonal production variation*
- *Daily production variation (peaking/balance)*

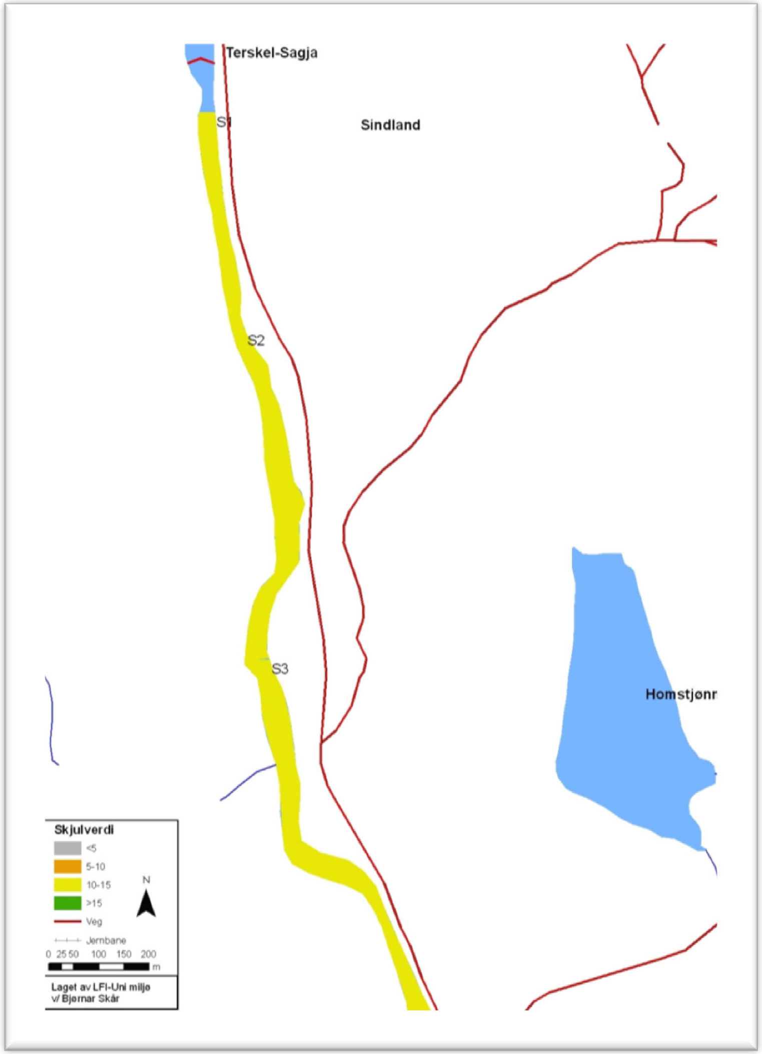


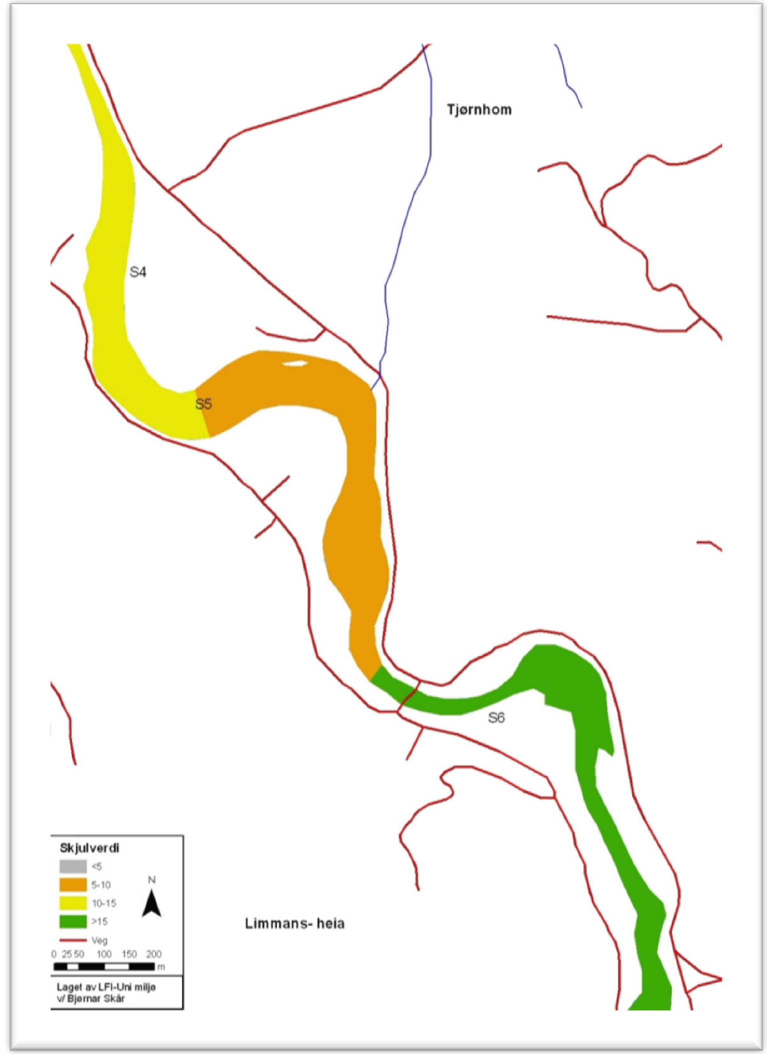




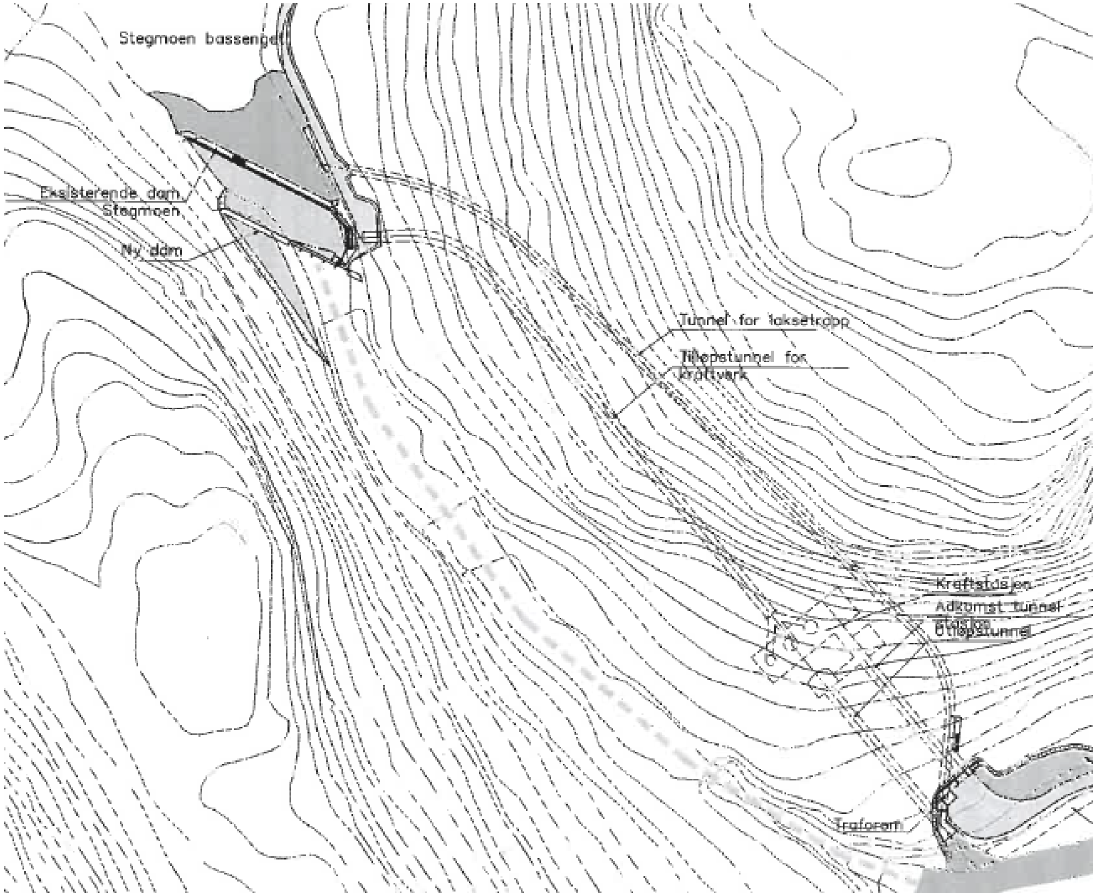

Total wetted area down streams power plant
Wetted area (1000 m2)
540
520
500
480
460
440
420
400
11 %
reductio
n
67 % reduction
5
10
15
20
25
30
35
40
45
50
Flow (m3/s)

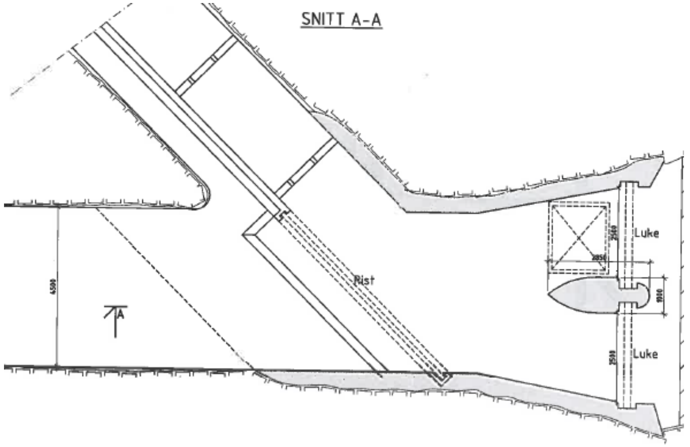
Spatial distribution of shelter for juvenile salmon





New salmon fishways

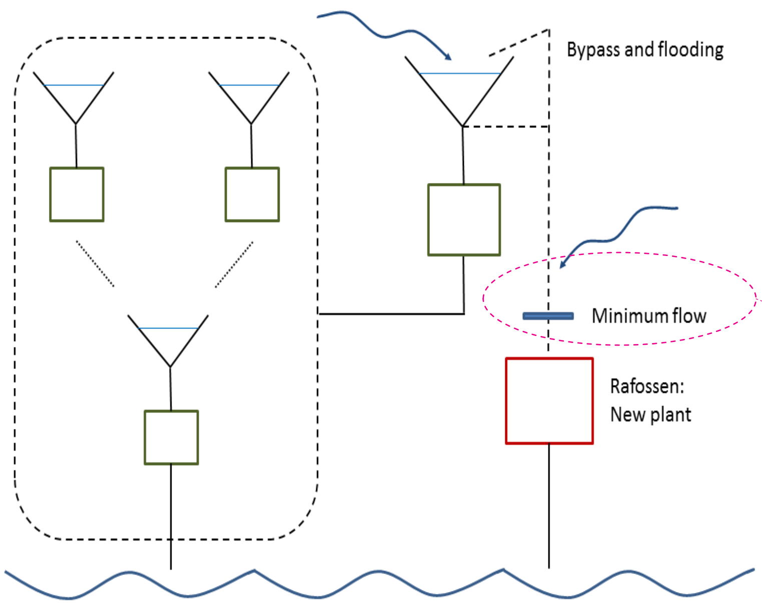


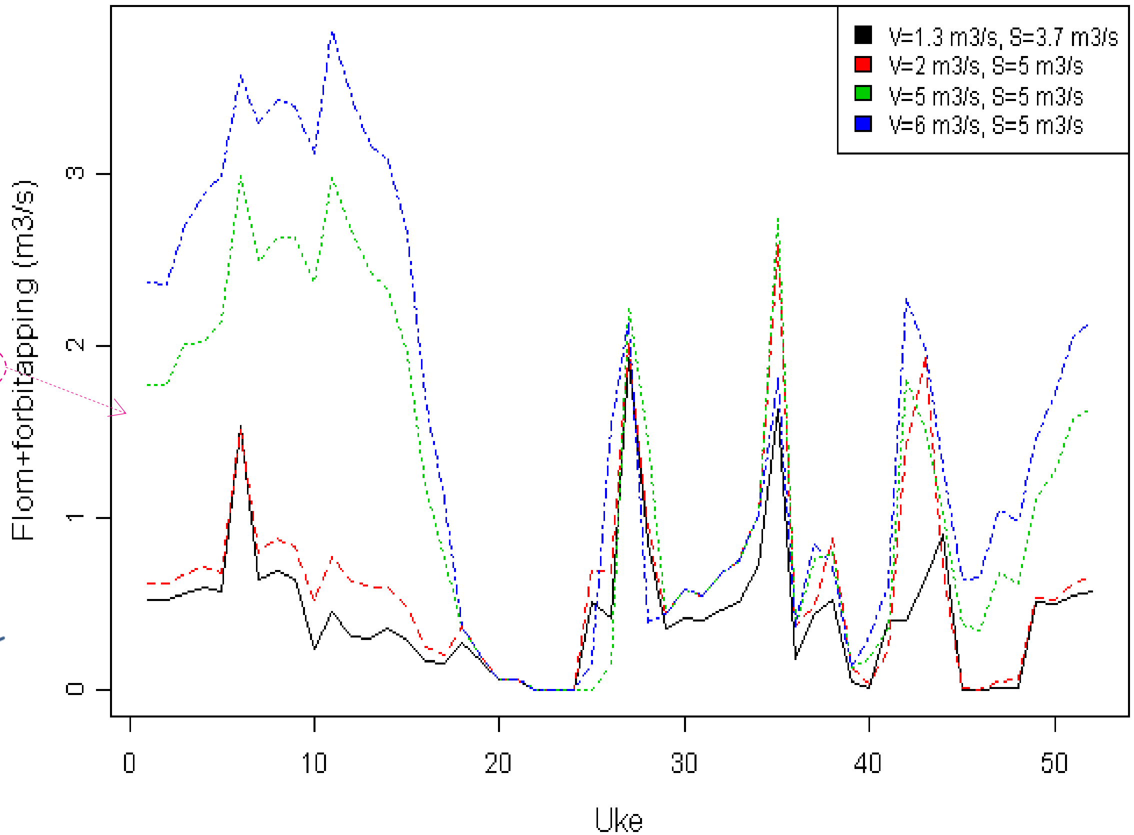


"Water bank" – water use

	Vintervannføring		Sommervannføring		Smoltslipp		Fiskeslipp		Sum slipp	
	Forslag (m^3/s)	Mm^3	Forslag (m^3/s)	Mm^3	Forslag[#]	Mm^3	Forslag (m^3/s)[$]	Mm^3	Mm^3	% av vannbank*
Inkludert gammelt slipp										
Alt. 1	3	1,283	4	0,093	+30x48	0,348	15x2x3	1,777	3,501	3,5 %
Alt. 2	5	7,248	5	1,379	+30x48	0,348	15x2x3	1,777	10,752	10,8 %
Alt. 3	6	12,114	5	1,379	+30x48	0,348	15x2x3	1,777	15,618	15,7 %
Alt. 4	6	12,114	6	5,110	+30x48	0,348	15x2x3	1,777	19,349	19,4 %
Alt. 5	7	18,179	10	28,412	+30x48	0,348	15x2x3	1,777	48,716	48,8 %
Ekskludert gammelt slipp										

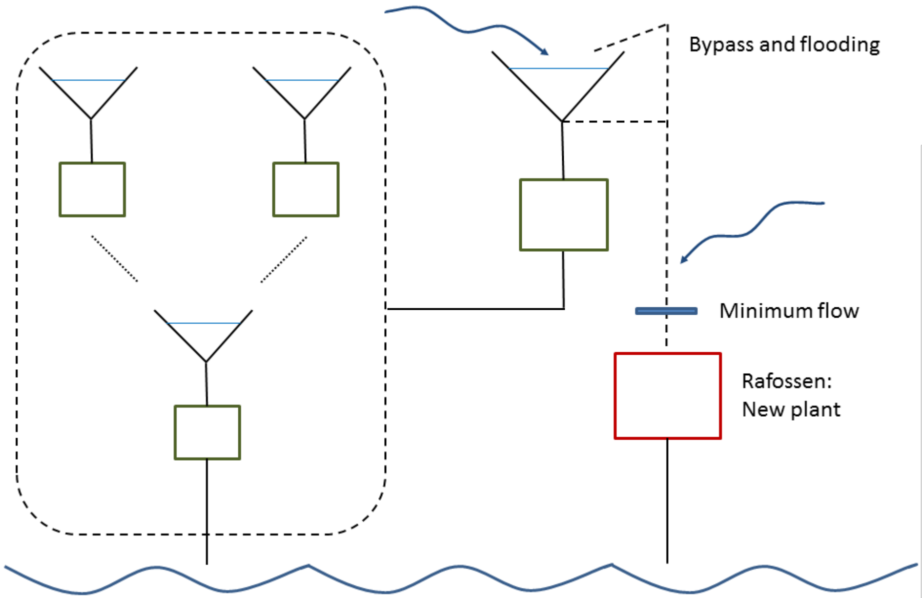
Estimating costs of environmental restrictions using ProdRisk

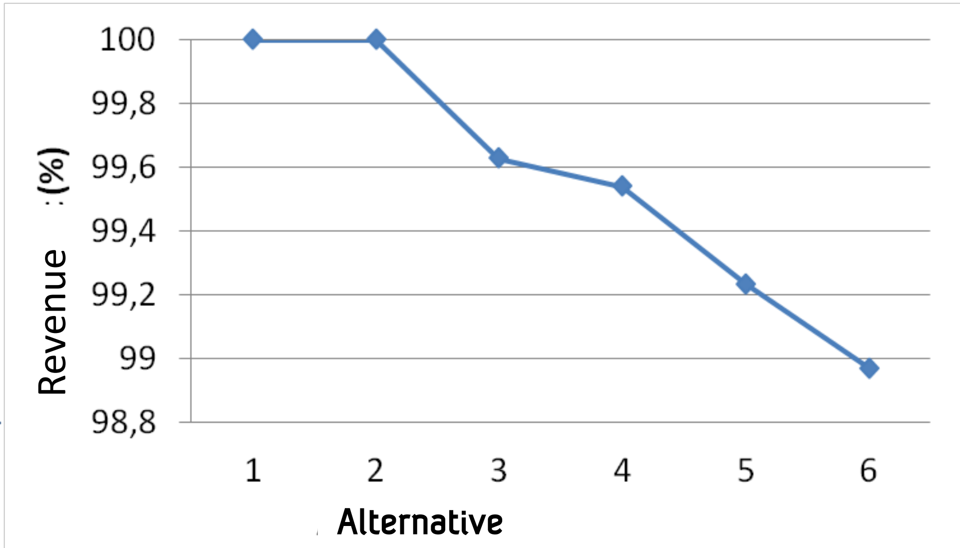




Project for Sira-Kvina 2012 (Follestad, Fjeldstad)

Estimating costs of environmental restrictions using ProdRisk





Summer (m3/s)	1,3	2	5	6	7,5	9
Winter (m3/s)	3,7	5	5	5	7,5	7,5

Project for Sira-Kvina 2012 (Follestad, Fjeldstad)

Mapping of carrying capacity in the upper Kvina

Classification	Area	Density	Minimum	Maximum	Mean
Not suited	73 700	2-4	1500	3000	2200
Partly suited	136 000	5-9	6800	12200	9500
Well suited	166 000	7-13	11 600	21 600	16 600
Totalt	375 700		20 000	37 000	28 000
Bremseth et al.			**18 000**	**35 000**	**26 000**

- Production loss under present condition: 12 000 – 17 000 smolts

How to replace 20 000 smolts?

	Alternative 2 (5 m³/s)			Alternative 3 (6 + 5 m³/s)	
	min	max		min	Max
Theoretical production upsteam of Rafoss	20 000	28 000		20 000	28 000
Realistic production upsteam of Rafoss	14 000	20 000		16 000	22 000
Reduced mortality in lower parts	2000	2900		3400	4900
Reduced turbine mortality (Trærlandfoss)	1700	2500		1700	2500
Habitat adjustments Stadion	600	800		600	800
Habitat adjustments Svindland-Åmot	?				?
Increased smolt production	**18 000**	**26 000**		**22 000**	**30 000**
Extra release of water from reservoir	**11 %**			**16 %**	