



# River restoration in Norway

## The River Mandal case

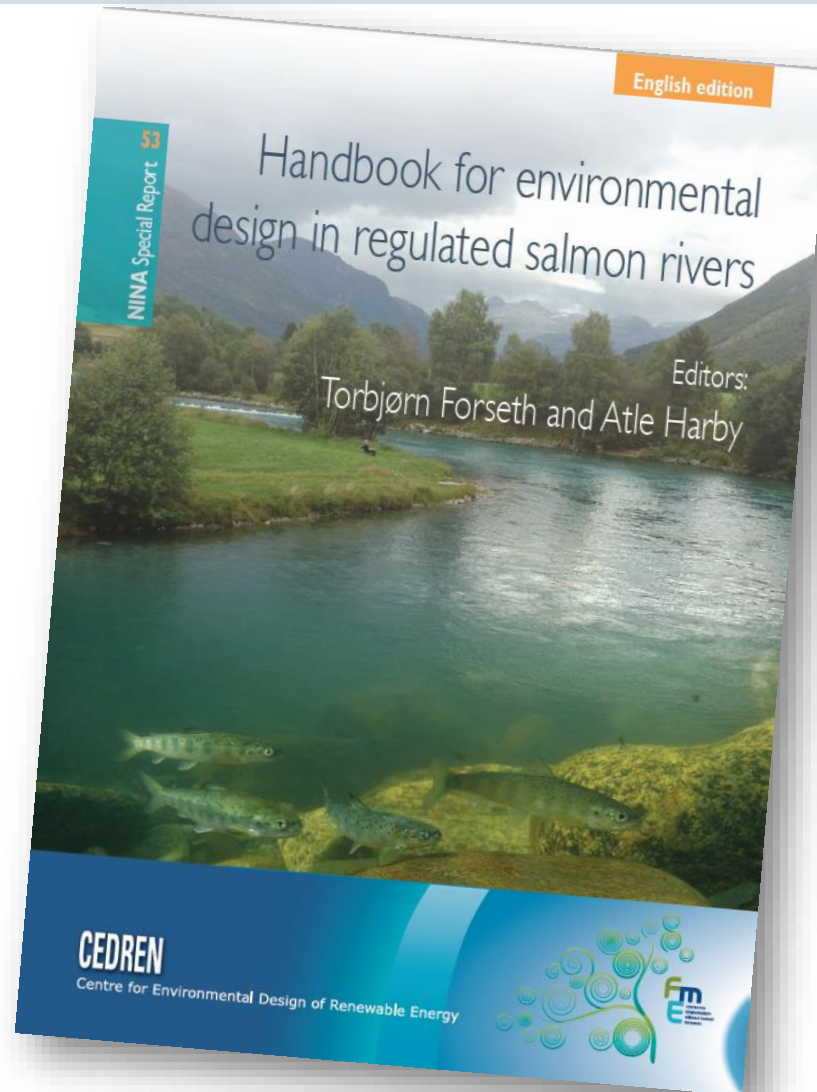
Torbjørn Forseth

# Mainly salmon rivers!

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# The environmental design approach





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...how to explore, develop and implement measures that improves conditions for Atlantic salmon in regulated rivers in optimal trade-offs with hydropower production

**DATA COLLECTION AND TOOLS**

- Mapping and survey of river types, substrate and shelter
- Mapping and survey of extent and spatial distribution of spawning area
- Relationship between wetted area and water flow
- Hydrological analysis
- Temperature data or modelling
- Collection of population data
- Description of hydropower system and regulation effects

**CLASSIFICATION SYSTEMS**

- The salmon population
- The hydropower system

**DIAGNOSIS**

**Habitat bottlenecks**

- Shelter
- Spawning areas

**Hydrological bottlenecks**

- Flow
  - summer and winter flow
  - water level at spawning
  - smolt migration flow
  - 0+ habitat
  - river habitat consistency
  - habitat deterioration
- Water temperature
  - 0+ growth
  - smolt age

**DESIGN SOLUTIONS AND MEASURES**

**Habitat measures**

- Shelter
  - cleaning of gravel banks
  - establishment of shelter
  - removal of weirs and other restoration measures
  - "a river in the river"
- Spawning habitat
  - cleaning of gravel banks
  - installation of spawning gravel

**Water use**

- Water temperature
  - flexible discharge systems
  - discharge volumes in key periods
  - active use of different waterways
- Flow
  - increased minimum flow
  - redistribution
  - water level and flow at spawning
  - situation-dependent flow release
  - expansions

**ASSISTING TOOLS**

- Building Block Method
- The Water Pool
- Flow duration curves
- Priority table
- Water negotiations
- Impact assessments-water use
- Impact assessments-habitat measures



# Classification - Spawning habitat

|   |                    | Extent of spawning habitat as a percentage of river area. |                  |              |
|---|--------------------|---|------------------|--------------|
|   |                    | Small (<1%)   | Moderate (1-10%) | Large (>10%) |
| <b>Distance between spawning habitats</b> (across all segments) | Large (>500 m)     | Small   | Small            | Moderate     |
|   | Medium (200-500 m) | Small   | Moderate         | Large        |
|   | Small (<200 m)     | Moderate  | Large            | Large        |

# Classification – Shelter availability

*Table 2. A system for the classification of access to shelter based on field measurements (DI) and calculations of the depth-weighted average shelter values within each river segment.*

| Access to shelter (depth-weighted value) |          |      |
|--|----------|------|
| Poor                                     | Moderate | Good |
| <5                                       | 5-10     | >10  |



# Combined classification – habitat bottlenecks and productivity

|         |                 | Spawning habitat |          |         |
|---------|-----------------|------------------|----------|---------|
|         |                 | Small            | Moderate | Large   |
| Shelter | Poor (<5)       | Both             | Shelter  | Shelter |
|         | Moderate (5-10) | Spawning         | Both     | Shelter |
|         | Good (>10)      | Spawning         | Spawning | None    |

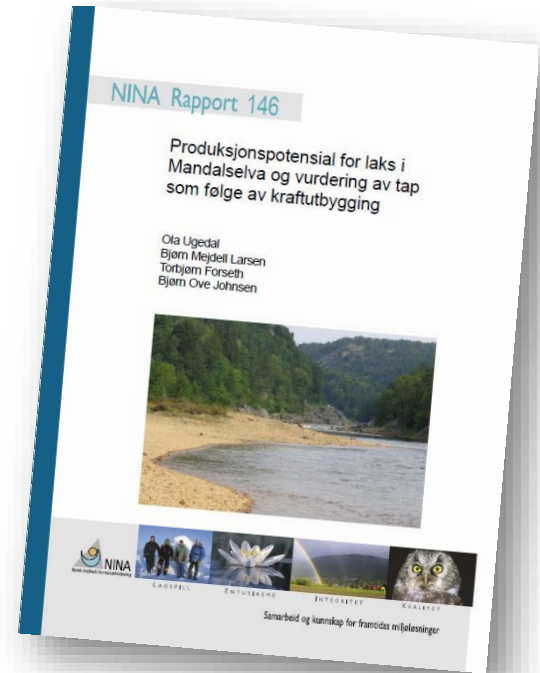
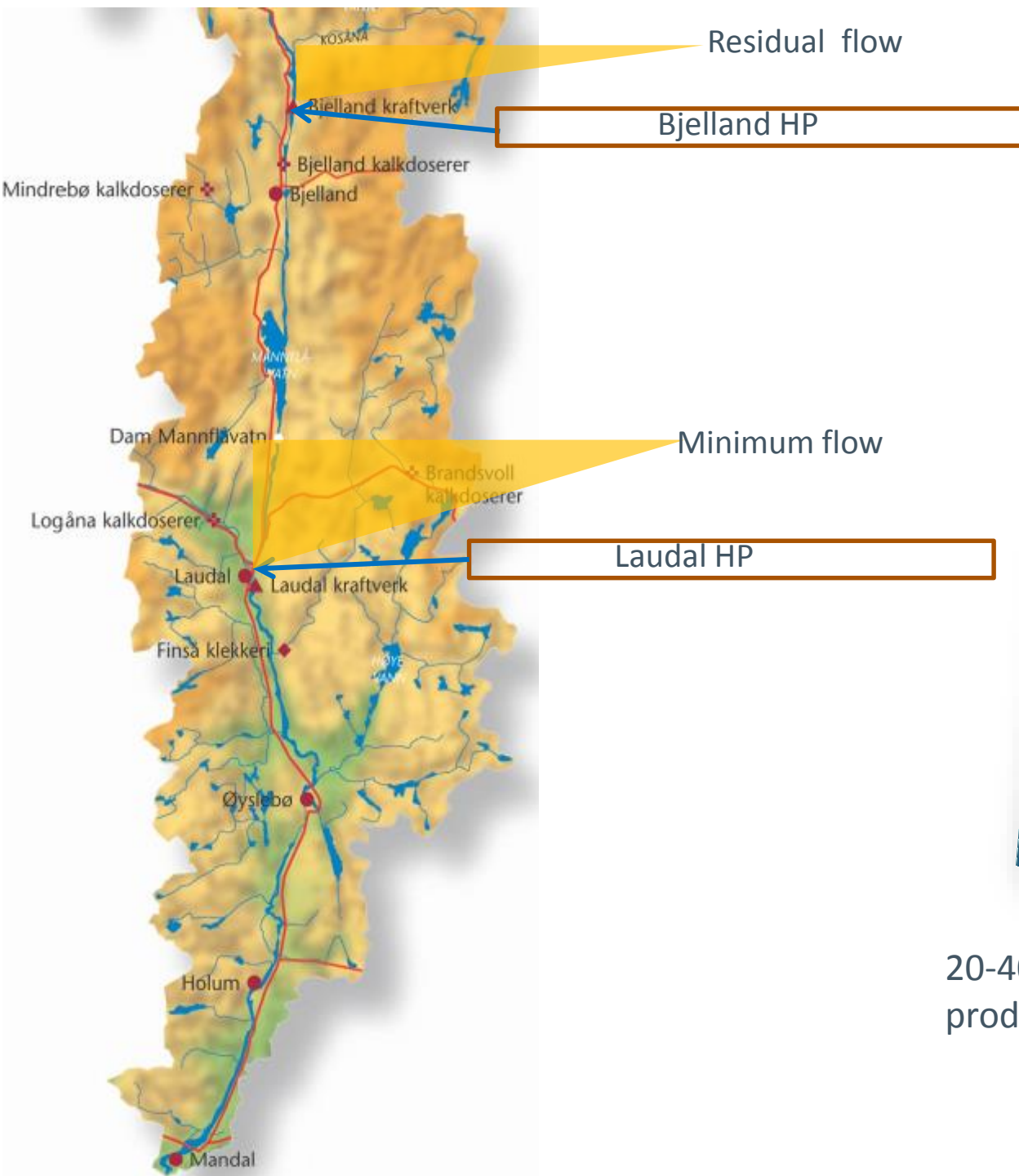


# Diagnosis → Habitat measures

| Reach | Length (m) | Segment | Length (m) | Population regulation stage | Habitat bottleneck | Productivity (1-3) |
|-------|------------|---------|------------|-----------------------------|--------------------|--------------------|
| 1     | 4000       | 1       | 800        | Fry                         | Spawn              | 1                  |
|       |            | 2       | 1000       | Fry                         | Spawn              | 1                  |
|       |            | 3       | 600        | Fry                         | Spawn              | 1                  |
|       |            | 4       | 900        | Fry                         | Spawn              | 2                  |
|       |            | 5       | 700        | Fry/Parr                    | Both               | 1                  |
| 2     | 3500       | 6       | 500        | Fry/Parr                    | Both               | 1                  |
|       |            | 7       | 600        | Parr                        | Shelter            | 2                  |
|       |            | 8       | 800        | Parr                        | Shelter            | 2                  |
|       |            | 9       | 500        | Parr                        | Shelter            | 2                  |
|       |            | 10      | 600        | None                        | None               | 3                  |
|       |            | 11      | 500        | None                        | None               | 3                  |
| 3     | 2300       | 12      | 1000       | Fry                         | Spawn              | 2                  |
|       |            | 13      | 800        | Fry                         | Spawn              | 1                  |
|       |            | 14      | 500        | Fry                         | Spawn              | 2                  |
| etc.  |            | etc.    |            |                             |                    |                    |

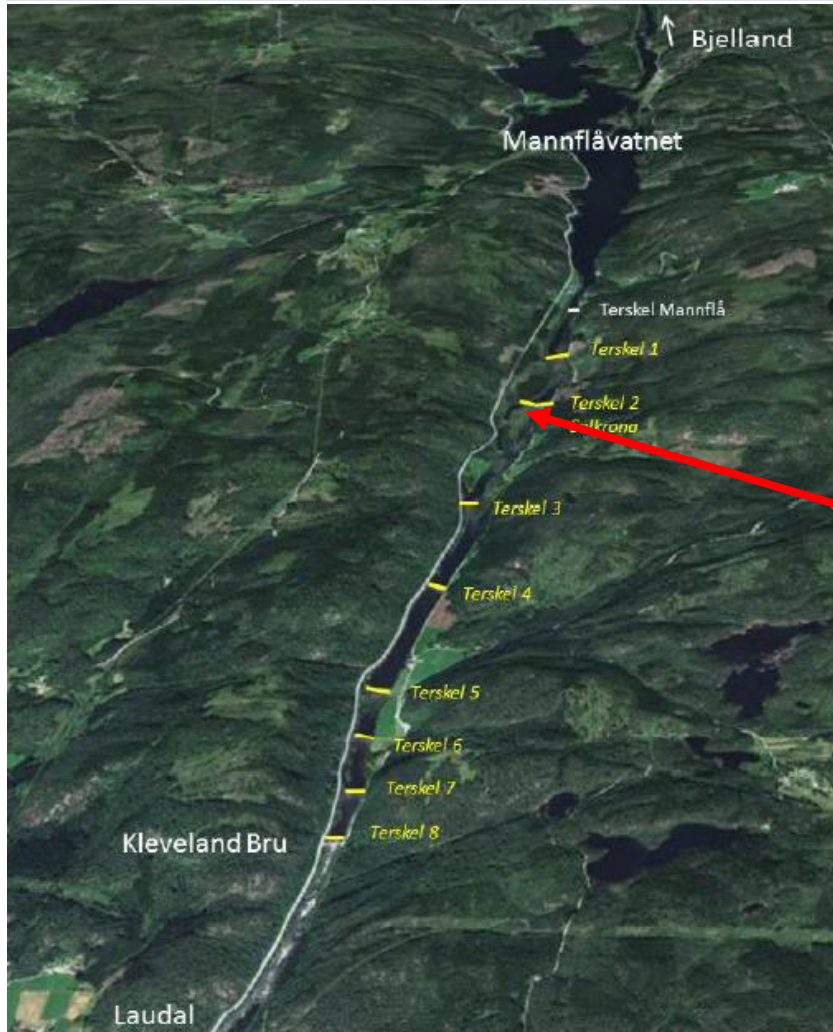
The right measures in the right place!





20-40 % loss in salmon smolt production

# The Laudal minimum flow reach



8 weirs!

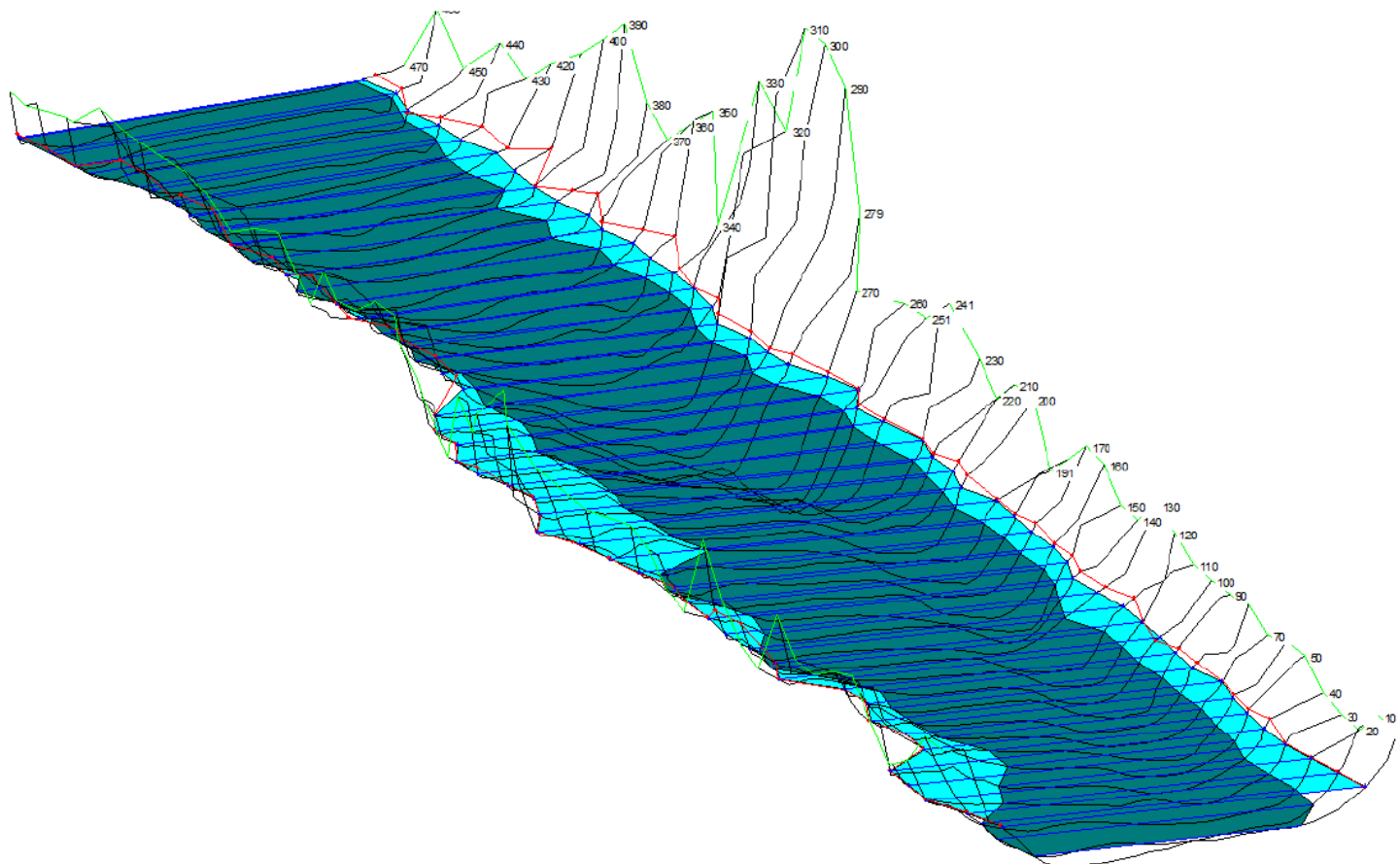
# Pre-restoration work

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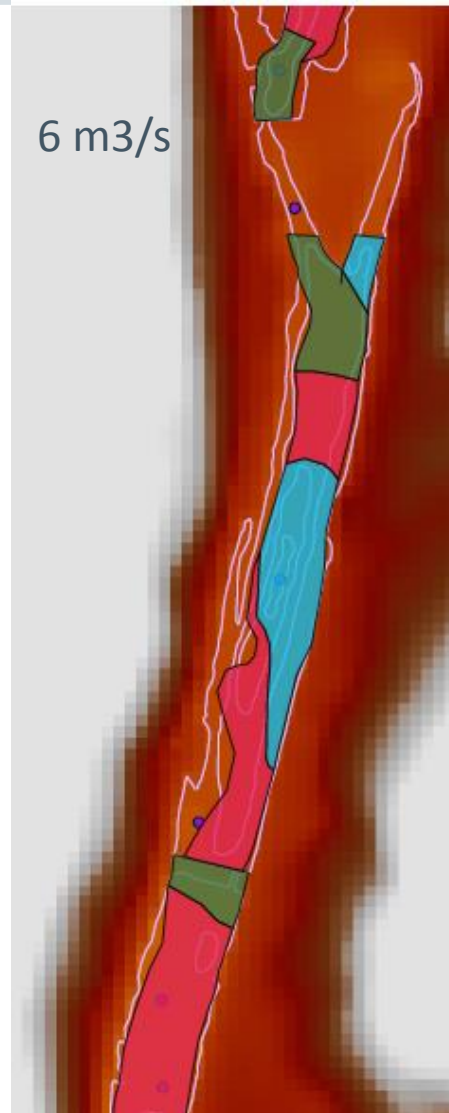
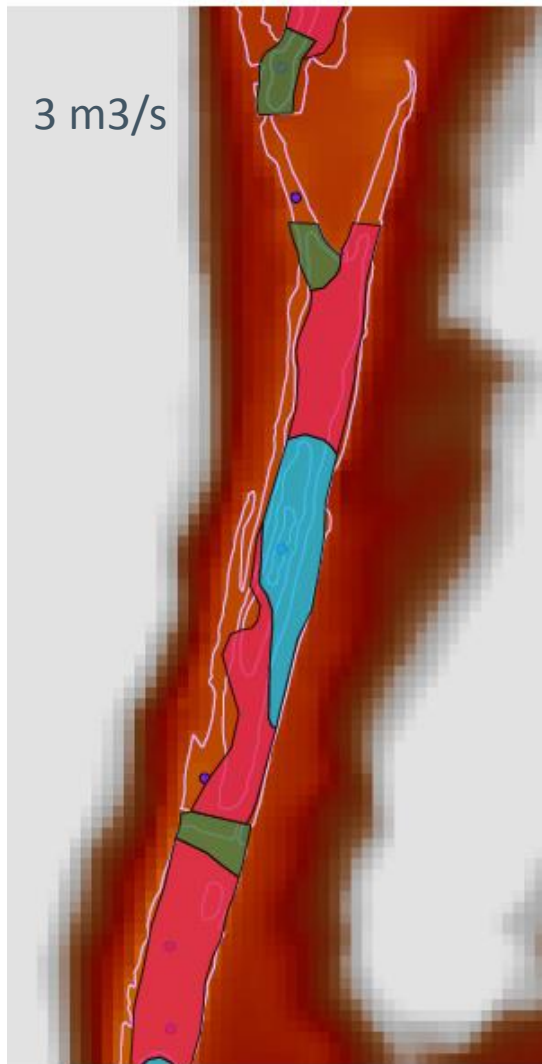
- Wetted area and meso-habitat distribution after weir removal as function of discharge
- Diagnosis:
  - ▶ Mapping of present and potential spawning area
  - ▶ Mapping of shelter availability
- Restoration plan – how to handle each weir
- Estimates of effects of restoration (changes in smolt production)
- Information and local opposition



# Establishing a hydraulic model



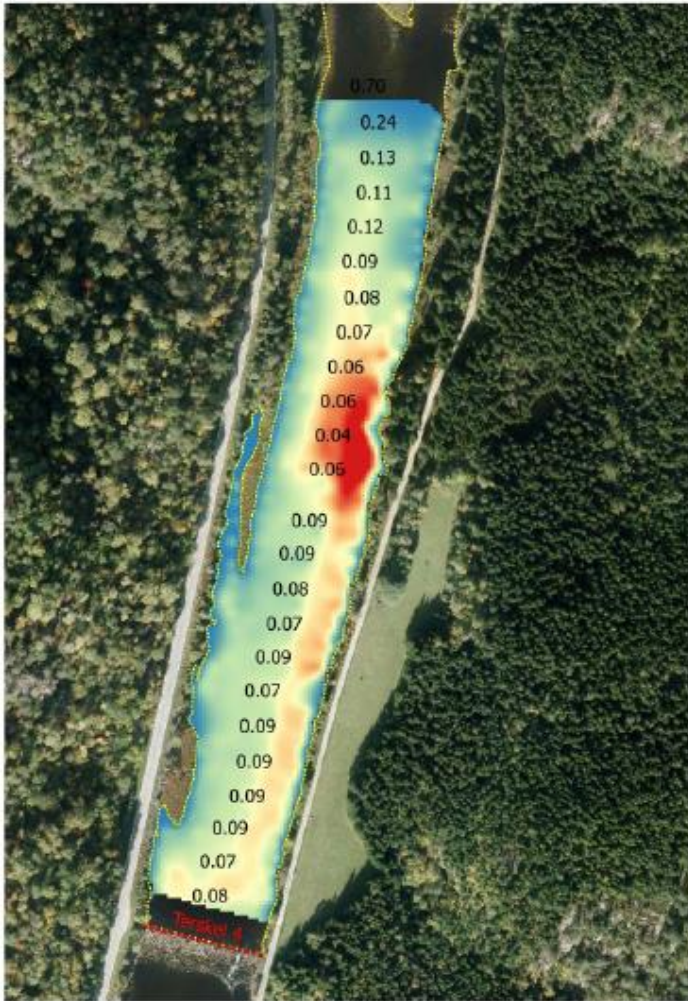
# Wetted area and meso-habitat



- D Shallows
- C Pool
- B1 Glides
- B2 Glides
- G1 Riffles
- G2 Riffles

Winter habitat,  
growth &  
survival,  
spawning and  
fishing

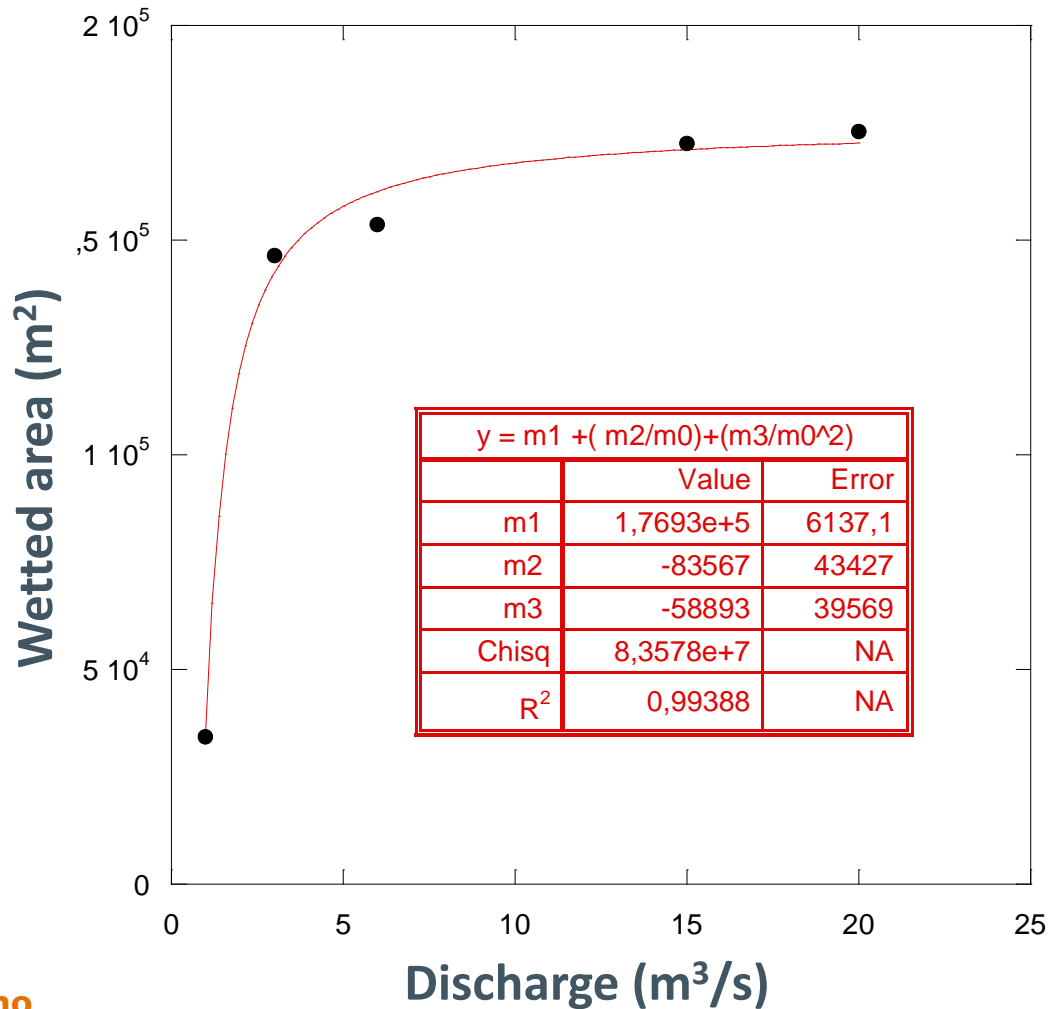
# Depth and velocities



Q6



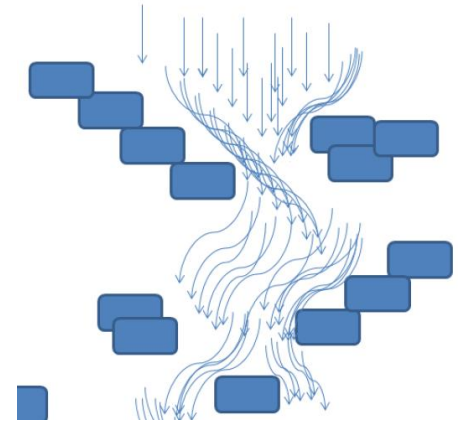
# Wetted area vs discharge





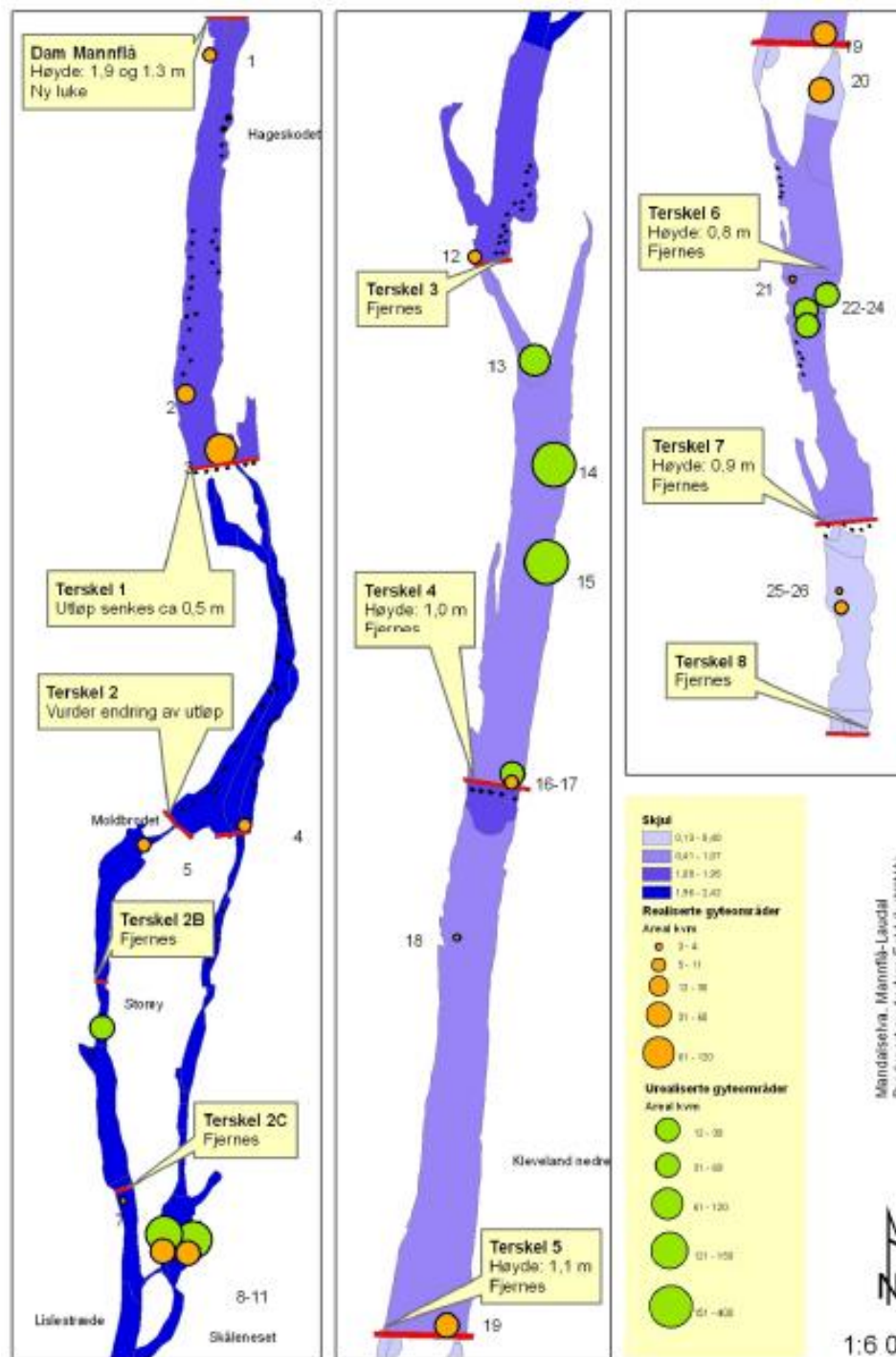
# The restoration plan

- Remove 7 out of 8 weirs – modify the last
- Use the weir material (stones and bolder) to construct high shelter areas and increase local velocities
- Construct two new spawning areas



# Dignosis og smolt production

| Nå                             |        |                      |                        |        |                |         |             |       |              |               |         |           |            |          |           |
|--------------------------------|--------|----------------------|------------------------|--------|----------------|---------|-------------|-------|--------------|---------------|---------|-----------|------------|----------|-----------|
| Segm.                          | L. (m) | A. (m <sup>2</sup> ) | Gyte (m <sup>2</sup> ) | % Gyte | Gyte A. klasse | Avstand | Gyte klasse | Skjul | Skjul klasse | Produktivitet | Begrens | Smolt min | Smolt maks | Prod min | Prod maks |
| 1                              | 709    | 36873                | 943                    | 2,56   | moderat        | liten   | mye         | 10,8  | mye          | Høy           | Ingen   | 7         | 13         | 2581     | 4793      |
| 2                              | 1420   | 154582               | 0                      | 0,00   | lite           | stor    | lite        | 0,6   | lite         | Lav +         | Begge   | 1         | 2          | 1546     | 3092      |
| 3                              | 350    | 13140                | 50                     | 0,38   | lite           | moderat | lite        | 21    | mye          | Moderat       | Gyte    | 5         | 9          | 657      | 1183      |
| 4                              | 677    | 49603                | 200                    | 0,40   | lite           | stor    | lite        | 6,2   | moderat      | Lav           | Gyte    | 2         | 4          | 992      | 1984      |
| 5                              | 683    | 22009                | 0                      | 0,00   | lite           | stor    | lite        | 14,4  | mye          | Moderat       | Gyte    | 5         | 9          | 1100     | 1981      |
| Sum                            | 3839   | 276207               | 1193                   | 0,43   |                |         |             |       |              |               |         |           |            | 6876     | 13032     |
| Etter, ved 2 m <sup>3</sup> /s |        |                      |                        |        |                |         |             |       |              |               |         |           |            |          |           |
| 1                              | 709    | 36873                | 943                    | 2,56   | moderat        | liten   | mye         | 10,8  | mye          | Høy           | Ingen   | 7         | 13         | 2581     | 4793      |
| 2                              | 1420   | 75992                | 400                    | 0,53   | lite           | liten   | moderat     | 0,6   | lite+        | Moderat +     | Begge   | 4         | 8          | 3040     | 6079      |
| 3                              | 350    | 13140                | 50                     | 0,38   | lite           | moderat | lite        | 21    | mye          | Moderat       | Gyte    | 5         | 9          | 657      | 1183      |
| 4                              | 677    | 40125                | 700                    | 1,74   | Moderat        | moderat | moderat     | 6,2   | moderat+     | Moderat       | Gyte    | 5         | 9          | 2006     | 3611      |
| 5                              | 683    | 22009                | 0                      | 0,00   | lite           | stor    | lite        | 14,4  | mye          | Moderat       | Gyte    | 5         | 9          | 1100     | 1981      |
| Sum                            | 3839   | 188139               | 2093                   | 1,11   |                |         |             |       |              |               |         |           |            | 9384     | 17647     |
| Etter, ved 6 m <sup>3</sup> /s |        |                      |                        |        |                |         |             |       |              |               |         |           |            |          |           |
| 1                              | 709    | 36873                | 943                    | 2,56   | moderat        | liten   | mye         | 10,8  | mye          | Høy           | Ingen   | 7         | 13         | 2581     | 4793      |
| 2                              | 1420   | 86534                | 400                    | 0,46   | lite           | liten   | moderat     | 0,6   | lite+        | Moderat       | Begge   | 5         | 9          | 4327     | 7788      |
| 3                              | 350    | 13140                | 50                     | 0,38   | lite           | moderat | lite        | 21    | mye          | Moderat       | Gyte    | 5         | 9          | 657      | 1183      |
| 4                              | 677    | 42012                | 1200                   | 2,86   | Moderat        | moderat | moderat     | 6,2   | moderat+     | Moderat +     | Gyte    | 6         | 10         | 2521     | 4201      |
| 5                              | 683    | 22009                | 0                      | 0,00   | lite           | stor    | lite        | 14,4  | mye          | Moderat       | Gyte    | 5         | 9          | 1100     | 1981      |
| Sum                            | 3839   | 200568               | 2593                   | 1,29   |                |         |             |       |              |               |         |           |            | 11186    | 19946     |



# The core area



Existing spawning area

Possible spawning area

Spawning area after weir removal













Betongterskel



















# Results

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- 60-100 % increased smolt production
- Easy and rapid upstream adult migration
- Strongly improved fishing opportunities
  - ▶ New fishing beats
  - ▶ Homing adults





# Samarbeid og kunnskap for framtidens miljøløsninger











