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Report

River Classification for Environmental Flow Targets

Final Report of the Workshop on 29 January 2014 and data compilation of wetted width in Norwegian rivers

Author(s)
Peggy Zinke
Odd Terje Sandlund

SINTEF Energy Research
Water Resources
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SINTEF Energi AS
SINTEF Energy Research
Address:

NO-
NORWAY
Telephone:+47 73597200
Telefax:+47

energy.research@sintef.no
www.sintef.no/energi
Enterprise /VAT No:
NO 939 350 675 MVA

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AUTHOR(S)
Peggy Zinke
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ABSTRACT
For the setting of environmental objectives in a large number of rivers with flow alterations, environmental flow targets have to be developed on the spatial scale of water bodies to fulfil the requirements in the EU Water Framework Directive (WFD). The existing Norwegian river classifications for river water bodies, however, do not sufficiently include geo- and hydro-morphological parameters, such that it is very difficult to use them for the assessment of environmental flow requirements. Thus, there is a need to develop generalized and cost effective methods to describe and classify river morphology at different spatial scales and to link the classification to eco-hydrological threshold-values and to the river typology of the WFD.

This report presents the results of a workshop held on 29 January 2014 in Trondheim with the following main objectives: (i) to get an overview about relevant Norwegian and international river classification systems, (ii) to identify key parameters in river type classification for e-flow targets, (iii) to formulate the outline of a project proposal.

In addition, the report contains a compilation of available data on wetted width to flow ratios in a number of Norwegian rivers. This data may serve as a basis for future work on the hydro-morphological characterization of Norwegian rivers, with the goal to support the definition of environmental flow targets.

PREPARED BY	SIGNATURE
Peggy Zinke	P. Zinke
CHECKED BY	**SIGNATURE**
Håkon Sundt	H. Sundt
APPROVED BY	**SIGNATURE**
Knut Samdal	Knut Samdal

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Version No. 2.0	2014-04-30	Final report, with additional chapters "Water-covered area" and appendix A.3 "Project outlines"

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List of abbreviations

Frequently used abbreviations:

CEDREN	Centre for Environmental Design of Renewable Energy
EF	Environmental flow
HQ_{200}	Extreme flood with a recurrence interval 200 years (analogue for other intervals)
NEA	Norwegian Environmental Agency
NINA	Norwegian Institute for Nature Research
NTNU	Norwegian University of Science and Technology in Trondheim
NVE	Norwegian Water Resources and Energy Directorate
Q	Discharge, flow (m^3/s)
Q_{95}	Flow that is exceeded 95 % of the time
Q_{CLF}	Common low flow
Q_{MAF}	Mean annual flood
Q_{MF}	Mean annual flow
Q_{min7d}	Seven-day minimum flow (low flow)
RC	River classification
SINTEF	SINTEF Energy Research
W	Wetted width (m)
WFD	EU Water Framework Directive

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1 Background

For the revision of a large number of hydro power licenses in Norway, environmental flow targets have to be developed on the spatial scale of water bodies to fulfil the requirements in the EU Water Framework Directive (WFD). A recent study by the Norwegian Water and Energy Directorate (NVE) and the Norwegian Environmental Agency (NEA) (Sørensen 2013) investigated the priority of hydropower licenses which need to be revised with respect to environmental requirements until 2022. It suggested 50 water courses with high priority and 53 with lower priority for measures affecting hydropower production such as environmental flow releases.

The existing Norwegian river classifications for river water bodies, however, do not sufficiently include geo- and hydro-morphological parameters, such that it is very difficult to use them for the assessment of minimum flow requirements. In practice, the Q_{95} (flow that is exceeded 95 % of the time) or the similar "common low flow" Q_{CLF}[1] are often used as a starting point to set residual flow when a licence is needed, without taking into consideration the morphology of the individual river reach. The existing mesohabitat method (Borsanyi 2006), in contrast, requires detailed field surveys and is therefore a time- and cost-intensive tool when it comes to environmental flow assessment. A scientifically based method of the up- and downscaling between the mesoscale and reach scale classifications is missing.

Thus, there is a need to develop generalized and cost effective methods to describe and classify river morphology at different spatial scales and to link the classification to eco-hydrological threshold-values and to the river typology of the WFD. Several European countries like Slovenia and UK have recently implemented systems for acceptable flows deviations (factors) taking river-type specific variations into account for Eflow settings (Mielach et al. 2012, Poff et al. 2010, Acreman & Ferguson 2010). On-going work by the REFORM project and Common Implementation Strategy (GEP harmonisation under ECOSTAT and WG on Eflow) are addressing the need for developing management tools on these issues.

Moreover, the recently approved environmental quality standards for wild Atlantic salmon (Miljøverndepartementet 2013) defined the net reduction of water-covered area as a key parameter for the classification of regulation effects on salmon populations. A practical application of this standard requires that the water covered area can be related to a given discharge percentile (e.g MQ or Q_{95}) and measurement location(s) in the river of interest.

In December 2014, SINTEF Energy Research and the Norwegian Institute for Nature Research (NINA) were contracted to organize an expert workshop on behalf of the Norwegian Environment Agency (NEA).
The workshop (below called the RC workshop) discussed the possible development of a river classification method which can support environmental flow assessments and is linked to the Norwegian classification of river water bodies within the WFD.

The specific objectives of the RC workshop project were:

1. Preparation and realization of the RC workshop
2. Analysis and reporting of the RC workshop results
3. Identify key parameters for river type classification for E-flow targets
4. Compilation of Norwegian data on wetted area and flow for various rivers
5. Formulating the outline of a RC project proposal

The present report documents the workshop and the project results.

[1] The common low flow is approximately the 0.956 quantile of the flow duration curve, i.e. the flow that is exceeded 95.6 % of the time.

2 Workshop on River Classification

2.1 Objectives and program for the workshop

The main objectives of the workshop were defined as follows:

- To get an overview about relevant Norwegian and international river classifications
- To identify key parameters in river type classification for e-flow targets
- To formulate the outline of a larger project proposal

The workshop was held on 29 January 2014 at in the locations of the Norwegian Environment Agency in Trondheim (Brattørkaia 15). The program and a list of the participants is attached in Appendix 1.

2.2 Preparation, evaluation and results of the workshop

The workshop participants were selected during the project meeting between SINTEF, NINA and NEA on 9 December 2013. Two preparation notes were distributed to the participants on 17 and 24 January, the latter including the workshop objectives, group distribution and the questions for the group work discussions (Figure 2.1).

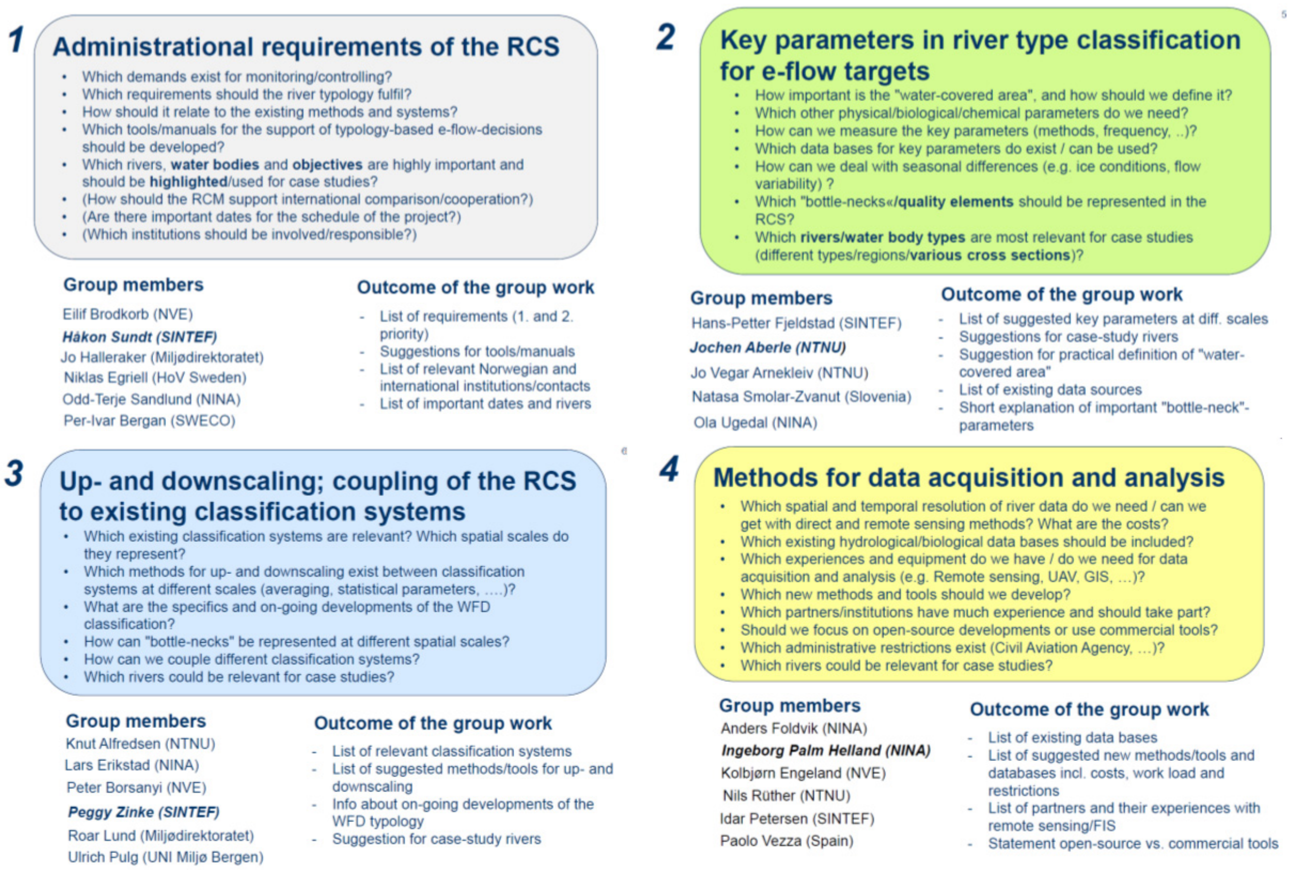


Figure 2-1: *Planned questions and participants for the group work.*

During the group work and plenary presentations and discussions, much information and some hints to references and other potential project partners were given. The results of a workshop evaluation survey are provided in Appendix 2. Within this survey, the following additional comments on the discussed questions or the content of the planned project were formulated by the participants:

- The link between river classification/e-flow target and biological elements is somewhat unclear. What is the core/objective of the planned project – ecology or river morphology/hydrology?
- There is a clear need for the project from the researcher environments, but for success it is crucial to gain support from larger groups of the public, government/state administration and relevant private companies.
- A "strategy for habitat quality" is needed.

After the workshop, the PDF-files of the presentations and plenum discussions were sent to all participants. They are therefore not included into this report. In the following chapters the workshop results are compiled and structured with respect to the workshop objectives, based on the presentations and reviews of additional information provided during the workshop.

3 Overview about relevant Norwegian and international river classifications

3.1 Main groups of stream classification systems

3.1.1 Scales and classification

Rivers are holistic systems where process scales range from small micro-habitats to entire watersheds, with combinations of broad scale trends in energy, matter, and habitat structure, as well as local discontinuous zones and patches (Figure 3.1).

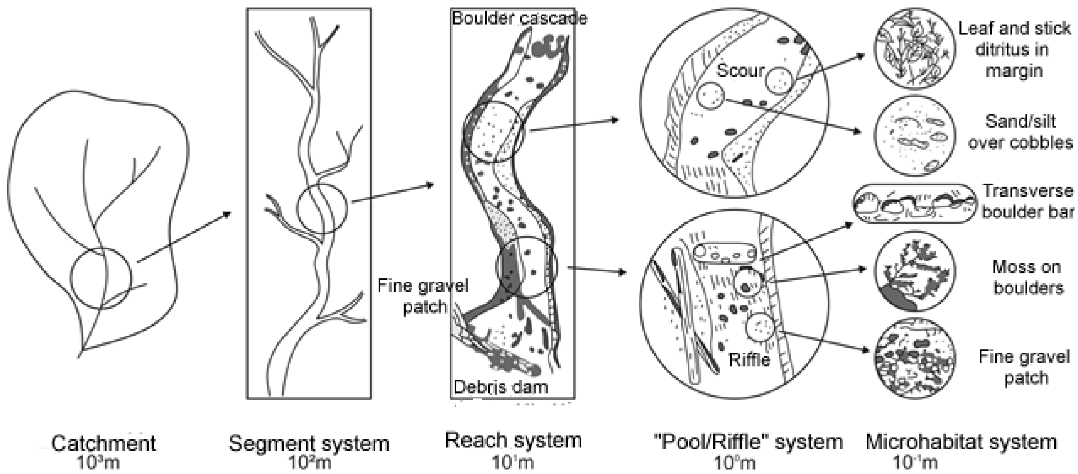


Figure 3-1: *Hierarchical organisation of a stream system. Presented by J. Aberle.*

A wide variety of river typologies and classification systems for different scales has been developed over time, focussing either on physical features and habitats (e.g. geomorphological approaches to stream classification), biota (macroinvertebrates, macrophythes, fish) or catchment properties, as shown in Figure 3.2 based on a review by Acreman (2005). Sections 3.1.2 and 3.1.3 provide some examples for these three groups, with special focus on existing Norwegian classification systems.
The European Water Framework Directive (WFD) requires the development of new nation-wide typologies on the spatial scale of the "river water body" – a spatial unit that can range from river reaches and segments (for large rivers) to catchment areas (for smaller streams). These typologies include both physical and biological aspects, in order to categorise their ecological sensitivity, and are briefly described in Chapter 3.2.

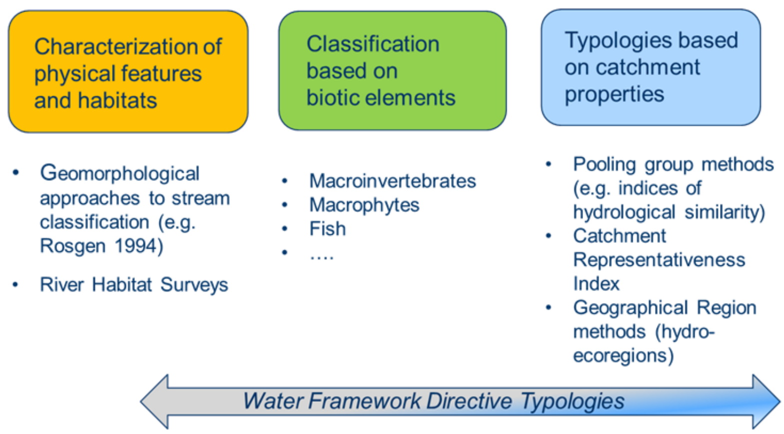


Figure 3-2: *Main groups of traditional classification systems (cp. Acreman, 2005).*

3.1.2 Classification based on physical features and habitats

Traditionally, alluvial channel patterns on the **river reach scale** have been classified as straight, meandering and braided (Leopold & Wolman 1957). Later classifications were based on the dominant modes of sediment transport, often related to differences in discharge, valley slope, sediment supply and relative bank strength (Schumm 1985, Church 2006, Eaton et al. 2010).

The popular Rosgen (1994) classification system distinguishes between eight major stream types (Figure 3.3), which are further divided into 94 sub-types based on the factors entrenchment ratio, width/depth ratio, sinuosity, slope, and bed material. The system has been widely used in the USA. It has been criticized for the lack of process-based classification (Montgomery & Buffington 1997) and for its limited applicability across physical environments (Juracek & Fitzpatrick 2003). Montgomery & Buffington (1997) presented an alternative process-based mountain channel classification, with the types reflecting downstream changes in the balance between transport capacity and sediment supply.

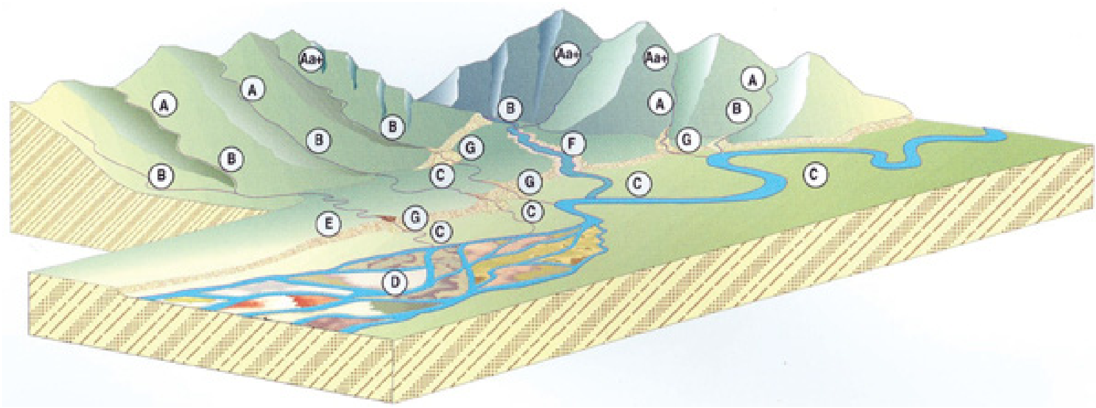


Figure 3-3: *Major stream types suggested by Rosgen (1994). From http://www.fs.fed.us/t-d/pubs/htmlpubs/htm10232808/images/fig23.jpg*

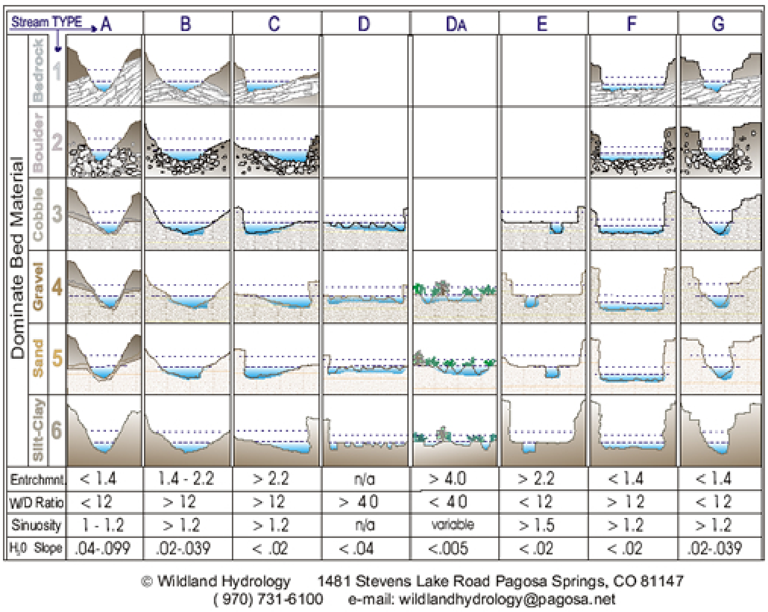


Figure 3-4: *Longitudinal, cross-sectional and plan views of major stream types according to Rosgen (1994). From http://www.fgmorph.com/fg_4_25.php*

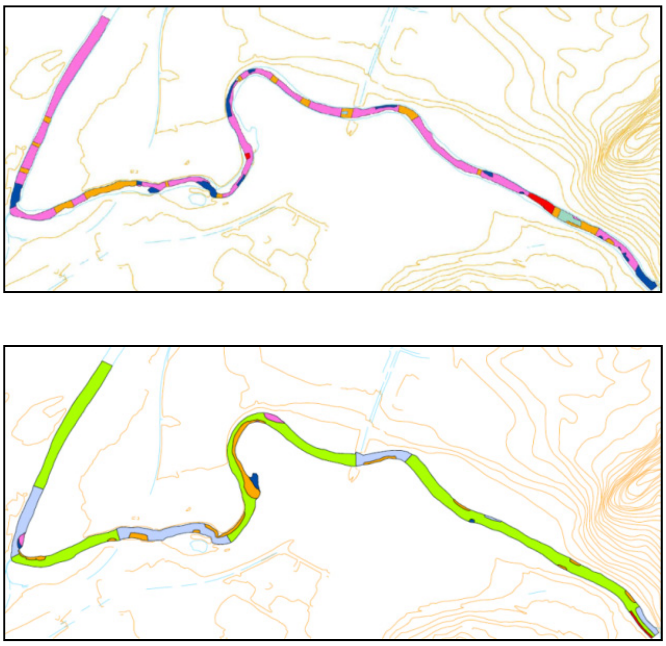
Brierly & Fryirs (2000) developed the "River Styles" approach for Australian environments. River Styles are characterized by channel geometry and plan-form attributes and the assemblage of geomorphic units that make up a river reach. The system is process-based and hierarchical, allowing linkages across scale hierarchy. Moreover, it is set within the context of river evolution and allows an assessment of the river's geomorphic condition and recovery potential. The approach has been applied in many cases and further developed as a management tool (Fryirs & Brierley 2013).

Classification systems on the **meso-scale** are based on the description of hydro-morphological units (HMU) such as runs, glides, pools, and cascades. The Norwegian meso-habitat classification (Borsányi 2005) distinguishes between 10 mesohabitat types, based on the water surface pattern, surface gradient, surface velocity and water depth (Figure 3.5 and 3.6). The distribution of meso-habitats in the river depends on the discharge.

Table 1. Decision tree for HMU classification (Borsányi, 2005).

surface pattern	surface gradient	surface velocity	water depth	code	NMCM name
smooth/rippled	steep	fast	deep	A	Run
			shallow		No existing combinations
		slow	deep		
			shallow		
	mild	fast	deep	B1	Deep glide
			shallow	B2	Shallow glide
		slow	deep	C	Pool
			shallow	D	Walk
broken/unbroken standing waves	steep	fast	deep	E	Rapid
			shallow	F	Cascade
		slow	deep		No existing combinations
			shallow		
	mild	fast	deep	G1	Deep splash
			shallow	G2	Shallow splash
		slow	deep		
			shallow	H	Rill

Figure 3-5: *Decision tree for of the Norwegian mesohabitat classification. From Borsányi (2005).*



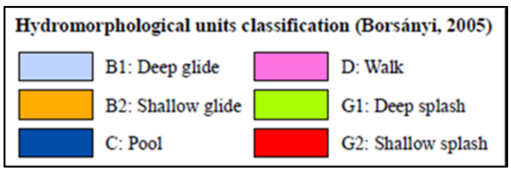


Figure 3-6: *Mesohabitats in the Lundesokna river for Q = 0.45 m^3/s (above) and Q = 16 m^3/s (below). From Escudero-Uribe (2011).*

Pulg et al. (2011) used a more detailed approach tailor-made for small brown trout streams, which distinguished between the meso-habitat types "spawning area", "riffles", and "channel". Habitat quality for each of them was assessed by assigning a habitat quality class between 1 and 4 for the habitat qualities "morphology", "substrate" and "bank vegetation and woody debris".

Table -3.1*: Assessment scheme for habitat mapping in small brown trout streams. From Pulg et al.(2011), translated and modified. v = flow velocity, d = water depth, F = Fine sediment percentage (< 1 mm).*

Mesohabitat-type	Habitat quality	Spawning area	Riffle ("Stryk")	Channel ("Renne")
Description		Dominated by typical spawning gravel	Spawning gravel not dominating	Spawning gravel not dominating
Dom. flow velocity		See below	>0.3 m/s	<0.3 m/s
Gradient			>0.3 %	< 0.3 %
Morphology	1 – ill-suited	v=0.1 m/s or 1 m/s, d = 5 cm	Channelized, no holes –shelter and hollows at <50% of the area	
	2 – less suitable	v=0.1-0.2 m/s or 0.8-1 m/s, d = 5 cm	Channelized with loose stones or low morph. Diversity; shelter and hollows at <50% of the area	
	3 – suitable	v=0.2-0.8 m/s, d=5-10 cm	Channelized with loose stones or low morph. Diversity; shelter and hollows at 50-100% of the area	
	4 – most suitable	v=0.2-0.8 m/s, d>10 cm	High morphological diversity, natural floodplains, shelter and hollows at 50-100 % of the area	
Substrate	1 – ill-suited	F>20 % or packed or covered by vegetation	Only bedrock/blocks	Only fine sediments or bedrock
	2 – less suitable	F > 10 % or partly covered by vegetation	Bedrock/ blocks and cobbles	Fine sediment and cobbles/blocks/bedrock,/ gravel/trees
	3 – suitable	F < 10 % and partly covered by vegetation	Bedrock/blocks, gravel and cobbles/trees	Fine sediment and cobbles and blocks/gravel/trees
	4 – most suitable	F < 10 % and not covered by vegetation	Bedrock/blocks, cobbles, trees and spawn. gravel spots	Fine sediments and cobbles and gravel and blocks/trees
Bank vegetation and dead wood	1 - little	Coverage 0-25 %		
	2 - medium	Coverage 25-50 %		
	3 - much	Coverage 50-75 %		
	4 - dense	Coverage 75-100 %		

3.1.3 Typologies based on catchment properties

Norway can be divided into **hydrological zones**, based on various hydrological indexes for example for low flow or floods.

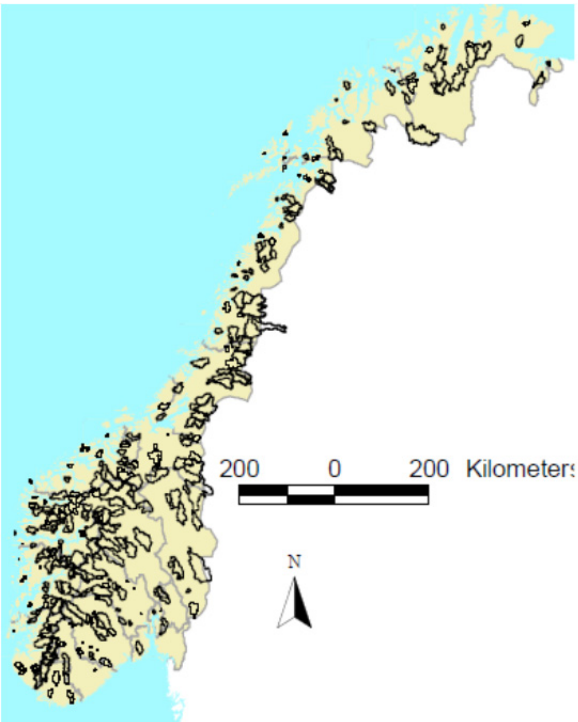
Figure 3.7 shows the **zones for low flow estimation**, which were created by establishing regression equations between low flow indices and the following catchment characteristics (presented by K. Engeland):

- Area (+ length of catchment)
- Lake percentage (+ glacier, forest, bog)
- Gradient of river and catchment
- Effective lake percentage
- Annual average runoff
- Average precipitation (year, summer, winter)
- Average temperature (year, summer, winter)

One regression equation was derived for each region. As a general rule, the number of regions was only increased if it increased the predictability of the model. The final model includes 12 regions: East summer, east winter, south summer, south winter, west-mid-north summer, west winter, mid winter, north winter, Finnmark, glaciers south, glaciers north. The following results were obtained with respect to Q95 or QCLF (the "common low flow"):

Q_{95}/Q_{CLF}

- increases with area, length, average runoff, average precipitation, lake percentage, glaciers
- decreases with catchment steepness, bogs



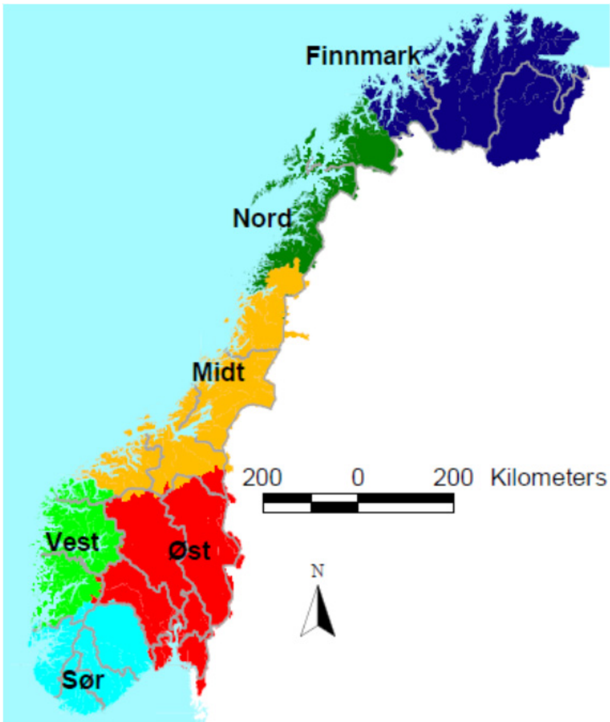


Figure 3-7: *Selected stations for the low flow mapping project (left) and zones for low flow estimation (right) in Norway. Presented by K. Engeland.*

Q_{95} summer

- decreases with temperature, minimum elevation and forest percentage
- increases with maximum elevation and mountain percentage

Q_{95} winter

- decreases with temperature, minimum elevation and forest percentage
- decreases with maximum elevation and mountain percentage

Other hydrological zones can be distinguished for flood estimations. Internationally, the **mean or median flood** is usually used as the index flood. For an ungauged site or sites with limited data, regression formulas for the index flood and growth curve available for established regions can be applied (Sælthun 1997), see Figure 3.8.

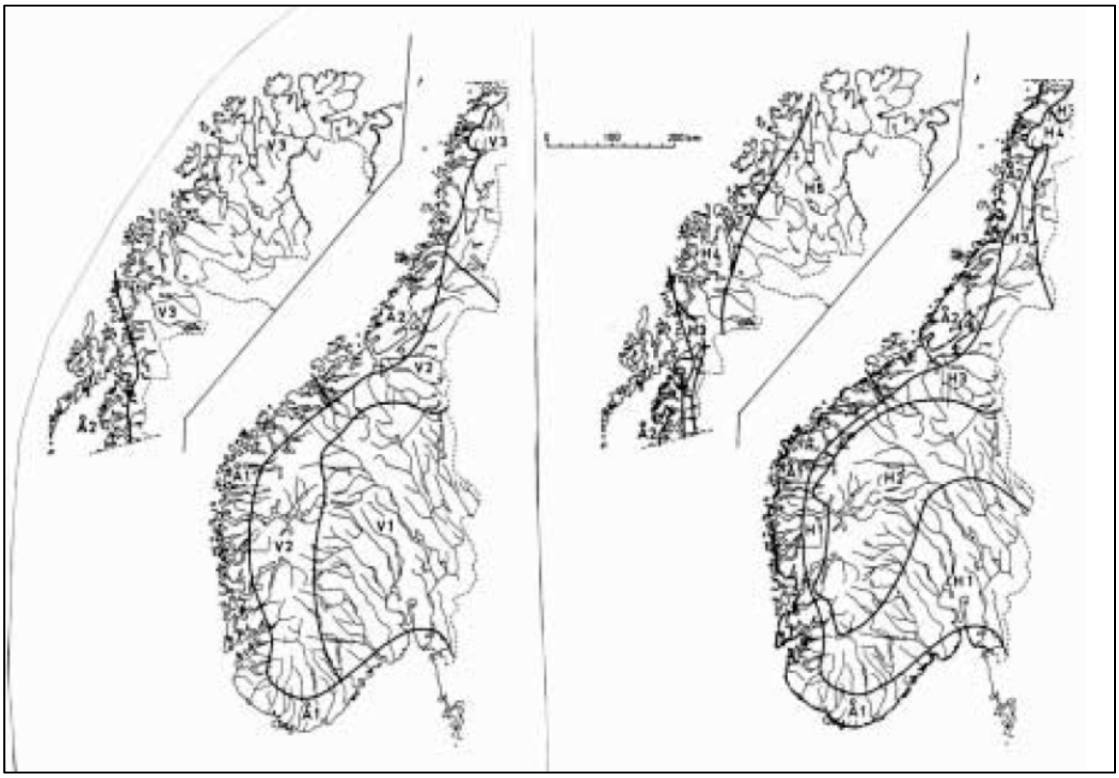


Figure 3-8: *Flood regions in Norway. Presented by K. Engeland, from Sælthun (1997).*

The flood regions have been defined by cluster analysis on the basis of 212 catchments with at least 20 years of observations and no or only minimal influence from regulation (Sælthun 1997).

Wilson et al. (2011) have described the method and regional differences as follows in their review of the existing flood estimation zones: "The catchments were first separated into four classes according to the season during which the most critical floods (in terms of annual flood peak magnitude) occur: 1) spring floods during the snow-melt season, 2) summer/autumn floods usually generated by heavy rain, 3) annual, i.e. catchments where the occurrence of critical floods is not limited to a particular season but may occur during several seasons of the year, and 4) catchments with a glacier percentage ≥ 5%. Catchments along the west coast of Norway typically belong to the annual flood class, whereas both spring and summer/autumn catchments are present in all other parts of Norway. Separate geographical regions were delineated for the three classes based on a hierarchical cluster analysis with six climatic parameters (mean annual precipitation, the relationship between mean annual precipitation and precipitation with a 5-year return period (%), mean total number of days with snow cover, mean annual snow depth, mean temperature in January and July). The homogeneity within the identified regions was verified with respect to Wiltshire's homogeneity test. This resulted in two annual regions, four spring flood regions and three summer/autumn flood regions (…) as well as a separate glacier region."

Figure 3.9 and 3.10 show the recently published annual flood regions (Wilson et al. 2011) and the respective regression formulas. The mean annual flood is described as a function of the catchment area, mean annual runoff, mean annual precipitation, effective lake percentage, exposed bedrock percentage, catchment length, and gradient of the main river. Investigations about the effects of climate change (e.g. Roald et al. 2002) indicate that also the envisaged countrywide changes in the annual runoff in Norway show characteristic zonings.

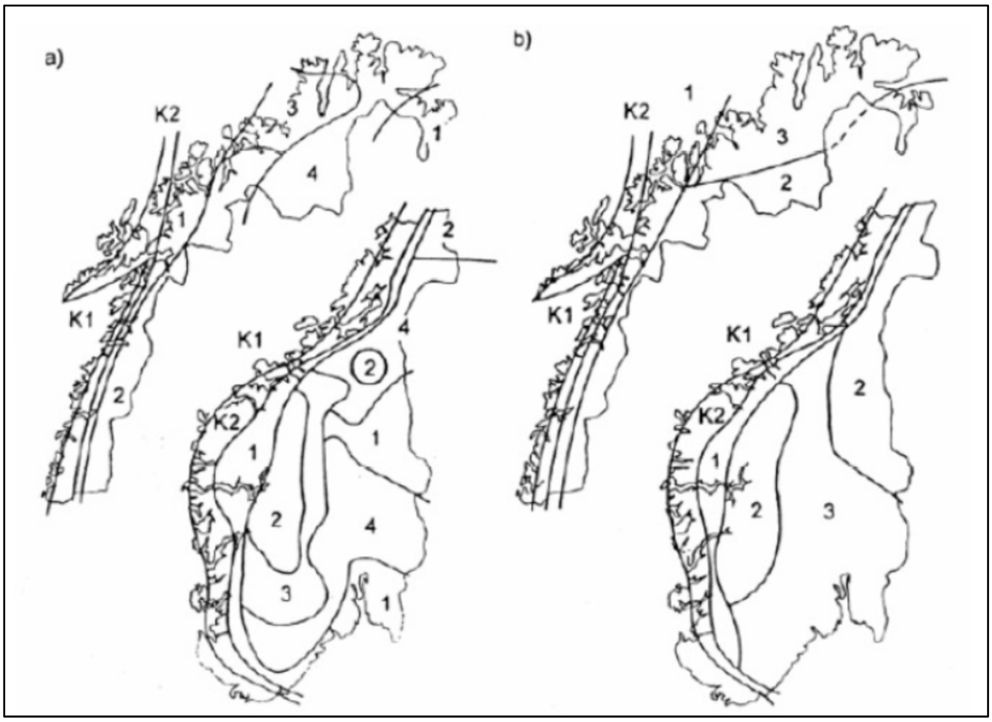


Figure 3-9: *Flood regions: annual flood regions (K1 and K2), together with (a) regions for spring floods (V 1-4) and (b) regions for summer and autumn floods (H 1-3; Midttømme et al., 2011). From Wilson et al. (2011).*

Spring flood regions	
1	$\ln Q_M = 0.2722 \cdot \ln S_T - 0.1406 \cdot \ln A_{SE} + 0.1006 \cdot \ln A_{SF} + 0.6172 \cdot \ln Q_N + 2.11$
2	$\ln Q_M = 0.0930 \cdot \ln S_T - 0.0816 \cdot \ln A_{SE} + 0.0281 \cdot \ln A_{SF} + 0.5076 \cdot \ln Q_N + 3.59$
3	$\ln Q_M = 0.3066 \cdot \ln S_T - 0.0220 \cdot \ln A_{SE} + 0.0939 \cdot \ln A_{SF} + 0.3252 \cdot \ln Q_N + 3.09$
4	$\ln Q_M = 0.1848 \cdot \ln S_T - 0.0137 \cdot \ln A_{SE} + 0.0873 \cdot \ln A_{SF} + 0.5143 \cdot \ln Q_N + 2.77$
Autumn flood regions	
1	$\ln Q_M = 1.2805 \cdot \ln Q_N - 0.2267 \cdot \ln(A/L_F) + 0.0664 \cdot A_{SE} + 0.0053 \cdot S_T + 1.00$
2	$\ln Q_M = 1.2910 \cdot \ln Q_N - 0.1602 \cdot \ln(A/L_F) + 0.0508 \cdot A_{SE} + 0.0065 \cdot S_T + 0.65$
3	$\ln Q_M = 1.2014 \cdot \ln Q_N - 0.0819 \cdot \ln(A/L_F) + 0.0268 \cdot A_{SE} + 0.0013 \cdot S_T + 1.07$
Glacier and annual flood regions	
BRE	$\ln Q_M = 0.0119 \cdot Q_N - 0.0848 \cdot A_{SE} + 0.0165 \cdot L_F + 5.81$
K1	$\ln Q_M = 1.5212 \cdot \ln Q_N - 1.1516 \cdot \ln P_N - 0.0569 \cdot A_{SE} - 0.0093 \cdot L_F + 8.80$
K2	$\ln Q_M = 1.1524 \cdot \ln Q_N - 0.0463 \cdot A_{SE} + 1.57$

Where: A = catchment area (km^2), Q_N = mean specific annual runoff (ls^{-1}km^2), P_N = mean annual precipitation (mm), A_{SE} = effective lake (%), A_{SF} = exposed bedrock (%), L_F = catchment length (km), S_T = gradient of the main river (m/km).

Figure 3-10: *Regional formulas for derivation of the index flood (Q_M in ls^{-1}km^2). From Wilson et al. (2011).*

3.2 The EU Water Framework River Classification

3.2.1 General requirements for river typologies

The general principle of the WFD is that the ecological status of water bodies should be assessed and classified based on the condition of four ecological quality elements relative to a defined reference condition for the particular water body. These ecological quality elements are phytoplankton (in lakes), periphyton (in rivers), higher vegetation (in lakes), zoobenthos (both lakes and rivers), and fish (both lakes and rivers). Supporting chemical and physical parameters are eutrophication, acidification and hydromorphological changes. It should be noted that, according to WFD, the ecological status of a water body cannot be established based only on the supporting parameters. Classification must be based on the status of the ecological quality elements. In principle some sort of dose-response curve for the correlation between environmental parameters (chemistry, hydro-morphology) and the status of the ecological quality elements should be available. A central issue concerning environmental flow and fish in relation to WFD is to establish this dose-response curve and to identify possible discontinuities which may indicate class borders (in particular between Good and Moderate status).

The WFD requires that Member States differentiate the relevant surface water bodies with respect to type and that reference conditions are established for these types. The main purpose of typology is to enable type specific reference conditions to be defined which in turn are used as the anchor of the classification system. The following excerpts from the WFD pertain to water body types:

> Annex II: 1.1 (ii)
> *For each surface water category, the relevant surface water bodies within the river basin district shall be differentiated according to type. These types are those defined using either "system A" or "system B" identified in Section 1.2.*
>
> Annex II: 1.1 (iv)
> *If System B is used, Member States must achieve at least the same degree of differentiation as would be achieved using System A. Accordingly, the surface water bodies within the river basin district shall be differentiated into types using the values for the obligatory descriptors and such optional descriptors, or combinations of descriptors, as are required to ensure that type specific biological reference conditions can be reliably derived.*

Table 3.2 and Figure 3.11 show the ecoregions and surface water body types for river from the WFD, including the obligatory and optional factors. The ecoregions (Fig. 3.11) are based on Illies (1978). The REFCOND working group dealt specifically with issues relating to the establishment of reference conditions and ecological status class boundaries for inland surface waters. The following conclusions and recommendations were given relative to specific issues concerning the water body types (EU 2003):

- There are two possible ways to differentiate water body types: ”System A” or ”System B” (see above);
- The two systems are similar in that they contain the same obligatory factors: Geographic position, altitude, geology, size and (for lakes) depth;
- Optional factors of System B can be used as desired by Member States and can be complemented with factors other than those mentioned in the WFD;
- The WFD descriptors of geology (in System A) refer to the dominating character (calcareous, silicious, etc.), expected to have the strongest influence on ecological quality of the water body;
- The WFD requirement that Member State must achieve the same degree of differentiation with System B as with System A is interpreted to mean that if System B is used, it should result in no greater degree of variability in type specific reference conditions than if System A had been used. Hence, if a lower number of types, using System B, results in equally low or lower variability of reference conditions values as would be given by System A, this would be acceptable;

- Water body specific reference conditions, within a range of values for the type as a whole, may be used in order to cope with natural variability within types.

According to EU (2003), "the two systems A and B are about the same in that the same obligatory factors are to be used in both: geographic position, altitude, size, geology and, for lakes, depth. The difference is that System A prescribes how water bodies shall be characterised spatially (ecoregions) and with respect to specific altitude, size and depth intervals, and that System B, besides lacking this prescription, permits the use of additional factors. It is up to Member States to decide on what system to use, and most Member States have indicated that they prefer to use System B".
Unlike the WFD CIS Guidance Document No. 5 on transitional and coastal waters, the REFCOND working group did not propose a common European typology system for inland surface waters. Member States sharing the same (eco) region, however, were encouraged to initiate activities to harmonise typology for inland surface waters on the most appropriate (eco)regional scale as soon as possible or latest in early 2003. This harmonisation should at least cover the types selected to be included in intercalibration.

Table 3.2: *EU WFD, ANNEX II, Chapter 1.2.1: Ecoregions and surface water body types for rivers*

System A	
Fixed typology	Descriptors
Ecoregion	Ecoregions shown on map A in Annex XI
Type	Altitude typology • high: > 800 m • mid-altitude: 200 to 800 m • lowland: < 200 m Size typology based on catchment area • small: 10 to 100 km2 • medium: > 100 to 1 000 km2 • large: > 1 000 to 10 000 km2 • very large: > 10 000 km2 Geology • calcareous • siliceous • organic

System B	
Alternative characterisation	Physical and chemical factors that determine the characteristics of the river or part of the river and hence the biological population structure and composition
Obligatory factors	• altitude • latitude • longitude • geology • size
Optional factors	• distance from river source • energy of flow (function of flow and slope) • mean water width • mean water depth • mean water slope • form and shape of main river bed • river discharge (flow) category • valley shape • transport of solids • acid neutralising capacity • mean substratum composition • chloride • air temperature range • mean air temperature • precipitation

1. Iberic-Macaronesian region
2. Pyrenees
3. Italy, Corsica and Malta
4. Alps
5. Dinaric western Balkan
6. Hellenic western Balkan
7. Eastern Balkan
8. Western highlands
9. Central highlands
10. The Carpathians
11. Hungarian lowlands
12. Pontic province
13. Western plains
14. Central plains
15. Baltic province
16. Eastern plains
17. Ireland and Northern Ireland
18. Great Britain
19. Iceland
20. Borealic uplands
21. Tundra
22. Fenno-Scandian shield
23. Taiga
24. The Caucasus
25. Caspic depression

Figure 3-11: *Ecoregions for rivers and lakes from ANNEX XI, MAP A, System A of the WFD*

The Nordic countries have preferred System "B", because it allowed a more free choice about how to designate types and type-specific conditions. The highest coastline during the last glaciation and the tree line, for example, were considered ecologically more relevant than using the fixed altitude classes prescribed in System A, and chemical measures of humic substances and calcium content were considered more relevant than the prescribed geology classes "organic" and "calcareous" (Wallin & Fölster 2002).
The intercalibration exercise is referred to in the Directive (Annex V section 1.4.1). Its objective is to harmonise the understanding of 'Good ecological status' in all Member States, and to ensure that this common understanding is consistent with the definitions of the Directive. The intercalibration exercise is carried out within 14 Geographical Intercalibration Groups (GIGs). These are groups of Member States that share ecological types of rivers, lakes and coastal/transitional waters, which facilitates comparison of monitoring results. Table 3.3 shows the GIG intercalibration types for Northern rivers, including Finland, Ireland, Norway, Sweden and the UK.

Table 3.3: *Description of common intercalibration types for the Northern GIG. From EU (2013).*

Type	River characterisation	Catchment area (of stretch)	Altitude & geomorphology	Alkalinity (meq/l)	Organic material (mg Pt/l)
R-N1	Small lowland siliceous moderate alkalinity	10-100 km^2	< 200 m or below the highest coastline	0.1 - 1	< 30 (< 150 in Ireland)
R-N3	Small/medium lowland organic low alkalinity	10-1 000 km^2		< 0.2	>30
R-N4	Medium lowland siliceous moderate alkalinity	100-1 000 km^2		0.2 - 1	< 30
R-N5	Small mid-altitude siliceous low alkalinity	10-100 km^2	Between lowland and highland	< 0.2	< 30

3.2.2 Examples for WFD river typologies that support environmental flow requirements

Slovenia

Many reports and studies for evaluation of environmental flow (EF) were prepared by the Institute for Water of the Republic of Slovenia (IfWRS) and financed by Ministry of the Environment and Spatial Planning. The decree was a compromise between experts' point of view and practical use of EF implementation. The following description is based on the presentation of Natasa Smolar-Zvanut from IfWRS during the workshop and information provided by Mielach et al. (2012).

In the process to identify appropriate methods for EF assessment from existing methods it was recognised that approaches based solely on hydrological indices are not suitable because they are not site specific. As a consequence, the 'rapid assessment method' was established with the aims of being quick to apply, based on basic hydrological data, site information including an inventory of habitats, and ecological and morphological information. The 'detailed assessment method' utilizes similar information, but in addition requires the sampling of zoobenthos and periphyton in different aquatic habitats of the relevant sections of river. The rapid assessment method is used unless the proposal is influenced by any one or more of the following factors:

- If the running water is in a preserved or legally protected area.
- If there are rare, endangered or protected species of flora and fauna in the running water or in the riparian zone.
- If the spawning grounds of fish are threatened by water use.
- If the river reach is affected by the water use over a long river section (i.e. for rivers with a catchment area more than 100km^2 a 'long river section' is deemed to be more than 200m).
- If the water abstraction is not returned to the river further downstream and is larger than 20% of mean annual minimum flow.
- If the public interest demands multi-designation use of the water
- If the inventory of habitats, the fieldwork or ecological survey work carried out during the application of the rapid assessment method raise any of the issues outlined above and hence require the application of detailed assessment method.

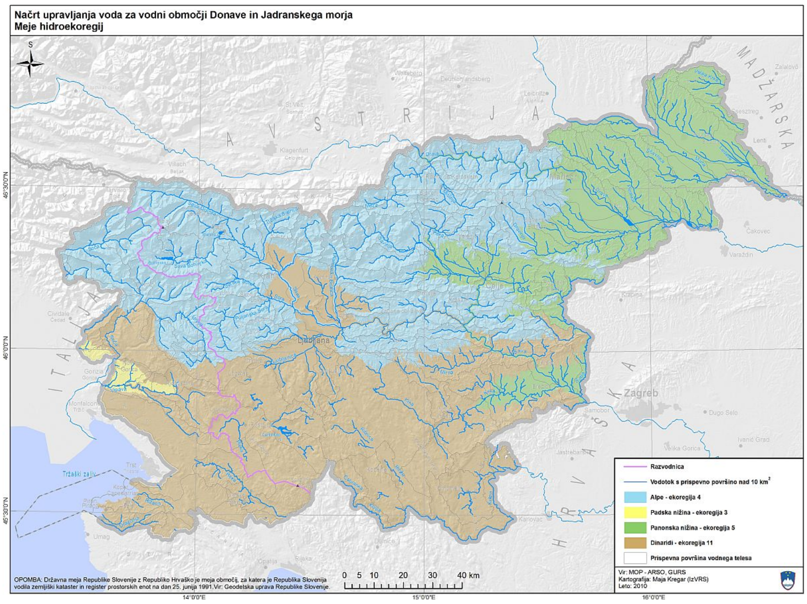


Figure 3-12: *Hydro-ecoregions in Slovenia. Presented by N. Smolar-Zvanut*

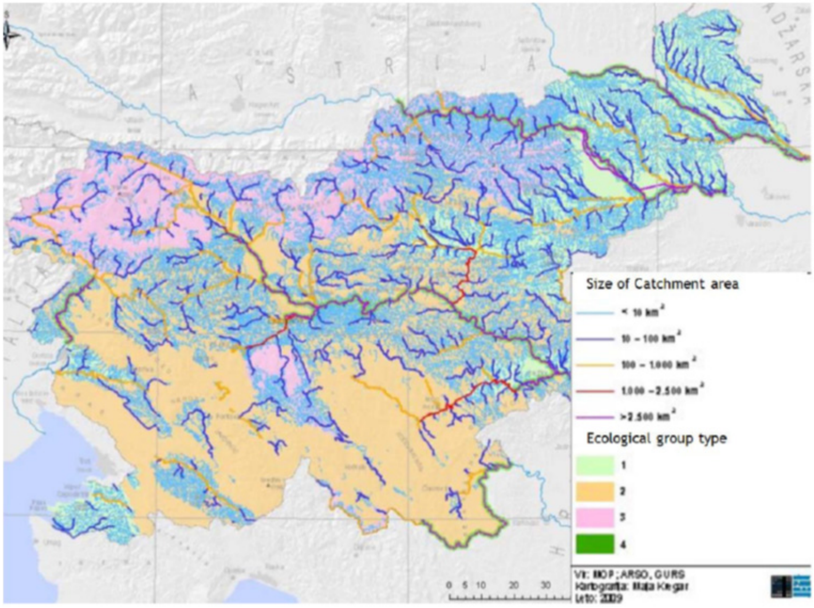


Figure 3-13: *Ecological group types and size of catchment areas for Slovenian rivers. From Mielach et al. (2012).*

The definition of EF for certain water uses is supported by prepared data layers with ecological types of rivers and the size of the catchment area (Fig. 3.12 and 3.13). A HER (hydroecoregions) typology defines a system of ecological regionalization with ecoregions according to Illies (1978) with application of altitude, catchment size and geology as mandatory surface water factors. For the estimation of EF, the catchment area and the ecological group type have to be extracted from Figure 3.13.

Using the hydrological method, EF shall be calculated on the basis of hydrological elements by means of the following formula:

$$EF = f \cdot MALQ_d$$

where

- f = a coefficient depending on:
  - Irreversible or reversible water abstraction;
  - The length of the river section with reversible water abstraction (point, short or long, whereby short is defined as less than 100 m in catchments ≤100 km^2 and less than 500 m in catchments >100km^2);
  - The quantity of abstracted water, defined with reference to the value of the mean flow at the abstraction site (MQ <> 50 m^3/s when catch. area >1000 m^3);
  - The ratio between mean water flow (MQ) and mean low flow ($MALQ_d$) (if $MQ/MALQ_d$ exceeds 20, the factor f shall be multiplied by 1.6 for watercourses in ecological type 1 and 2);
  - The ecological type group of watercourses (1 to 4);
  - size of catchment area (<10, 10-100, 100-1000, 1000-2500, >2500km^2);

- $MALQ_d$ = mean low discharge in a period and is the arithmetic average of the lowest annual mean daily flow (LQ) on the spot over a longer observation period (usually at least 30 years).

$$MALQ_d = \sum_{i=1}^{N} LQ_i$$

- $MALQ_d$ = mean small discharge
- LQ_i = lowest mean daily discharge in calendar year 'i'
- N = number of years in the observation period.

The equations were formed according to the correlation of the EF data provided in previous years, with data on the mean low flow at the withdrawal site.

Table 3.4: *Determination of factor f for reversible water withdrawals (Slovenian Water Act Annex 1). From Mielach et al. (2012)*

Ecological group type	Size of catchment area <10km²	10 - 100km²	100 - 1000km²	1000 - 2500km² and sQs < 50m³/s	> 2500km² or sQs > 50m³/s
Point abstraction					
1 [1]	0.7	0.7	0.5	0.4	
2 [1]	0.7	0.5	0.4	0.4	
3	0.5	0.4	0.3		
4					0.3
Short abstraction all year or long withdrawal in dry period					
1 [1]	1.2	1.2	1.0	0.8	
2 [1]	1.2	1.0	0.8	0.8	
3	1.0	0.8	0.7		
4					0.7
Long abstraction in wet period					
1 [1]	1.9	1.9	1.6	1.3	
2 [1]	1.9	1.6	1.3	1.3	
3	1.6	1.3	1.1		
4					1.1

[1] Factor f is multiplied by 1.6, if ratio between MQ and $MALQ_d$ at the withdrawal location is higher than 20.

Table 3.4 shows the values for multiplication factor f in the case of a reversible withdrawal. At first the catchment area and the ecological group type have to be extracted from Figure 3.13. An analysed section of Oplotnica river, for example, has a catchment size of 10 to 100 km^2 and belongs to ecological group type 3. The monitoring area shows mean flow (MQ) of 1.82 m^3/s and a mean low flow ($MALQ_d$) of 0.38 m^3/s. For point withdrawals (powerhouse is situated at the same location as dam or weir) factor f would be 0.4, leading to an EF of 0.15m^3/s, while for short withdrawals (derivation ≤100 m for catchment areas ≤100 km^2) factor f would be 0.8 resulting in a EF of 0.30 m^3/s. Finally for long withdrawals factor f depends on the period of the year. During the dry period (Dec. to Feb. and June to Sep.) the factor f of 0.8 leads to a EFDRY of 0.30 m^3/s while for the wet period (other months) a factor f of 1.3 results in EFWET of 0.49 m^3/s. (Mielach et al. 2012).

The value of EF may be changed according to the opinion of the impact of water use on the fish status and according to the nature protection policies.

UK

A comprehensive work for the development of environmental standards for the WFD has been done in the UK. Acreman et al. (2005) reviewed typologies and classification systems of relevance to the setting and implementation of environmental flow standards. They proposed "that a typology for environmental flow setting in the UK should be:

- Ecologically meaningful; thus, the typology should yield types that are ecologically distinct
- Readily amenable to the application of flow sensitivity targets; further to the above point, defensible criteria should be applicable for these types
- Based on readily available data sets
- Applicable from desktop setting – thus, based on parameters which do not necessitate field visits. Hence, preference is given towards methods which can be applied using a desktop analysis – in particular, broad scale data sets available at a catchment level, which are readily applied in a GIS setting, rather than site-based parameters which require field observation
- Hierarchical, to enable application across scales;
- Applicable alongside existing systems, which may cover different elements of the scale hierarchy – such as the RAM[2] framework."

The development of the UK river typology included the following main steps (Acreman et al. 2005, 2006):

1. Review of existing classifications
2. Selection of the most appropriate one (a typology based on macrophyte communities from 1500 sites, from Holmes et al., 1998)
3. Integration of other classifications (fish) to come up with a reasonable number of WFD-Types

Data from selected river sites and 733 gauging stations were used to construct classification trees, which allowed classifying all water bodies based on the parameters average annual rainfall, drainage area and base flow index from hydrology of soil types (Fig. 3.14). Table 3.5 shows the characteristics of the respective river water reach types.

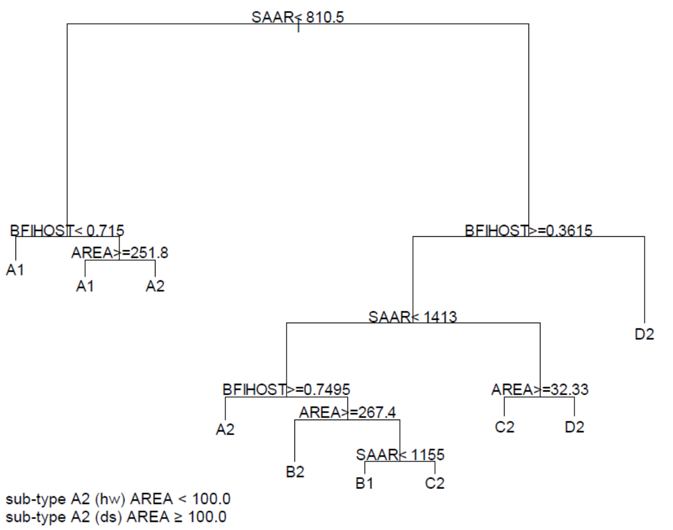


Figure 3-14: *Tree-based model for six river types. SAAR = average annual rainfall, AREA = drainage area, BFIHOST = baseflow index from hydrology of soil types. From Acreman et al. (2006).*

[2] The RAM (Resource Assessment and Management Framework) is a UK typology designed to be sensitive to ecological considerations.

The coupling between river types and minimum flow estimations was achieved by a workshop-based decision about abstraction limits for each of the river types (Table 3.6). According to Acreman & Ferguson (2010), these estimates contain many uncertainties, and further research is needed to confirm or correct them.

Table 3.5: *River water reach types based on Holmes et al. (1998). From Acreman & Ferguson (2010)*

Holmes *et al.* type	Holmes *et al.* sub-type	Final WFD48 type
A. Low altitude; low slope; eutrophic; silt/clay-gravel bed; smooth flow	A1 lowest gradients (0.8 ± 0.4 m km^{-1}) and altitudes (36 ± 25 m), predominantly clay	A1 as sub-type
	A2 slightly steeper (1.7 ± 0.8 m km^{-1}), low altitude (55 ± 38 m)	A2 (hw) headwaters as sub-type with catchment area <100 km^2
	Chalk catchments; predominantly gravel beds, base-rich	A2 (ds) downstream as sub-type with catchment area >100 km^2
B. Hard limestone and sandstone, low-medium altitude, low-medium slope; mesotrophic; gravel-boulder (mainly pebble-cobble), mostly smooth flow, small turbulent areas	B1 gradient (4.1 ± 9.9 m km^{-1}), altitude 93 ± 69 m	B1 as sub-type
	Hard sandstone, calcareous shales	
	B2 shallower than B1 (2.7 ± 10.7 m km^{-1}); altitude 71 ± 58 m	B2 as sub-type
C. Non-calcareous shales, hard limestone and sandstone, medium altitude, medium slope, oligo-meso-trophic; pebble, cobble, boulder bed, smooth flow with abundant riffles and rapids	C1 gradient 5.4 ± 6.5 m km^{-1}; altitude 101 ± 84 m; hard limestone; more silt and sand than C2; mesotrophic	C1 as sub-type
	C2 steeper than C1 (7.3 ± 10.8 m km^{-1}); altitude 130 ± 90 m; non-calcareous shales; pebble-bedrock; oligo-mesotrophic	C2 as sub-type
D. Granites and other hard rocks; low and high altitudes; gentle and steep slopes; ultraoligo – oligotrophic; cobble, boulder, bedrock, pebble; smooth with turbulent areas – torrential	D1 medium gradient (11.3 ± 15.6 m km^{-1}); low altitude (93 ± 92 m), oligotrophic, substrate finer than D2 (incl silt & sand); more slow flow areas than D2. Includes acid heaths	D1 as sub-type
	D2 high gradient (25.5 ± 33 m km^{-1}); high altitude (178 ± 131 m); stream orders 1 & 2, bed rock and boulder; ultra-oligotrophic, torrential.	D2 as sub-type
		Salmonid (juvenile salmon and trout spawning and nursery areas) – headwater streams

Table 3.6: *Standards for UK river types/sub-types for achieving Good Ecological Status given as % allowable abstraction of natural flow (thresholds for annual flow statistics). From Acreman & Ferguson (2010).*

Type or sub type	Season	Flow > Qn_{60}	Flow > Qn_{70}	Flow > Qn_{95}	Flow < Qn_{95}
A1	Apr.–Oct.	30	25	20	15
	Nov.–Mar.	35	30	25	20
A2 (ds), B1, B2, C1, D1	Apr.–Oct.	25	20	15	10
	Nov.–Mar.	30	25	20	15
A2 (hw),	Apr.–Oct.	20	15	10	7.5
C2, D2	Nov.–Mar.	25	20	15	10
Salmonid spawning &	June–Sep.	25	20	15	10
nursery areas	Oct.–May	20	15	Flow > Q_{80}	Flow < Q_{80}
(not chalk rivers)				10	7.5

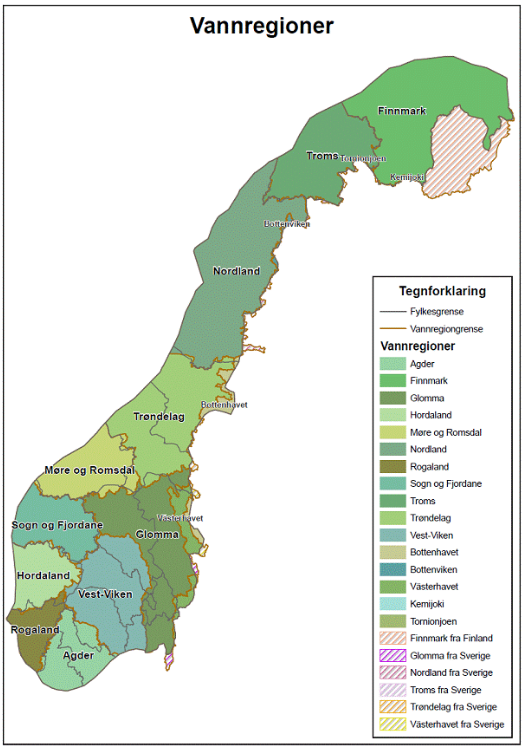
3.3 The Norwegian WFD Typology and linked classification systems

3.3.1 Definition of water bodies and river types

Figure 3.15 shows the Norwegian water districts ("vannregioner") and an example for a river water body in the Trøndelag river basin district. River water bodies were defined based on the following rules:

- Drainage area > 10 km^2 (recommended),
- Can be defined as collection of small streams ("bekkefelt")
- Can consist of several river reaches with small lakes in between
- Composed water bodies should have the same water type and condition class
- River water bodies can be defined as one REGINE[3]-field, parts of it or several REGINE-fields

Actual information about the WFD implementation in Norway can be found at:
www.vannportalen.no (methods for characteristic of water bodies, classification manuals, etc.)
http://vann-nett.no (maps and information sheets for selected water bodies and water districts)



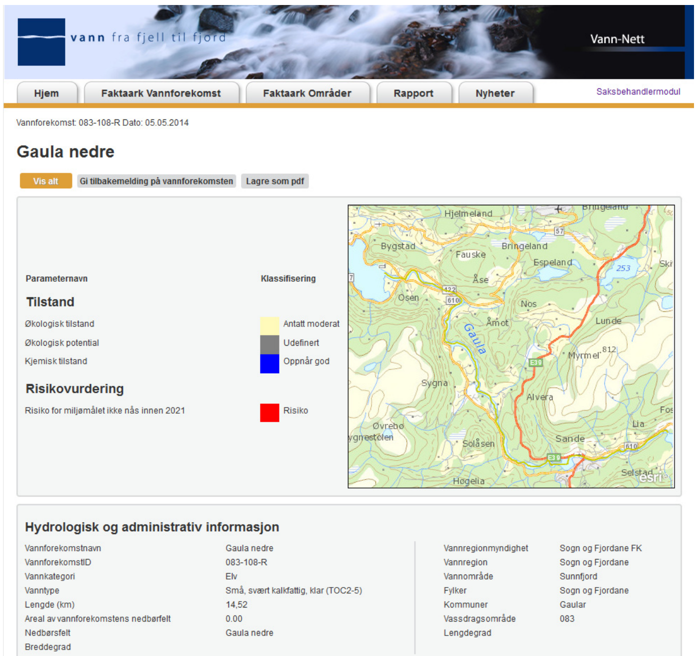


Figure 3-15: *Water districts in Norway (left, from http://lovdata.no/dokument/SF/forskrift/2006-12-15-1446) and example for the description of river water bodies in vann-nett.no (right)*

[3] REGINE is a river identification system for Norway developed by NVE.

__Table 3-7:__ Overview of eco- regions and parameter values for rivers. From Direktoratsgruppa Vanndirektivet (2013), translated.

Kriterium	**Parameter value**
Eco region (see map Figure 3.16)	• Østlandet • Sørlandet • Vestlandet • Middle-Norway • Northern Norway (outer) • Northern Norway (inner)
Elevation above sea level (climate zone)	• Lowland: < 200 m asl (should not be used north of Saltfjellet) • Woodland: 200-800 m, or below the tree line • Highland: > 800 m asl., or above the tree line
Lime content, Alkalinity	• Very lime-deficient: Ca < 1mg/l, Alk < 0.05 meq/l • Lime-deficient: Ca = 1 - 4 mg/l, Alk = 0.05-0.2 meq/l • Moderate lime-rich: Ca > 4 - 20 mg/l, Alk 0.2-1 meq/l • Lime-rich: Ca > 20 mg/l, Alk > 1.0 meq/l
Organic content	• Clear: Farge < 30 mg/l, TOC < 2 mg/l • Clear: Farge < 30 mg Pt/l, TOC 2 - 5 mg/l • Humic: Farge 30-90 mg Pt/l, TOC 5-15 mg/l • Very humic (rarely occuring): Farge >90 mg Pt/l,TOC >15 mg/l
Turbidity (only lowland water courses)	• Clear: STS < 10 mg/l (anorganic content at least 80%) • Loam-affected: STS > 10 mg/l (anorganic content at least 80%) • Glacier-affected: STS > 10 mg/l (anorganic content at least 80%)
Size of river - drainage area	• Small: <10km^2 • Medium: 10-100 km^2 • Medium to large: 100 – 1000 km^2 • Large: 1000-10 000 km^2 • Very large: > 10 000 km^2

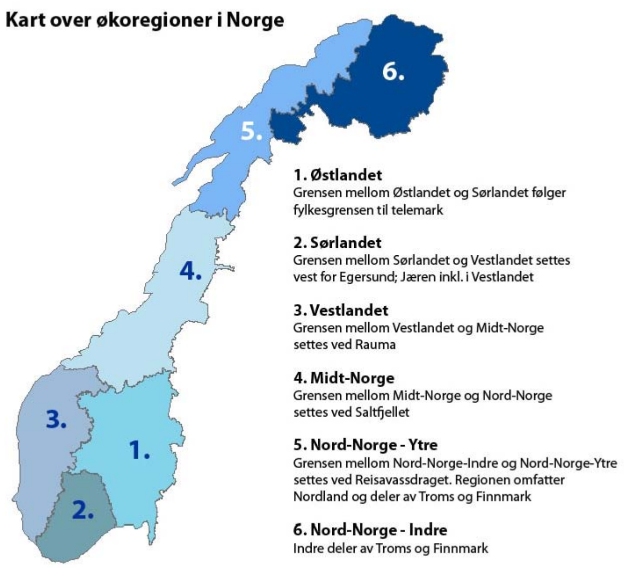


__Figure 3-16:__ Eco regions in Norway. Fromhttp://www.vannportalen.no/hovedEnkel.aspx?m=59162&amid=3522162

Table 3-8: *Common river types in Norway. From http://www.vannportalen.no/hoved.aspx?m=47396&amid=2109711, translated*

Elevation region	Type no.	Nordic index	Ecostat IC type Northern GIG	Type description	Size km^2	Ca mg/l	Org. content mg Pt/l
Lowland	1	L2+L5	R-N2	small-medium, lime-deficient, clear,	10 - 1000	1-4	< 30
	2	L3+L6	R-N3	small-medium, lime-deficient, humic	10 - 1000	1-4	> 30
	3	L1+L4	R-N1+ R-N4	small-medium, lime-rich, clear	10 - 1000	> 4	< 30
	4			small-medium, lime-rich, humic	10 - 1000	> 4	> 30
	5			small-medium, lime-rich, turbide	10 - 1000	> 4	< 30
	6	L8		large, lime-deficient, clear	> 1000	1-4	< 30
	7	L7		large, lime-rich, clear	> 1000	> 4	< 30
Woodland	8			small-medium, very lime-deficient, clear	10 - 1000	< 1	< 30
	9	B2+B5	R-N5	small-medium, lime-deficient, clear	10 - 1000	1-4	< 30
	10	B3+B6		small-medium, lime-deficient, humic	10 - 1000	1-4	> 30
	11			small-medium, lime-rich, clear	10 - 1000	> 4	< 30
	12			small-medium, lime-rich, humic	10 - 1000	> 4	> 30
	13	B8		large, lime-deficient, clear	> 1000	1-4	< 30
	14			large, lime-rich, clear	> 1000	> 4	< 30
Mountains	15			small-medium, very lime-deficient, clear	10 - 1000	< 1	< 30
	16	H2+H5	R-N7	small-medium, lime-deficient, clear	10 - 1000	1-4	< 30
	17			breelver (small-medium, lime-deficient, turbide)	10 - 1000	1-4	< 30
	18			small-medium, lime-rich, clear	10 - 1000	> 4	< 30

Norwegian water bodies are grouped into 6 ecoregions (Figure 3.16) depending on climate and biogeographic distribution patterns for various biological quality elements, such as fish or invertebrates. In particular fish has an immigration history that leads to a larger number of natural species in the ecoregions Østlandet and Øst-Finnmark than in Vestlanded and outer regions of Northern Norway (Lyche Solheim et al. 2004, Sandlund & Hesthagen 2011).
The existing WFD typology (Tables 3.7 and 3.8) contains the obligatory parameters (ecoregion, elevation, catchment size, Ca- and humic content as geological indicators) and information about the acid neutralising capacity (alkalinity) as optional factors.

3.3.2 Classification system for biotic elements and fish within the WFD

The ecological quality elements to be used in classification of ecological status according to the WFD which are relevant for Norwegian rivers are periphyton, zoobenthos and fish. We have no river water bodies with self-sustaining phytoplankton communities, and macrophytes (mainly mosses and higher plants) have so far not been included in the classification system for rivers. The main reason is that data on the occurrence, distribution and ecology of these groups in Norwegian rivers are scarce.

For periphyton (benthic algae), response curves and indices for classification of ecological status have been developed for the chemical parameters eutrophication and acidification (see Schneider & Lindstrøm 2009, 2011, Schneider et al. in press, Direktoratsgruppa Vanndirektivet 2013). The relationship between hydromorphological changes and periphyton in rivers has not been considered.

The available indices for assessing the ecological status of zoobenthos in rivers also mainly relate to eutrophication (nutrients, organic load) and acidification (cf. Direktoratsgruppa Vanndirektivet 2013). In some rivers, the status of the red-listed species river mussel (*Margaritifera margaritifera*) may be used as an indicator of hydromorphological changes. The river mussel is sensitive to a number of environmental impacts, including reduced water flow and increased sedimentation rates, and it is therefore a good indicator, but it is only present in a few rivers.

In most parts of Norway, i.e. along the coast and in the mountain areas, surface waters have an extremely low ionic content. In southern Norway, acid precipitation has been the major chemical encroachment, while eutrophication in the form of nutrient enrichment and organic load has been restricted to a few lowland areas. Water chemistry is a support parameter which has been developed over many years, and which until the emergence of the WFD was a parameter often used as a proxy for ecological status in lakes and rivers. In Norway, chemical parameters such as pH and ANC (acid neutralizing capacity) have been used for decades in the monitoring of water quality in rivers and lakes impacted by acid precipitation. Consequently, we have a relatively good understanding of the relationship between acid water and fish (e.g. Hesthagen et al. 2008).

The role of fish in the assessment of ecological status of limnic water bodies in Norway has recently been reviewed, and a number of systems for classification of different water bodies in relation to various environmental impacts have been proposed (Sandlund et al. 2013). Some of these, in particular pertaining to lakes, have been included in the new guidelines for classification of ecological status (Direktoratsgruppa Vanndirektivet 2013).

In the guidelines (Direktoratsgruppa Vanndirektivet 2013), indices for reduced water flow and water covered area in regulated rivers have been included. The impact of reduced water flow (and thereby water covered area) is assumed to be most biologically relevant when measured as the seven-day minimum (Q_{min7d}) in winter and in summer (cf. also Sandlund 2009). The index for reduced water flow is Q_{minreg} / Q_{minnat}, i.e. the regulated minimum vs. the natural minimum (Table 3.9). For autumn-spawning salmonids, such as brown trout and Atlantic salmon, seven-day minimum in winter is most critical. It is also recommended that during sampling of fish in the field, a practical assessment of the present water covered area relative to the expected water covered area on the specific sampling localities should be done.

Table 3-9 *Classification based on the support parameters water flow and water covered area. Changes in water flow is represented by in winter or in summer under regulated conditions (Q_{minreg}) relative to natural minimum 7-day mean (Q_{minnat}): Q_{minreg}/Q_{minnat}. Water covered area relates to assessments made on the sampling locality during field work (electrofishing), where A_{pre} is estimated water covered area under natural conditions, while, A_{now} is the water covered area under present (regulated) conditions.*

Pressure	Very good	Good	Moderate	Poor	Very poor
Q_{minreg}/Q_{minnat} *Winter*	>0,80	0,80 - >0,60	0,60 - >0,40	0,40 - >0,25	≤0,25
Q_{minreg}/Q_{minnat} *Summer*	>0,70	0,70 - >0,50	0,50 - >0,30	0,30 - >0,20	0
A_{now}/A_{pre}	>0,90	0,90 – 0,75	0,75 - 0,50	0,50 - 0,10	<0,10

Sandlund et al. (2013) suggest indices for the degree of fragmentation of rivers due to human encroachment, and for barrier effect of dams etc. to fish migration (Figure 3.17). Degree of fragmentation is simply the river stretch which was naturally accessible to upstream fish migration divided by the number of artificial barriers. Barrier effect focuses on the portion of the stretch of river which under natural conditions was accessible to upstream migration from a lake or the sea, and which has been made inaccessible by a man-made barrier. Indices based on the density of juvenile salmonids in rivers as measured by electrofishing are also suggested by Sandlund et al. (2013). This has been relatively well developed for rivers affected by acidification, but is still under development for hydromorphological changes.

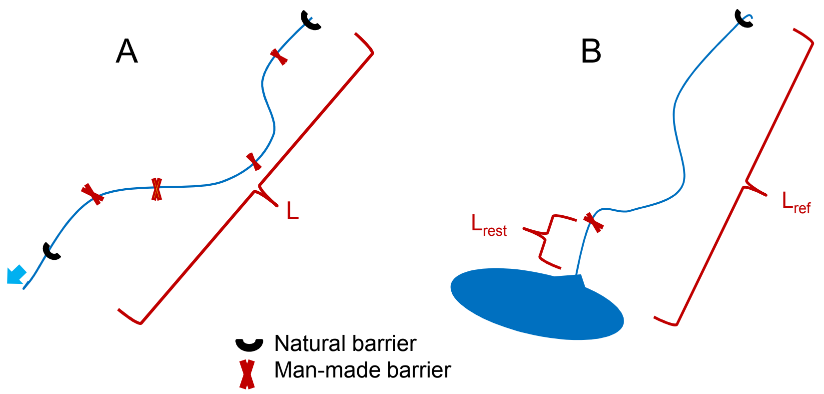


Figure 3-17: *Schematic representation of degree of fragmentation (A); and barrier effect (B). Degree of fragmentation: FG = 1 - 1/(N+1), where N is the number of man-made barriers to upstream migration on the river section (L) between two natural barriers. Barrier effect: BE = 1 – (L_{rest}/L_{ref}), where L_{ref} is the length of river section upstream from a lake to the first natural barrier to upstream migration, and L_{rest} is the length of river from the lake to the first man-made barrier.*

There are a series of remaining issues regarding fish as an ecological quality element and hydro-morphological changes in rivers. This regards both water flow/water covered area, sediment transport / sediment packing of substrate, and fragmentation/migration barriers/river discontinuities. In relation to hydropower, environmental flows, and the impact on fish, the main challenge is on the one hand, to identify the relevant hydrological and hydraulics parameters which can be easily and cheaply measured, and on the other hand, the relevant parameters regarding the fish population which also can be measured in a simple way. For the implementation of the WFD, monitoring and assessment methods requiring costly and detailed sampling of data will be of little use, as sufficient funds will not be available. Research into approaches to hydrological river classification of relevance in this context should aim to develop simple methods.

3.3.3 The "Nature Types in Norway" (NiN) Classification

The system "Nature types in Norway" (in Norwegian: "Naturtyper i Norge"; NiN) describes an approach to assign nature types to all areas of Norway (terrestrial, freshwater and marine areas) at different scales. A nature type is defined as "a unique type of nature that includes all plant- and wildlife and the environmental factors acting there" (Halvorsen et al. 2009). The NiN system has been developed by a number of Norwegian experts on behalf of the Norwegian Biodiversity Information Centre (Artsdatabanken, www.artsdatabanken.no). It claims to be an integrated tool to classify and describe variation in the Norwegian nature and intends to meet the requirements of all potential users (e.g. municipalities, Public Road Administration, etc.), to support an integrated planning of nature use and to allow communicating recent knowledge about nature variation to the society. NiN covers all Norwegian territories including the marine zones and the Norwegian Arctic (Svalbard and Jan Mayen).

Figure 3.18 illustrates that the actual version of the NiN system (version 1.0 and 1.1) is based on five nature type levels (scales) on the vertical axis: Region, Landscape (LA), Landscape Part (LP), Nature System (NS), and Living Medium (LI). Each of them has up to three levels of generalisation (Basis Type, Major Type, Major Type Group), which are placed above each other in the figure between the horizontal lines that separate the nature type levels. The horizontal axis groups the nature types depending on the sources of variation, e.g. regional ecoclines or landform variation.

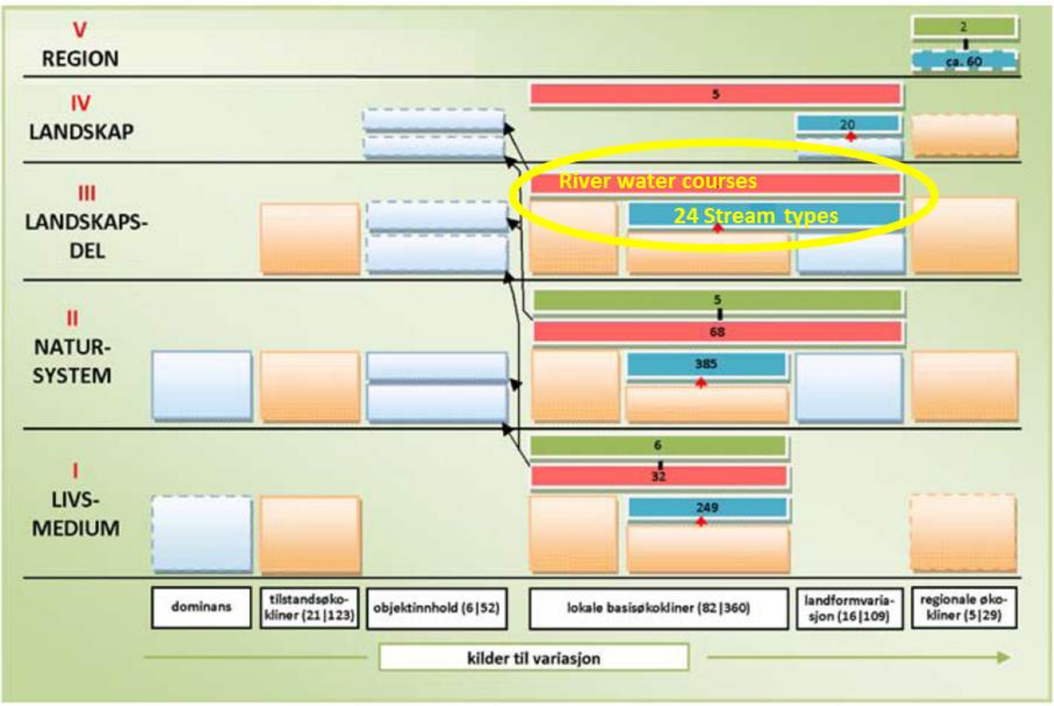


Figure 3-18: *Spatial scales and variation sources of the NiN 1.0 Classification. From Halvorsen et al. (2009), modified.*

Figure 3-19: *Examples for NiN stream types. (a) Slow-flowing river; Glomma close to the inlet of Lake Øyeren, (b) River rapids; Sjoa river in Nedre Heidal. From Halvorsen (2009)*

River water courses ("elveløp") and freshwater lakes are represented as LP Major Type ("Landskapsdel-hovedtype"), see Figure 3.18. This LP Major Type includes 24 river Basis Types ("Landskapsdel-grunntype"), ranging from the "clear lime-deficient slowly flowing river" to the "humic moderately lime-deficient river at water falls and water fall runs". Figure 3.19 illustrates two of the types.

The NiN system is linked to the water body typology of the WFD. The LP Major Types "River water course" and "Freshwater lake" correspond to river and lake water bodies defined within the WFD. The 24 Basic Types for rivers in NiN were derived by combining river types of the WFD with four slope classes (L. Erikstad, pers. comm.). The threshold values for the slope were inspired by the Rosgen stream classification (Rosgen 1994). The occurrence of geomorphological stream types such as braided rivers or meanders is included into NiN 1.0 as "landform variation" on different scale levels, as shown in Tab. 3.10.

Table 3-10: *Relation between river landform units and nature types (Major Types and Basis Types) at the four nature type levels (NiN 1.0). ++, + strong relation, <<,< one-sided correlation, where the land form unit is always related to a given nature type. From Halvorsen (2009), translated, without comments and colors.*

Nr	Landform Group	Relation between landform and Major Type at level				Includes in the description for the Major Type at level			Composed landform
	Landform-Unit	LI	NS	LP	LA	NS	LP	LA	
Deposition forms related to flowing water (Avsetningsformer, AR)									
AR-1	Delta			<<					
AR-2	Clay plain			++	+				
AR-3	River plain		++						
AR-4	Alluvial fan		++				2		
AR-5	River bank		++	<<		1	2		x
AR-6	Levee		++	++		1	2		x
River forms (Elveløpsformer, EL)									
EL-1	Braided river course			<<			1		x
EL-2	Meander		+	<<,+	<		1		
EL-3	Oxbow lake			<<,+	<		1		
EL-4	Blind valley			<<			1		
EL-5	Subterranean river		<1	<<2		1	2		x

The NiN system is currently under revision, and a new version (2.0) will be published in the autumn of 2014. The new version will include, i.a., the following improvements (L. Erikstad pers. comm.):

- The entire classification of the WFD can be linked to NiN allowing free water masses to be classified as nature systems. Here the same parameters and for a large part the same thresholds as in the WFD will be used. Nature systems linked to the bottom types (river beds and lake floors) will still be used and in combination this will mean a possibility for a much more detailed classification on the nature system level.
- There will be much clearer rules for the assignment of nature types. These will be linked to how much ecological difference there is between types. Ecological difference will be defined based on generalised lists of species.
- The "Landscape Part" will be replaced by "Nature type complex" or "Nature complex", defined as a cluster of nature systems that naturally belong together such as river channels.
- For rivers, the energy (reflected in the slope) will be one of the most important parameters for the classification of the nature complex river channel.

As a consequence, the river classification of the NiN system will be fully linked to the existing WFD typology for river and lake water bodies on the nature system level. At the same time it will allow a more detailed description of rivers by including river bed characteristic as the parallel nature system and slope as the main parameter to classify river channels.

4 Key parameters in river type classification for e-flow targets

4.1 E-flow targets and scope of the current study

Environmental flow (e-flow) is a term covering the quantity, timing, duration, frequency and quality of water flows required to sustain freshwater, estuarine and near-shore ecosystems and the human livelihoods and well-being that depend on them (Acreman & Ferguson 2010). A wide variety of methods including the Building Block Methodology (BBM) has been developed for its assessments (e.g. Bakken et al. 2012).

In Norway, assessing e-flow is normally a compromise between ecological, economical and social factors (eg. fish, fishing, landscape, costs). For small hydro power plants (< 10 MW), it is common to use the Q_{95} (summer/winter), but the effects are not well documented. For large hydro power plants (> 10 MW), the effects on the river system are usually well documented (long history), and a combination of methods including the BBM is used for assessing the e-flows based on a sufficient data set of hydrological and biological data (E. Brodtkorb, workshop presentation).

In connection with the revision of a large number of hydro power licenses, there is a need to obtain better estimates than Q_{95} for e-flow assessments by taking into account river morphology. Eco- hydrological threshold-values in particular for water-covered area (WCA) are required. The WCA (given in m^2 water surface area for a defined river section or as mean wetted width in m^2/m) is an important parameter for the assessment of the biological conditions in rivers and used for modelling tools such as IB Salmon (Hedger et al. 2013).

The workshop and planned river classification project focus therefore on the following questions:

1. What is the relationship between water flow and water-covered area (WCA)?
2. How can we establish the response curve for WCA vs. Fish status?

Several techniques can be used to classify rivers and establish flow-ecology linkages. A consensus of experiences and knowledge of a group of international scientists has been integrated into the "Ecological Limits of Hydrologic Alteration" (ELOHA) framework (Poff et al. 2010), see Figure 4-1.

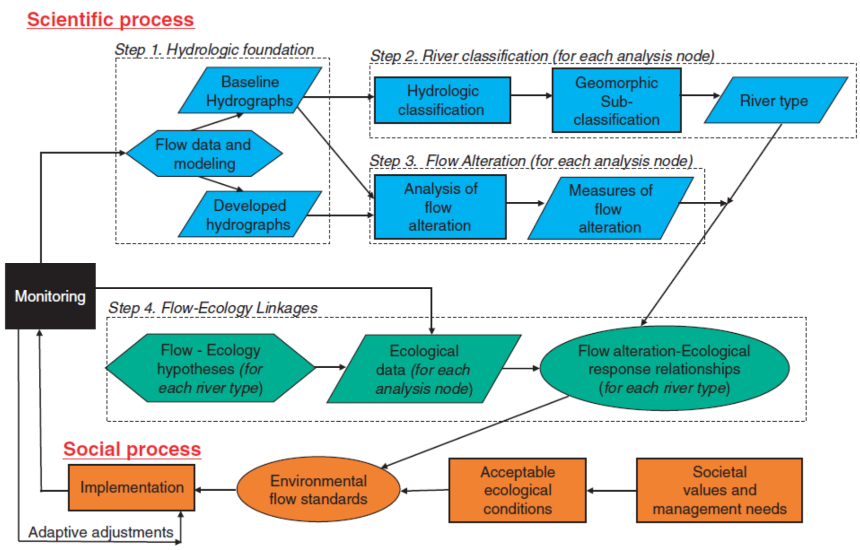


Figure 4-1: *Scheme of the processes of the ELOHA framework. From Poff et al. (2010).*

In the ELOHA framework, river classification is included as a statistical process of stratifying natural variation in measured characteristics among population of streams and rivers to delineate river types that are similar in terms of hydrologic and other environmental features. It is a top–down or a priori classification.

P. Vezza presented a substantially different bottom-up approach, where meso-scale habitat models were combined with a catchment classification technique. The catchment classification included fish community requirements for seven target species and hydro-morphological parameters in the Piedmont Region (Italy). It was found that water depth, mean column velocity, substrate, cover and HMU type were the most important variables for fish distribution on the meso-habitat scale. For the classification of entire catchments with respect to minimum flow, a regression tree approach was used, which identified the latitude, longitude and elevation as key parameters (Figure 4.2). The catchment centroid coordinates are significant in terms of total annual precipitation and climate, which affect runoff and the magnitude of discharge. The maximum elevation delineated a region characterized by higher water availability as a result of higher rainfall, snowpack storage and the presence of glaciers (Vezza et al. 2011).

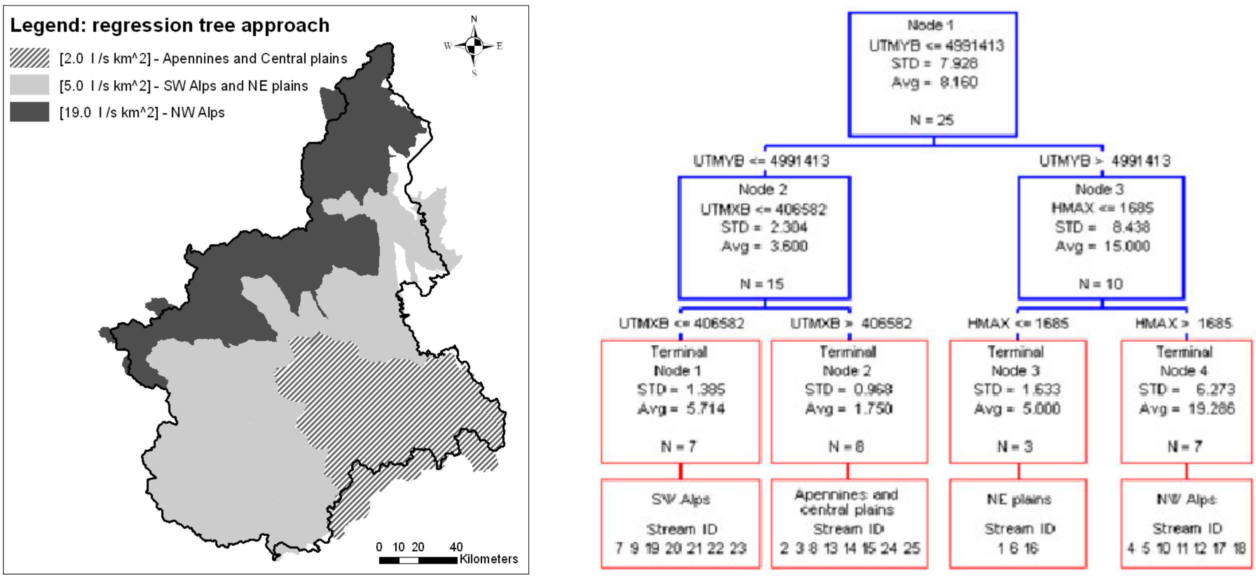


Figure 4-2: *Regression tree obtained using the minimum environmental flow values as target variable and the catchment/stream characteristics as independent variables. Presented by P. Vezza.*

4.2 Key parameters

Figure 4-3 presents the relevant hydro-morphological parameters which were suggested during the workshop. Parameters similar to obligatory or optional factors mentioned in System B of the WFD are marked in bold.

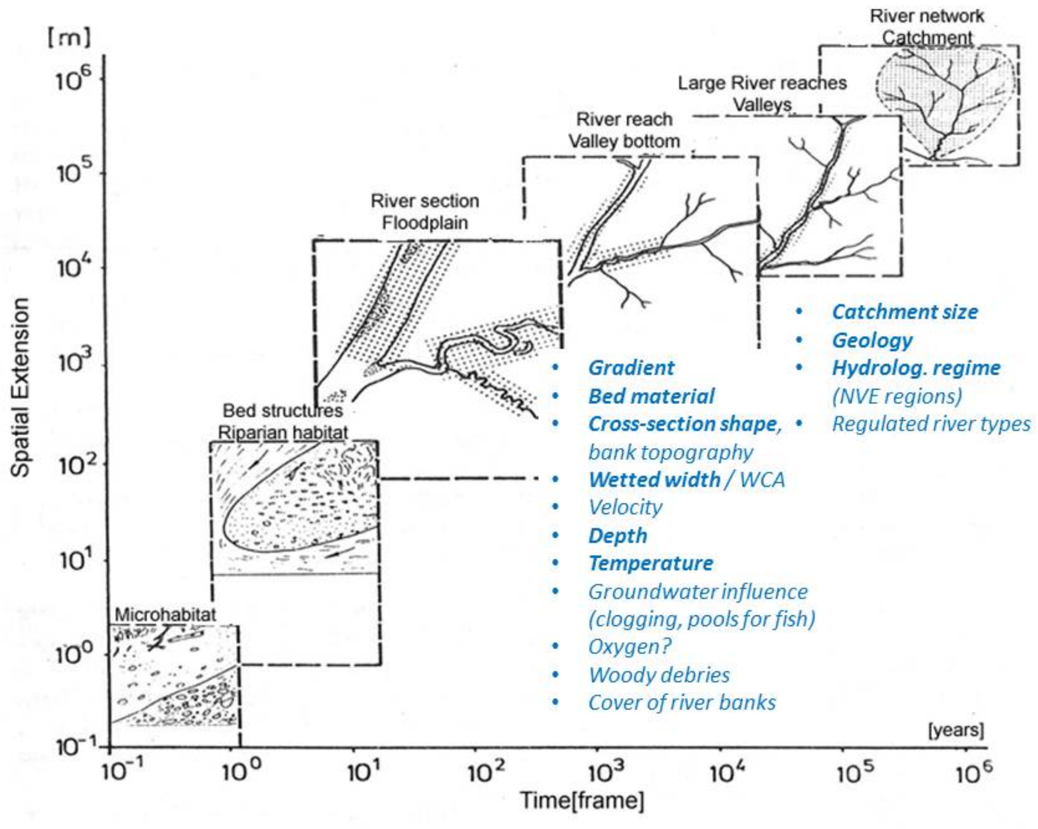


Figure 4-3: *Necessary hydro-morphological parameters for different scales suggested during the workshop. Parameters similar to obligatory or optional factors mentioned in System B of the WFD are marked in bold. Background-figure presented by J. Aberle.*

Table 4.1 allows a comparison of the parameters suggested during the workshop with those included into the existing Norwegian river typologies (mesohabitat-classification, WFD- and NiN typology), characteristics used for low flow and flood estimation (Chapter 3.1.3), parameters investigated by Vezza et al. (2011) and the parameters of System B of the WFD. Parameters occurring more than twice are marked in grey.

The comparison confirms the importance of the obligatory parameter of the WFD (Ecoregion, catchment area size, elevation). Other key parameters based on the table are the slope, the length of the main stream, mean water depth, mean flow velocity and the proportion of dissolved oxygen.

Table 4-1: *Overview over relevant parameters suggested during the workshop, in the Norwegian meso-habitat classification (Borsanyi 2005), for meso-habitats and watersheds (Vezza et al. 2011), for low flow and flood estimation (Chapter 3.1.3), in the Norwegian WFD and NiN typology and in System B of the WFD.*

Parameter	**Work-shop**	**N HMU** (B. 2005)	**HMU** (Vezza et al. 2011)	**WS** (Vezza et al. 2011)	**Flow estim.** (Ch. 3.1.3)	**Norw. WFD Typol.; NiN**	**WFD System B**	**Note**
Catchment and climate characteristics								
Catchment area size	x			x	x	x	x (obl)	
Centroid longitude				x		x	x (obl)	Ecoregion
Centroid latitude				x		x	x (obl)	Ecoregion
Max. elevation				x				
Min. elevation				x				
Mean elevation				x		x	x (obl)	
Range of altitude				x				
Mean catchment slope				x				
Catchment land cover %				x	x			
Mean annual precipitation				x	x		x	
Mean annual temperature					(x)			
Hydrological and morphological river characteristics								
Length of main stream				x	x		(x)	
Regulation type	x							
Hydrological regime	x							
Mean annual specific runoff				x	x			
Specific discharge exceeded 95 % of all days				x				
Mean slope	x	x	x	x	x	(x)*	x	*only NiN
(Mean) Water depth	x	x	**x**				(x)	
(Mean) Wetted width	x						(x)	
(Mean) Flow velocity	x	(x)*	**x**					*Surf. Vel.
Flow velocity stand. deviation			x					
Froude number		(x)[4]	x					
Substrate (Bed material, shelter)	x		**x**					
Cross-section shape	x							
HMU type (Run, riffle, ..)		x	**x**					
Other river characteristics								
Water temperature	x		x					
Min water temperature (winter)				x				
Max. water temperature (som.)				x				
Turbidity / susp. sediment						x		
Humic content						x		
Lime content						x		
Water pH			x					
Proportion of dissolved oxygen	x		x	x				
Cover (overhanging trees etc.)	x		**x**					
Woody debries	x							
Groundwater influence	x							

[4] Fr number can be related to water surface pattern, cp. Escudero-Uribe (2011)

5 Compilation of Norwegian data on wetted area and flow for various rivers

5.1 Introduction

The wetted area (given in m^2 water surface area for a river section of defined length or as mean wetted width in m^2/m) is an important parameter for the assessment of the biological conditions in rivers (Figure 5-1). Wetted width, together with altitude, distance from source, catchment area, slope, air temperature, presence/absence of lake upstream, is one of the environmental variables used to calculate the European Fish Index (EFI) supported in the Fish-based Assessment Method for European rivers (Schmutz 2004). Fish population models such as IBSalmon (Hedger et al. 2013) require the mean wetted area for river section lengths of 50 m as input parameter.

Figure 5-1: *Wetted width for two transects of a river in the Norwegian mountains. The dashed lines indicate the water line along the shore for the actual flow conditions.*

Based on a simple illustration of one type of a river cross-section in Figure 5-2, it can easily be understood that the severity of the reduction in flow for aquatic organisms is affected by the geometry of the individual transect. For uniform flow, this profile represents a transect with a threshold value ("break point"), where the wetted width starts to decrease rapidly with decreasing discharge when the water level falls below a profile-specific threshold.

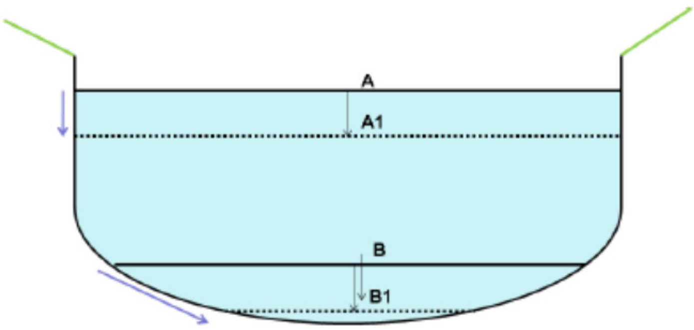


Figure 5-2: *The figure illustrates a simplified cross-section of a river where the levels A and B are natural flow conditions (typically wet and dry periods) where A1 and B1 illustrate the water level after certain abstraction of water. From Acreman, in Bakken et al. (2012).*

Wetted width and wetted perimeter have therefore been used to define minimum flows, assuming that the critical minimum discharge is supposed to correspond to a break point in the wetted perimeter vs. discharge curve (Gippel & Stewardson 1998). Filipek et al. (1987) found that for Arkansas streams breakpoint occurs at approximately 50 % of the mean flow ($Q/Q_{MF} = 0.5$). Tennant (1976) reported that 10 % of the mean flow ($Q/Q_{MF} = 0.1$) provided about 50 % of the wetted perimeter, while flows greater than 30 % of the average flow provided close to maximum wetted perimeter. The appearance of the break in the shape of the curve depends on the relative scaling and on the channel geometry. The position of the break has to be defined using mathematical techniques (Gippel & Stewardson 1998).

***Figure 5-3**: U-profile with fine substrate and flat river bed (left) and deep V-profile (right). From Størset (2012).*

A recent NVE report (Størset 2012) recommends accounting for the shape of the river profile when the capacity of a by-pass valve[5] in small hydro power plants is planned (Figure 5-3). Two profile shapes, the V- and the U-profile, were theoretically investigated as extreme cases when it comes to the decrease of water-covered area at abrupt discharge reductions. In the V-profile, the water-covered area decreased almost linearly with discharge, whereas the U-profile showed almost no reduction until a threshold value was reached. These calculations were conducted for steady uniform flow (HECRAS), hereby simplifying the naturally occurring flow conditions. Reported field measurements at the rivers Vigda, Skauga and Osaelva in Trøndelag showed that the reduction of water-covered area was small if a discharge of about 50 % of the mean flow was released into the river (Størset 2012).

5.2 Data sources and their suitability

For the compilation of Norwegian data on wetted area, the following potential data sources were investigated:

- A pilot study from SINTEF (Zinke & Carnerero 2014)
- Data from river studies performed by SINTEF, NTNU, NINA and others
- Publicly available biological reports from NINA and others
- NVE data from flood modelling studies
- Photo documentation of hydro power licence applications available at NVE's webpage

The financial frame for the current study required a selection of data sets and a restriction to data sets where both the wetted width and the respective discharge were directly provided.

[5] The by-pass valve ("omløpsventil") has to open automatically in case of unexpected turbine stops and provide enough flow in the downstream river.

5.2.1 SINTEF pilot study

The study (Zinke & Carnerero 2014) included data from 10 rivers that are natural habitats for Atlantic salmon (*Salmo salar*) in Norway, as shown in Figure 5-4. The rivers were located in various geographic regions including the northern, central and southern part of Norway, with catchment areas between 88 and 6257 km^2.

Wetted width data were extracted from the public aerial image webpage (www.norgeibilder.no), which contains geo-referenced images of different flight dates and spatial resolutions.

Discharge data was taken from the official hydrological data base of NVE. In total, 29 river reaches were selected for the analysis based on the following criteria, in order to obtain the wetted width of a selected river reach as function of the discharge:

- The river reach was situated close to a NVE gauge station where discharge data series were available
- Two or more aerial images from different dates with a spatial resolution of ≤ 1m were available for the reach.
- The discharges of the river for the flight dates were provided in the NVE data base.

A geographical information system (GIS) was used to extract the wetted width data of the rivers from aerial images, as illustrated in Figure 5-5. The distance between transects was no larger than half of the bankfull width, hereby covering the longitudinal width variations within the reach. The length of the investigated river reaches ranged from 200 to 2,500 m. The reaches started upstream of the gauge station and reached to the first significant tributary downstream of the gauge station, i.e. over a distance where the discharge measured at the gauge station could be considered as representative.

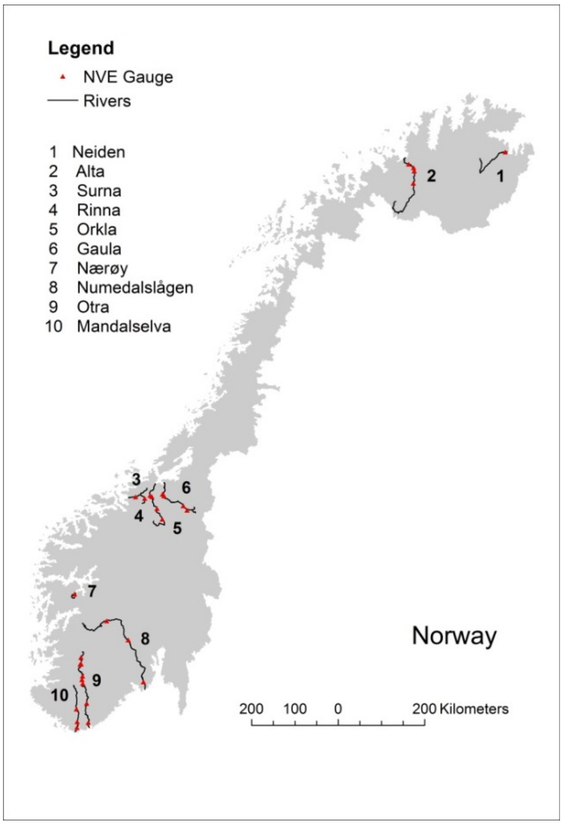


Figure 5-4: *Overview of the rivers and gauges included into the study. From Zinke & Carnerero (2014).*

For most of the investigated rivers, the quality of the aerial images was sufficient for identification of the shore line with an accuracy of ≈ 1 m. Difficulties occurred in case of very small rivers, overhanging trees or unfavourable light conditions during the flight.

Figure 5-5: *Example for extraction of wetted width transects for the Orkla river, Station 121.22, aerial image from 15 September 2009. From Zinke & Carnerero (2014).*

5.2.2 Wetted width data from river studies performed by SINTEF, NTNU, NINA and others

Some river studies performed by SINTEF, NTNU, NINA and others included field surveys and hydrodynamic model applications with information about wetted width and discharge for selected reaches.
The following readily available data were included:

- Discharge measurement data from five rivers (Ingdalselva, Orkla, Daleleva, Glomma, Lower Nidelva, Gråelva)
- 1D and 3D Modelling results from previous and on-going SINTEF projects (Nidelva, Surna, Daleelva, Mandalselva)
- 1D modelling results from NTNU for Orkla (provided by N. Timalsina)
- Data from NINA for Nausta (provided by R. Hedger)
- Data from Osaelva (Størset 2012)

Figure 5-6 shows the relationship between wetted area W and flow ratio Q/Q_{MF} (where Q is the actual flow and Q_{MF} is the annual mean flow) for a river reach of River Mandalselva near Krossen as an example. The chart is based on the results of a 1D hydrodynamic modelling for nine investigated cross-sections (Sauterleute 2012), covering a discharge ratio range between 0.2 and 3 Q/Q_{MF}. The flow conditions of this reach are represented by the NVE gauging station 22.4 Kjølemo, which has a catchment area of 1757 km^2 and a Q_{MF} of 82.7 m^3/s. For this station, the following flow statistics were determined (Væringstad and Hisdal 2005, NVE database; see list of abbreviations for the discharge definitions):

- $Q_{CLF} / Q_{MF} = 0.092$
- $Q_{min7d,S} / Q_{MF} = 0.127$ (s = summer)
- $Q_{min7d,W} / Q_{MF} = 0.149$ (w = winter)
- $Q_{MAF} / Q_{MF} = 5.2$

For five of the cross-sections, the wetted width increases nearly monotonic from a value between 90 and 110 m at 0.2 Q/Q_{MF} to a value between 110 and 135 m at 3 Q/Q_{MF}. In contrast, four of the nine cross-sections have wetted width between 10 and 70 m at the lowest investigated flow ratio and show a breakpoint.

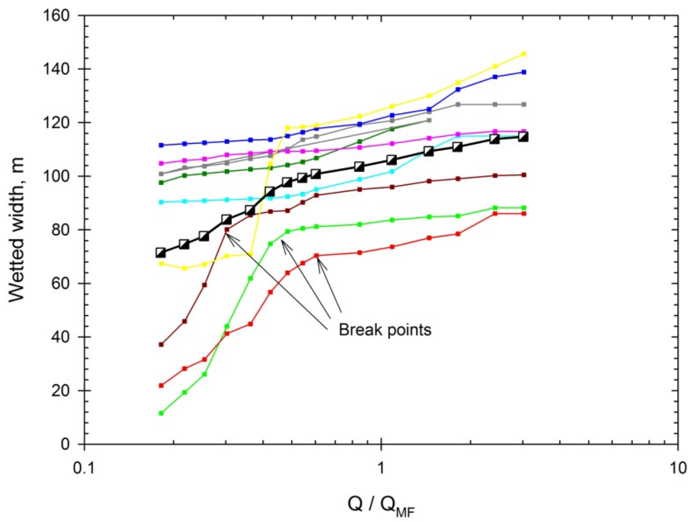


Figure 5-6: *Wetted width W against discharge ratio Q/Q_{MF} for a river reach near Krossen at Mandalselva in southern Norway. The bold line indicates the average wetted width. Data of a 1D hydrodynamic modelling study by Sauterleute (2012).*

5.2.1 Publicly available biological reports from NINA and others

A number of reports from NINA and other research institutions or consulting companies focusing on fish biology also include information about water-covered area or wetted width, since it is an important parameter for fish production. The water covered area of a river reach is often taken from topographical maps (TK N50, 1:50.000 and ØK, 1:5000), in many cases without information about the actual discharge. N50 seems to represent the river width for bankfull discharge (Jensen & Johnsen 2007). Area calculations based on N50 are standard for smolt calculations in many Norwegian water courses.

In some reports, the mean wetted width for a visible reach (200-300 m) was visually estimated on-site during electro-fishing. Then the mean wetted width was multiplied with the river length (often some kilometres) to obtain the water-covered area for a given river reach and flow situation (e.g. Johnsen et al. 2011).
Most of the reviewed reports (e.g. Jensen & Johnsen 2007, Johnsen et al. 2011) do not contain information about the exact discharge associated with the given wetted width or water-covered area. These data are therefore not sufficient for the extraction of wetted area information as function of the discharge.

Only a few biological reports reported field investigations of the water-covered area for exactly known discharge conditions and contained maps such as in Figure 5-7. They allow estimating the reduction in water-covered area as percentage of a reference flow condition. A comparison with the wetted width information from the other studies (i.e. a presentation of data in the form W = f (Q)) would require additional data processing (GIS-based extraction of river lengths or transects) and was not undertaken for this report.

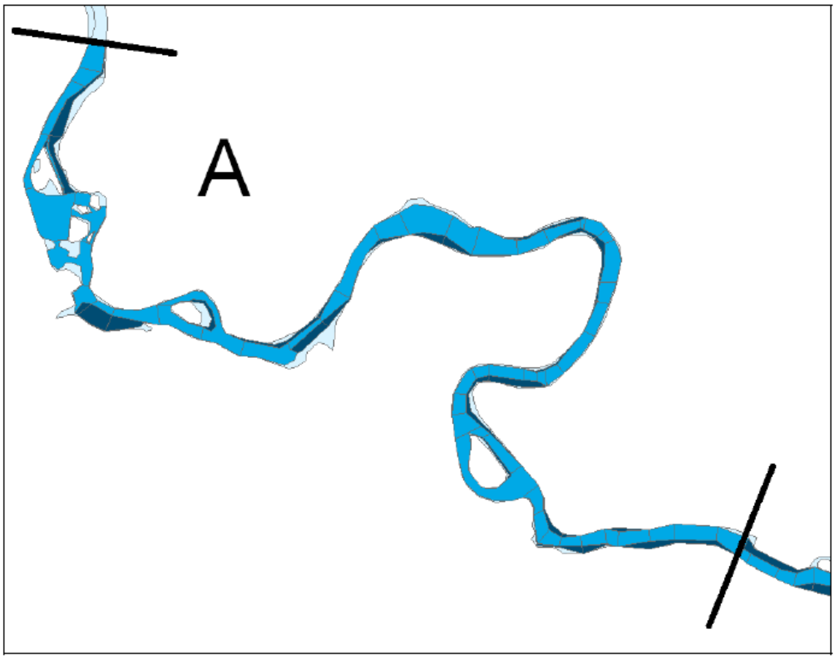


Figure 5-7: *Water-covered area in section A of the Åbjora river A at low discharge (2 m^3/s, blue) and high discharge (30 m^3/s, dark blue). The river area from the topographical map is indicated by light blue color. From Forseth et al. 2007.*

5.2.2 NVE data from flood modelling studies

NVE has performed many hydraulic computations to create flood inundation maps, mostly using 1D hydraulic modelling. In these studies, the water levels are typically calculated for flood flows with recurrence intervals between the mean annual flood (Q_{MAF}) and 200 or 500 years (HQ_{200} or HQ_{500}). These flood modelling studies were performed based on a limited number of river profiles and with a focus on floodplain inundation. The models were calibrated based on water level data for extreme floods.

Other hydrodynamic computations that are available at NVE have been performed on behalf of municipalities, private companies or the State Road Administration in connection with construction projects, for example new bridges. These calculations were usually performed for shorter river reaches based on roughness values from literature, because no measurement data for model calibration were available.

NVE provides a map of the existing projects and data (http://gis3.nve.no/link/?link=HydrologiskeRapporter). For this study, 18 river projects including different catchment sizes and geographical regions were selected. The NVE reports did not include the modelling results for the wetted width. This information was therefore taken from the modelling raw data (HECRAS) provided by NVE. For seven projects on behalf of institutions outside from NVE, the permission for using this data had to be obtained from the respective municipalities and administrations. An overview of the included rivers is given in Table 5-1 and Figure 5-8.

Table 5-1: Selected 1D modelling data sets from NVE, mainly Inundation map projects (IMP; "Flomsonekartlegging").

River	Reach	Drainage area, km^2	MAF, m^3/s	Calculated flows	Note
Beiarelva	Beiarn	712-856	401-474	Q_{MAF} to HQ_{500}	IMP
Drammenselva	Hellefossen outlet	16372	1020-1070	Q_{MAF} to HQ_{500}	IMP
Gaula	Outlet Gaulfoss	3090	938	Flood 1995	IMP
Gaula	Kotsøy	1795	637	Q_{MAF}, Flood 1940	IMP
Hallingdalselva	Øyni (Ål, Buskerud)	2000	143	Q_{MAF} to HQ_{500}	New bridge
Lærdalselva	Lærdal (Tonjum-Stuvane)	994 (Stuvane)	258-270	Q_{MAF} to HQ_{1000}	IMP
Leirelva	Leirfjord	53	50	Q_{MAF} to HQ_{200}	New bridge
Lierelva	Lower part	310	103	Flood 1987	IMP
Målselv	Øverbygd		66.26	Q_{MAF} to HQ_{500}	IMP
Mandalselva	Mandal centrum	1746	445	Q_{MAF} to HQ_{500}, Floods 1987, 2000	IMP
Namsen	Namsos	6272	1970-2010	Q_{MAF}, PF1	IMP
Numedalslågen	Kongsberg	4100	340	Q_{MAF} to HQ_{500}, Floods 2000, 2004	IMP
Ognaana	Ogna	78	49	Q_{MAF} to HQ_{500}	IMP
Otra	Lower part, Mosby	3750	580	Flood 1987	IMP
Ranaelva	Leirfjord	42.7	49	Q_{MAF} to HQ_{200}	New bridge
Signadalselva	Storfjord, Mortendalselva	12.2	12.4	Q_{MAF} to HQ_{200}	New road
Steindalselva	Kvam	83.1	126.3	Q_{MAF} to HQ_{500}	
Stordalselva	Stordal	204	146	Q_{MAF} to HQ_{200}	Flood safety assessment

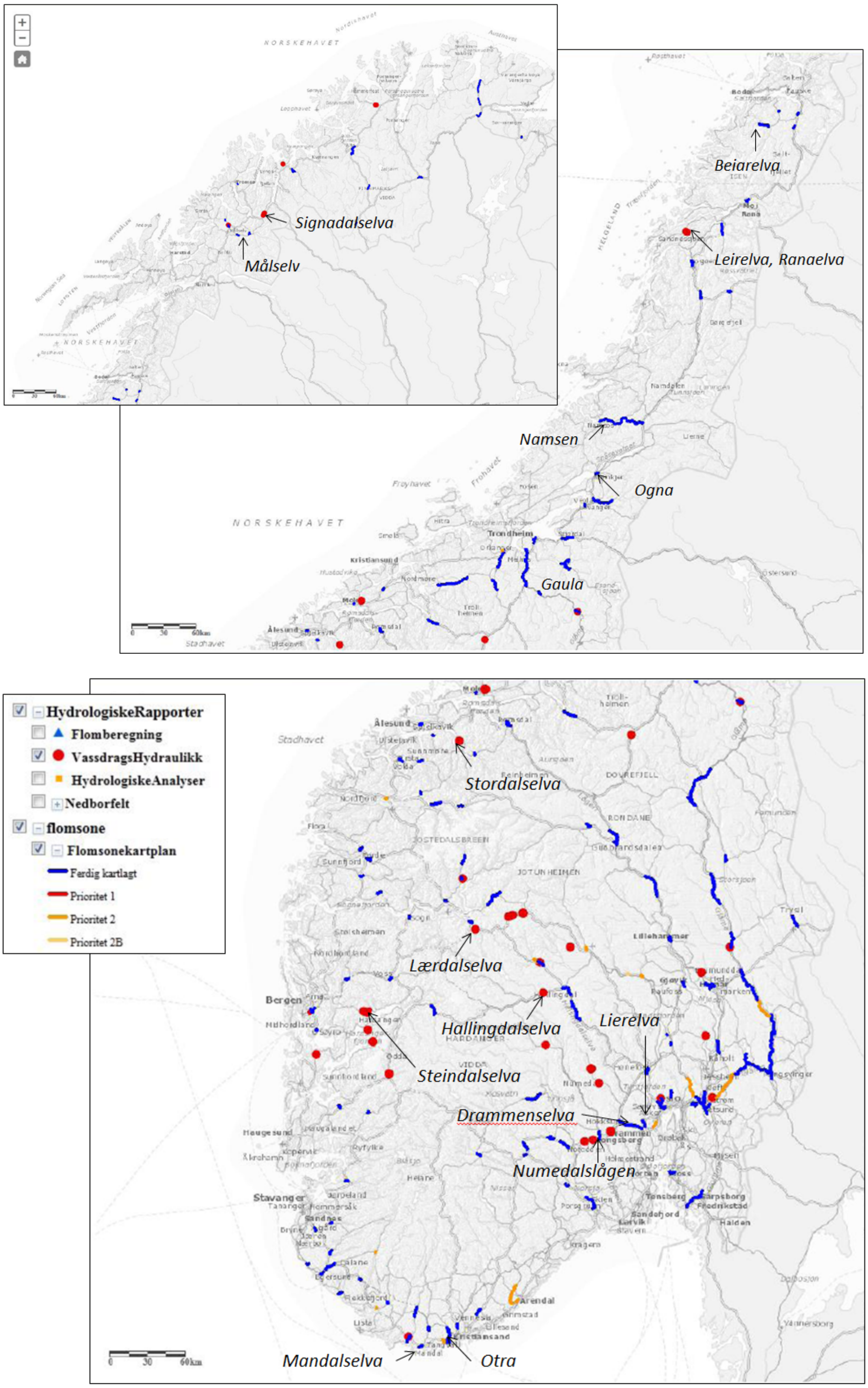


Figure 5-8: *NVE-Overview of the available hydrological reports and inundation mapping projects and projects selected for the data compilation.*

5.2.3 Photo documentation from licence applications

The Norwegian Water and Energy Directorate (NVE) has formulated data requirements for the licence applications for power plants (e.g. NVE 2012 for small power plants). The hydrological investigations have to include an estimation of the mean flow in minimum flow reaches before and after the power plant construction and the estimation of low flow parameters (common low flow Q_{CLF} or Q_{95} for summer, winter and the year). Many licence applications include photo documentation showing the water levels in the relevant river reaches at different discharges.

It was investigated to which degree these data in combination with publicly available maps could be analysed to obtain information about the water covered area in the investigated rivers. An example is given in Appendix A3. It clearly indicates the following issues for this source of information:

- The photos cover only short river sections and do not cover the structural properties of the entire reach.
- The analysis of these data is labour-consuming, because the coordinates of the photo positions are usually unknown or not documented.
- In many cases, the analysis of the photos is complicated by the different locations where the photos were taken.
- The photos and the aerial images are from different years, such that the effect of different discharges may be overlaid by on-going morphological and vegetation changes.

The wetted width data from these photos was inaccurate and incomplete due to the described issues. These data were therefore not included into the data compilation.

5.3 Results

5.3.1 Wetted width versus discharge compilation

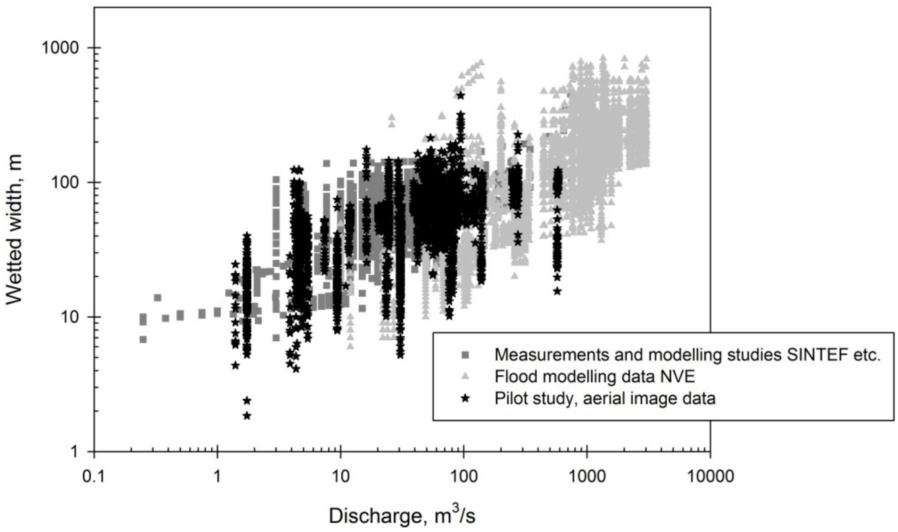


Figure 5-9: *Results of the data compilation for wetted width as function of the discharge (all data sources).*

Figure 5-9 illustrates the large variation of wetted width values within the investigated Norwegian river reaches for a given discharge, which is in agreement with the findings of recently published studies using high-resolution data of rivers in other countries (e.g. Carbonneau et al. 2012).

The data sets shown in Figure 5-9 are very heterogeneous with respect to their representativeness for the river reach and the level of uncertainty:

- Wetted width information from discharge measurements represent spot-wise data from locations that are not randomly chosen ("measurement profiles"; river accessibility by wading or boat required).
- The distance between measured transects in modelling studies is usually larger than those in the pilot study (cp. Figure 5-5; transect of the HECRAS modelling profile is included).
- The accuracy of modelling studies depends on the available measurement data for calibration. Results from non-calibrated models or extreme-flood computations may be very inaccurate.
- The flood modelling results include regulated or channelized river sections and backwater-effects from the sea or bridges.

The following figures (Fig. 5-10 and 5-11) show the compilation results separately for the different data sources. In Figure 5-11, the data from the aerial images and flood modelling studies were sorted using the river size classes of the newest version of the Norwegian classification guidelines within the European Water Framework Directive (Direktoratsgruppa Vanndirektivet 2013). The following size classes (SC) according to drainage area are defined:

- SC 1 – Small (< 10 km^2)
- SC 2 – Medium (10 – 100 km^2)
- SC 3 – Medium to large (100 – 1,000 km^2)
- SC 4 – Large (1,000 – 10,000 km^2)
- SC 5 – Very large (> 10,000 km^2)

The figures illustrate that, as would be expected, rivers with greater drainage areas and mean discharges tend to be wider than rivers with lower drainage areas, as it was found for other regions (e.g. Booker and Dunbar 2008).

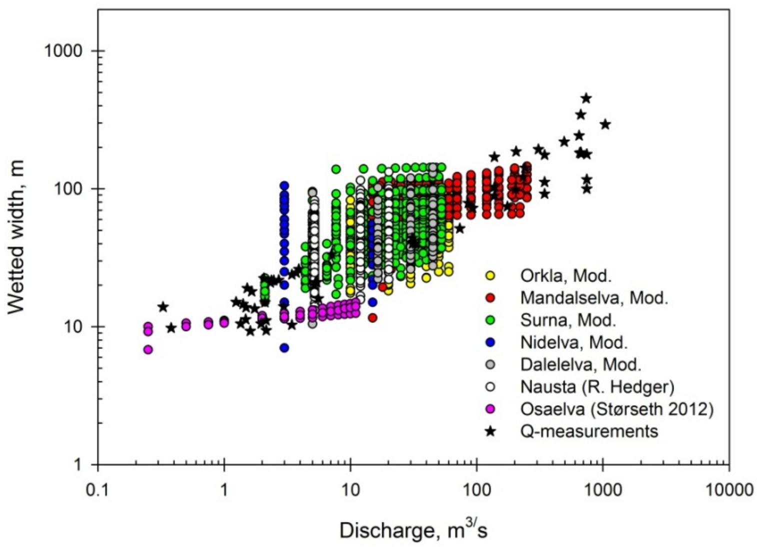


Figure 5-10: *Compilation of data from measurements and modelling studies performed by SINTEF, NTNU, NINA and others.*

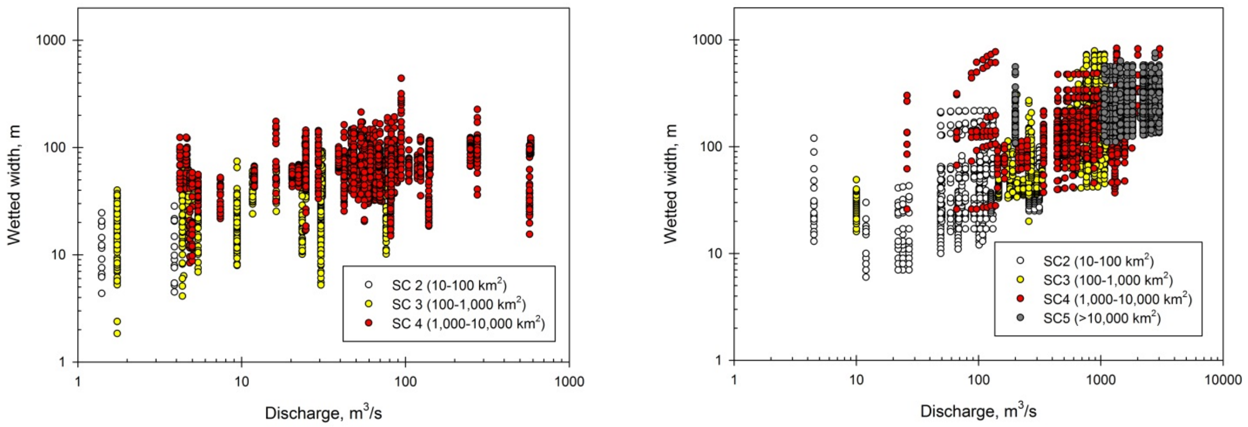


Figure 5-11: *Compilation of data gained from aerial images in the pilot study (left) and from the NVE flood modelling data (right).*

5.3.2 Preliminary data analysis for the results of the pilot study

Figure 5-12 presents the mean wetted widths as a function of the discharge ratio Q/Q_{MF}, where Q_{MF} is the annual mean flow (m^3/s) taken from the NVE database for the respective gauging station. For some stations, the Q_{MF} value was not available when the study was performed. The number of river reaches is therefore lower than in Figure 5-11 (left).

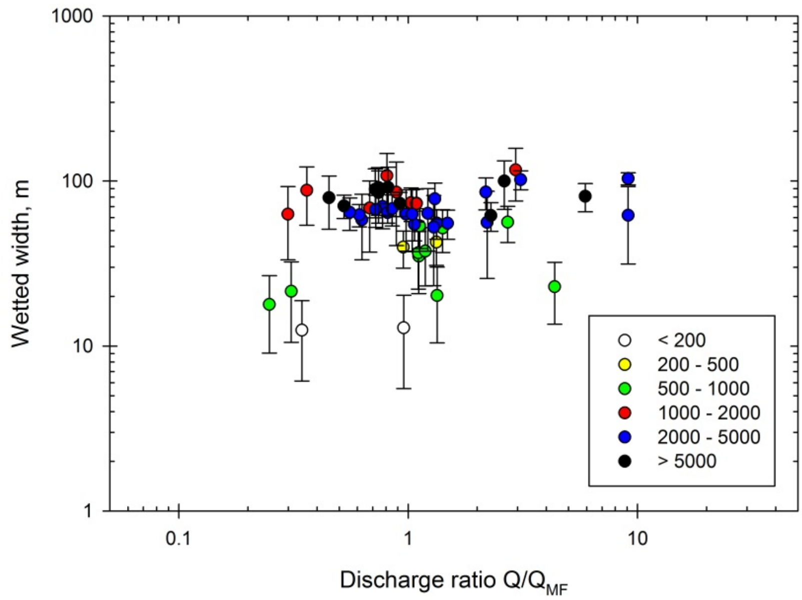


Figure 5-12: *Mean wetted width versus discharge ratio Q/Q_{MF} for data gained from the aerial images. The symbol colors indicate the size of the drainage area (in km²). Error bars show the standard deviation of the data.*

The error bars in Figure 5-12 indicate the standard deviation of the wetted widths which were collected within a given reach for a given discharge. The Shapiro-Wilk test (Shapiro & Wilk 1965) was applied to test the null hypothesis that the transect samples of the pilot study came from normally distributed populations. In 47 of 75 cases (63 %), however, the test indicated that the transect data were not normally distributed ($\alpha = 0.05$). As an example, Figure 5-13 shows the wetted width histogram for a reach of River Otra, a meandering river with gravel bars (cp. Fig. 5-5). Even though the Shapiro-Wilk test did not reject the hypothesis of a normal distribution in this case, the histogram suggests that other distribution functions could be more appropriate for the description of the transect data.
Minimum flow assessments in Norway are often focused on the "Common low flow" Q_{CLF} ($\approx Q_{96}$) or Q_{95}. In most cases, Q_{CLF} is less than 10 % of the mean flow, but Q_{CLF}/Q_{MF} can vary between <0.02 and >0.2 (Væringstad & Hisdal 2005). The comparison with Figure 5-11 reveals that this low flow range is not covered by data in the present study. The investigated aerial images were taken for discharge ratios Q/Q_{MF} between 0.2 and 10, i.e. discharges that did not allow us to gain information about the wetted width for the relevant low flow conditions.

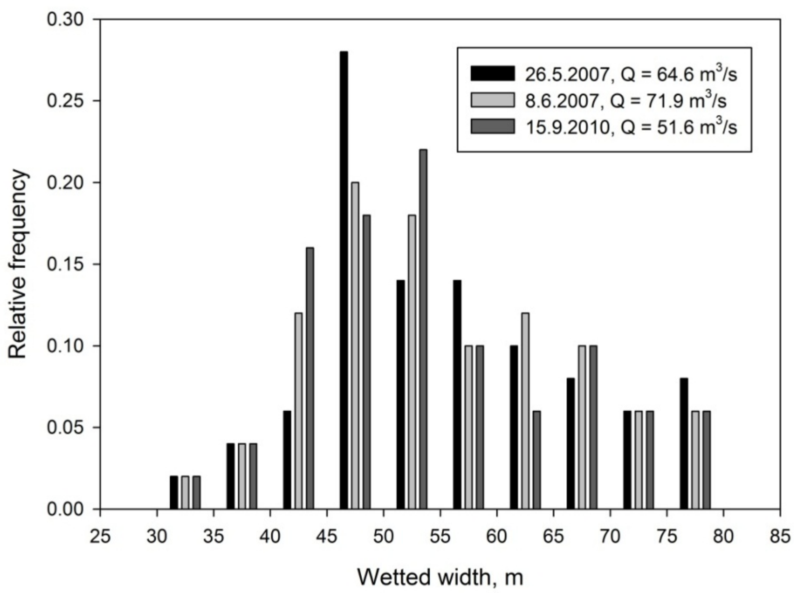


Figure 5-13*: Histogram of wetted widths (5 m classes) for Orkla River near gauge Nr. 121.22.*

5.4 Conclusions and recommendations

The results of the data compilation show that the wetted width within a reach for a given discharge can vary significantly, depending on the size of the catchment area and other factors. This is in agreement with the findings of recently published studies using high-resolution data from rivers. Alluvial rivers with greater drainage areas tend to be wider than rivers with lower drainage areas, as it was published for other regions.

The data analysis should be performed separately for data sets that come from different sources or methods and are characterized by different uncertainties.

In some regions, a relation between discharge and mean physical parameters may possibly be derived as functions of regional factors by using hydraulic geometry (HG) relationships (e.g. Booker 2010). In alluvial rivers under quasi-equilibrium conditions, the mean annual flood is regarded as "channel-forming discharge". The size of this flood is supposed to determine the bank-full river width. The Norwegian regression formulas established for this flood (Wilson et al. 2011) indicate an important role of drainage area size, mean specific annual runoff, mean annual precipitation, lake percentage, exposed bedrock percentage, catchment length and gradient of the main river as key parameters for the shape of the river profile. Many Norwegian rivers, however, are very much affected by glacial processes, which may restrict the applicability of HG approaches.

The pilot study for 29 salmon river reaches in the northern, central and southern part of Norway showed that the publicly available aerial images (www.norgeibilder.no) were suitable for the extraction of wetted width information for medium to very large Norwegian rivers. However, the investigated aerial images did not sufficiently cover low flow conditions ($Q/Q_{MF} \leq 0.2$). This did not allow gaining wetted width information for the conditions which are most relevant for environmental flow assessments. Therefore it will be necessary to conduct flight campaigns during low flow periods.

The preliminary results of the SINTEF pilot study suggest the possibility to describe wetted width of large salmon rivers based on hydraulic geometry (HG) coefficients for the reach-averaged mean wetted width and river type specific wetted width distribution functions. The salmon water courses are often concentrated in the lower parts of the rivers with more alluvial attributes. A much larger data set is necessary for the derivation of statistically firm regional HG regression models for alluvial river reaches in general, which take into account morphologically relevant factors (e.g. climate/precipitation, geology). This data should be gained within a larger project, including the development of GIS tools for automatized high resolution data processing and analysis. Hydrological models or suitable interpolation methods should be used to estimate the flow in river reaches without measurement station. For the data analysis, attention has to be paid to the fact that many Norwegian rivers are regulated. Their morphology may rather reflect transitional stages, instead of quasi-stable conditions that lie behind the assumption of HG.

The data compilation showed the need for a more standardised way of comparing flow versus wetted width relationships at selected river reaches. An appropriate hydro-morphological river classification system could foster decision-making for setting environmental flow targets in prioritised rivers.

6 Outline for a river classification project proposal

One of the specific objectives of the river classification workshop on 29 January 2014 was to formulate outlines for a larger project proposal that could be submitted to the Norwegian Research Council (NRC) as CEDREN-project (www.cedren.no) for example within the funding program ENERGIX (http://www.forskningsradet.no/prognett-energix/Forside/1253980140037).

To coordinate the CEDREN activities about hydro power license revisions, it was further decided to join the river classification ideas with those of the on-going CEDREN pilot project PolWater (Policy coordination and environmental improvements in heavily modified waterways).

Appendix A4 presents a draft for the proposal outline which was circulated to the workshop participants in March 2014. Subsequently, the following comments were received:

- From NINA:
  It should be examined whether the freshwater pearl mussel (*Margaritafera margaritafera*) could be included in addition to salmonid species. Both species groups are common in regulated rivers. The methodical challenges for the mapping of the population and the environmental requirements are similar. Freshwater pearl mussel is a high-priority and Red List species.
- From NTNU:
  The suggested tasks 3.1/3.2. (River survey tools, river scape analysis and classification) and 3.3 (Ecological analysis and population simulation tools) are quite comprehensive and require that at least two PhD or Postdoc positions (one for task 3.1/3.2 and one for 3.3) should be planned as part of WP3.

The project outline draft in Appendix A4 is preliminary and represents the working status from April 2014. The contents of the planned project proposal and the funding possibilities will be discussed and further developed within CEDREN.

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A Appendix

A.1 Program and participants

Program

08:30 – 8:45	Arrival and registration (w/coffee)	
08:45 – 9:00	Welcome address / Workshop introduction	NEA, SINTEF ER, NINA
Presentations		
09:00 – 09:20	Hydrodynamic characteristics of lowland and mountain rivers	Jochen Aberle, NTNU Trondheim
09:20 – 09:40	Regional hydrological differences and hydrological zoning in Norway	Kolbjørn Engeland, NVE Oslo
09:40 – 10:00	Estimation of minimum flow for hydro power licensing in Norway - overview, experiences and research needs	Eilif Brodtkorb, NVE Oslo
10:00 – 10:20	The Norwegian WFD typology and fish classification	Odd Terje Sandlund, NINA Trondheim
10:20 – 10:30	Short break	
10:30 – 10:50	Criteria for environmental flow evaluation in Slovenia	Natasa Smolar-Zvanut, Slovenia
10:50 – 11:10	Regional habitat models for river classification and minimum e-flow estimation	Paolo Vezza, Italy/Spain
11:10 – 11:30	Use of remote sensing data for river classification and estimation of water-covered area	Peggy Zinke, SINTEF, Trondheim
11:30 – 12:15	Lunch	
Group work		
12:15 – 12:30	Introduction to group work	Peggy Zinke
12:30 – 14:30	Group work	
14:30 – 15:00	Coffee break	
15:00 – 16:00	Plenary session: presentation of group work results and discussion	
16:00 - 16:30	Summarizing recommendations for the planned project proposal	NEA, SINTEF ER, NINA
16:30	Closure	

Participants

1	Aberle, Jochen	NTNU	Trondheim	Norway
2	Alfredsen, Knut	NTNU	Trondheim	Norway
3	Arnekleiv, Jo	NTNU	Trondheim	Norway
4	Kjetil Vaskinn	SWECO	Trondheim	Norway
5	Borsanyi, Peter	NVE (Hydrology)	Oslo	Norway
6	Brodkorb, Eilif	NVE (Licences)	Oslo	Norway
7	Engeland, Kolbjørn	NVE (Hydrology)	Oslo	Norway
8	Erikstad, Lars**	NINA	Oslo	Norway
9	Fjeldstad, Hans-Petter	SINTEF EN	Trondheim	Norway
10	Foldvik, Anders	NINA	Trondheim	Norway
11	Halleraker, Jo	NEA	Trondheim	Norway
12	Helland, Ingeborg P.	NINA	Trondheim	Norway
13	Lund, Roar*	NEA	Trondheim	Norway
14	Martine Bjørnhaug*	NEA	Trondheim	Norway
15	Niklas Egriell	Swedish Agency for Marine and Water Management	Göteborg	Sweden
16	Pulg, Ulrich	UNI	Bergen	Norway
17	Rüther, Nils	NTNU	Trondheim	Norway
18	Sandlund, Odd-Terje	NINA	Trondheim	Norway
19	Smolar-Zvanut, Natasa	Institute for Water of the Republic of Slovenia	Ljubljana	Slovenia
20	Ugedal, Ola	NINA	Trondheim	Norway
21	Vezza, Paolo	Universitat Politècnica de València	Valencia	Spain
22	Zinke, Peggy	SINTEF EN	Trondheim	Norway

** until lunch*

***via Lync (discussion after the workshop)*

A.2 Workshop evaluation

The participants were asked to assess their agreement to seven statements (E1 to E7) by assigning a score between 1 ("strongly disagree") and 5 ("strongly agree"). Score 3 means "Not sure".

Figure A2-1 shows the evaluation results, based on the feedback given by 10 participants directly after the workshop. 90 % of the respondents agreed that the workshop was well organized, and 50 % believed that the workshop met the stated goal (Score 4 and 5). Only 20 % of the respondents agreed that they were familiar with the existing Norwegian river typology of the WFD (Score 4 and 5). About 80 % of the participants believe that Norway needs a better river typology that can support environmental flow assessments (Score 4 and 5).

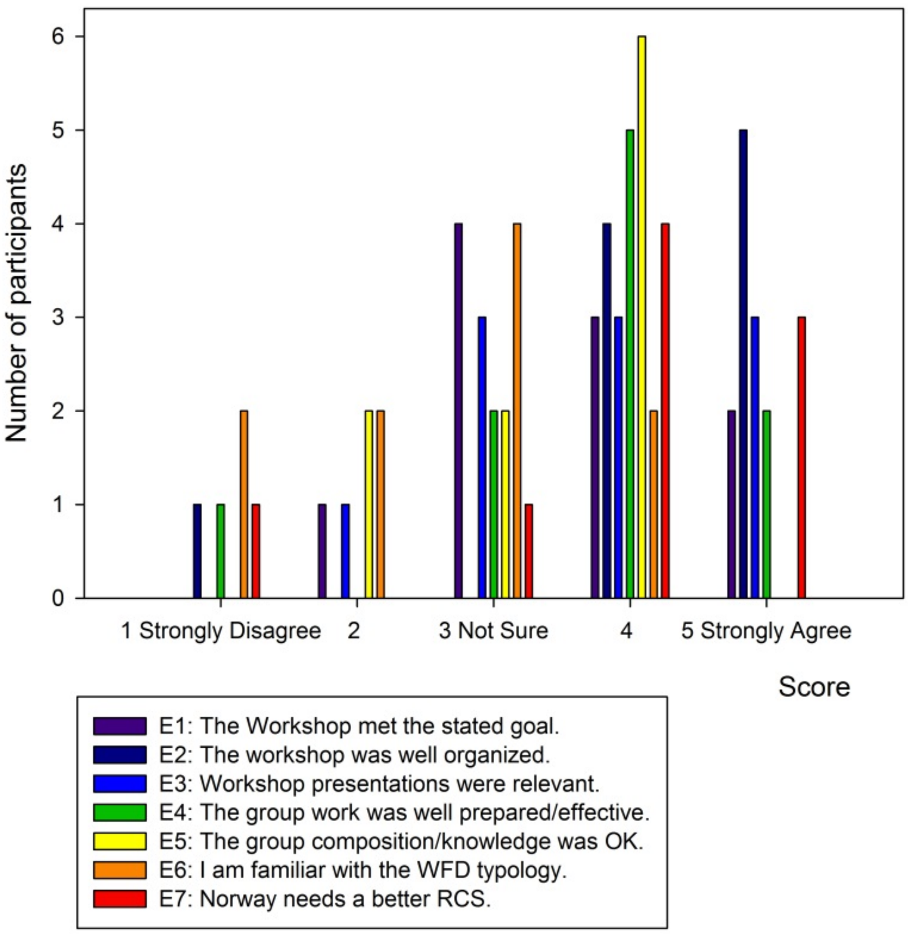

Figure A2-1: *Results of the workshop evaluation survey.*

A.3 Analysis of wetted width information from photo documentations in licence applications - example

The licence application for the "Rullestad and Skromme power plants" deals with the construction of small power plants in Etne Municipality, Hordaland District. They may affect the discharge in five rivers (Kvernhuselva, Daleelva, Sagelva, Skårselva, Bordalselva), as shown in Figure A3-1, left.

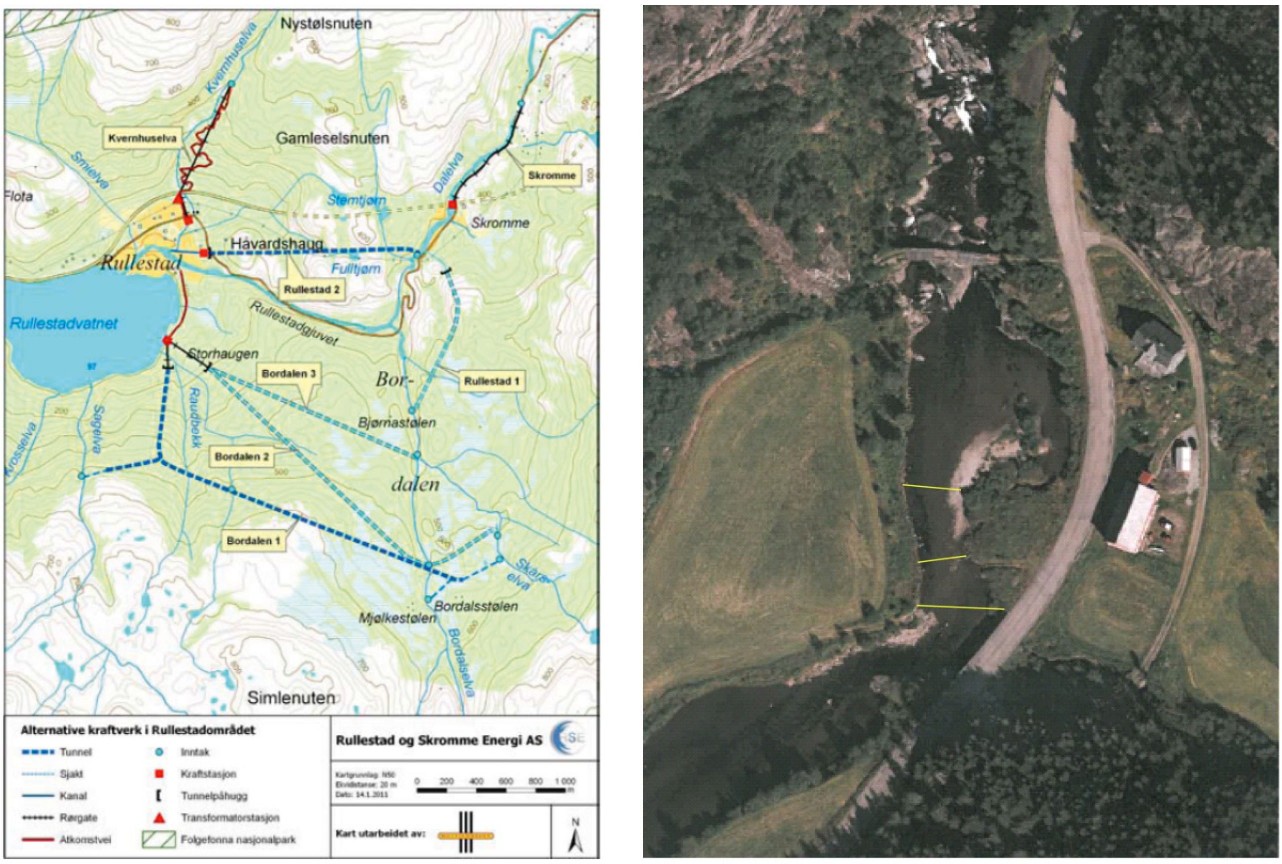

Figure A3-1: *Overview map construction options for the power plant project (left, from RSE 2011) and river Daleelva near Skromme, as it is shown at the aerial image from 2012 (Norgeibilder, Etne 2012).*

Figure A3-2 shows the photo-documentation of the licence application for the flow conditions at river Daleelva near Skromme, downstream from the outlet of the planned Skromme power plant. The catchment area at this site is 42.6 km^2 and the mean discharge at the power plant was calculated with 3.73 m^3/s (SWECO 2011). Based on the maps and the photos in the licence application, it was possible to identify the river reach in Norgeibilder (www.norgeibilder.no), the Norwegian data base for aerial images (Figure A3-1, right).

This allowed drawing some profiles perpendicularly to the flow direction, in order to get the river width for a "reference situation". The position of the three profiles in the photos (Figure A3-2) were visually estimated.

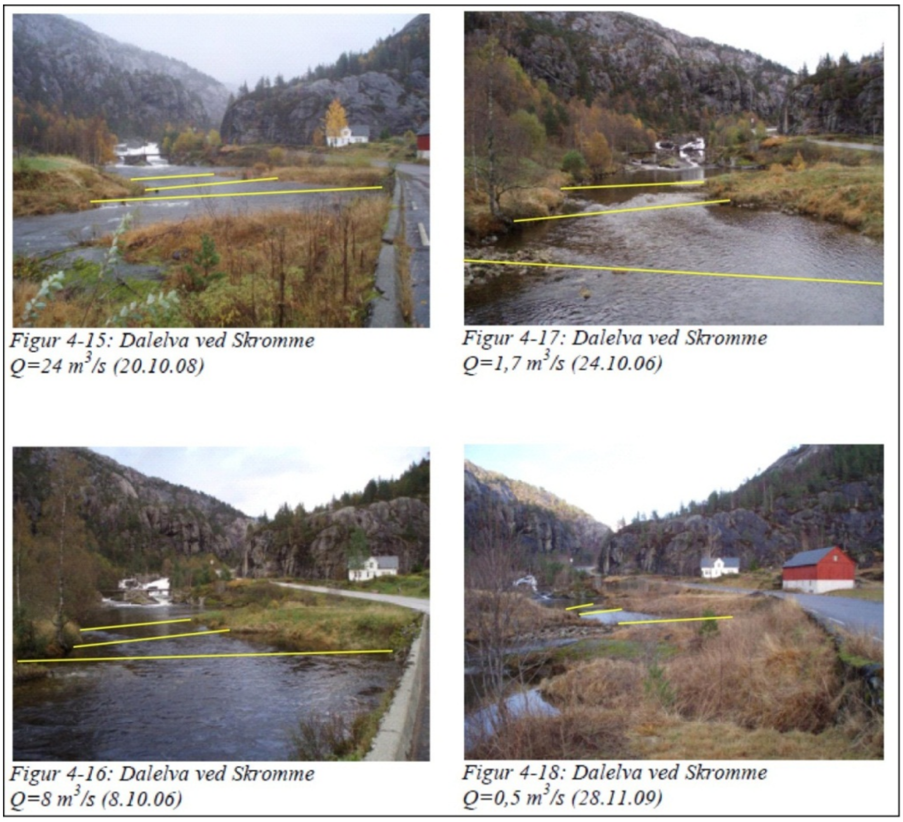

Figure A3-2: *Photo documentation of the river Daleelva near Skromme at different discharges (RSE 2011), with estimated position of the profiles shown in the aerial image (Fig. A3-1).*

Table A3-1: *Estimation of wetted width based on the photos and the manually drawn transects. BR = reference width (width in the aerial image)*

Nr.	Bankfull width m	B/BR			
		Q = 0.5 m^3/s	Q = 1.7 m^3/s	Q = 8 m^3/s	Q = 24 m^3/s
1	19.3	?	0.8	1.0	1.0
2	15.7	?	0.9	1.0	1.0
3	21.8	?	0.8?	1.0	1.0

Table A3-1 presents the results of an attempt to estimate the wetted with at the position of the three profiles based on the available information from the aerial image and the photos. It clearly indicates the following issues when this information is used:

- A larger number of photos would be needed to cover the structural properties of the entire river reach. In the present case, only the relatively narrow river reach close to the road was documented in the photos. No photos are available for the wider river zones further upstream, with river widths of more than 40 m (cp. aerial image).
- The analysis of the photos is complicated by the different locations where the photos were taken.
- The photos and the aerial image are from different years (2006-2012), such that the effect of different discharges may be overlaid by on-going morphological and vegetation changes.

A.4 Draft of the proposal outline

CEDREN
Centre for Environmental Design of Renewable Energy

MEMO

MEMO CONCERNING	DISTRIBUTION
Outlines for the project proposal – First draft	Workshop participants
AUTHORs	DATE
Peggy Zinke, Audun Ruud, Hans-Petter Fjeldstad, Odd Terje Sandlund	25 March 2014

Introduction

One of the specific objectives of the river classification workshop on 29 January 2014 was to formulate outlines for a larger project proposal that could be submitted to the Norwegian Research Council (NRC) within the funding program ENERGIX (http://www.forskningsradet.no/prognett-energix/Forside/1253980140037) as CEDREN-project (www.cedren.no).
To coordinate the CEDREN activities about hydro power license revisions, it was further decided to join the river classification ideas with those of the on-going CEDREN pilot project PolWater (Policy coordination and environmental improvements in heavily modified waterways).

Outlines for the ENERGIX proposal

The main objective of the project is to develop a set of tools and guidelines for the optimization between environmental qualities, hydro power production, and administrative efforts in order to support the re-licensing of a large number of hydro power plants (HPP) in Norway.

The following general work packages are suggested:

WP 1: Summary, evaluation and adaption of existing knowledge
WP 2: Governance and regulatory challenges
WP2-a: status of the Water Framework Directive (WFD) implementation
WP2-b: status of the revision process
WP 3: Environmental decision support tool box and hydropower optimization
WP 4: Management guidelines and Multi-criteria analysis methodologies in HPP licensing and revision
WP 5: Guidelines for optimized hydropower production and environmental design

The figure below illustrates the suggested content of WP 2. The issues discussed during the River Classification Workshop are represented in WP3. It focusses on river system mapping, analysis and hydropower production modelling, and ecological analysis and population simulation tools. Some more explanations for WP 3 are given below. The methods and tools will be tested and further developed during integrated case studies, for example in the Sira-Kvina region.

Centre for Environmental Design of Renewable Energy
Telephone: +47 73 59 72 00, E-mail: post@cedren.no
Main partners: SINTEF Energy Research, NINA, NTNU
www.cedren.no

Host: SINTEF Energy Research
Reception: Sem Sælands vei 11
Address: P.O.Box 4761 Sluppen, NO-7465 Trondheim
Enterprise No.: NO 939 350 675 MVA

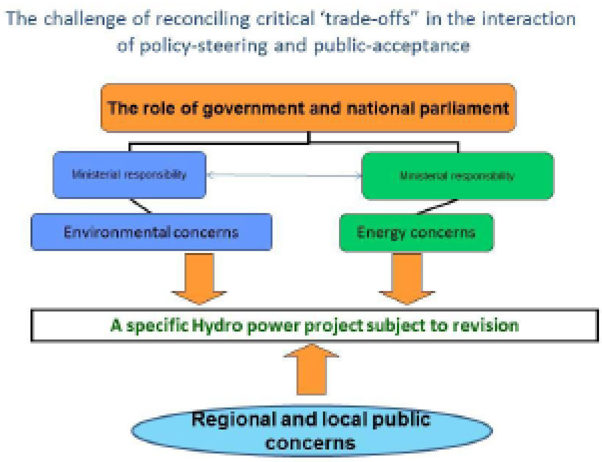

Figure: Scheme illustrating the governance and regulatory challenges. From Audun Ruud

The following methods/tools represent project tasks that were suggested during the workshop:

Task 3.1: River survey tools (UAV & GIS)

- Test and develop UAV-based river survey solutions for Norwegian conditions to produce high-resolution digital maps of topography, water depth, substrate, wetted width, vegetation and other parameters (including GIS-based image processing) for different flow conditions
- Create data base solutions to manage and analyze fluvial data ("fluvial information system", FIS)
- Derive second-order parameters such as mean flow velocity, stream power, shelter from the survey data

Task 3.2: River scape analysis and classification tools

- Use FIS data gained in Task 3.1 to extract information about the longitudinal distribution of physical parameters such as wetted width, substrate, etc. for a selected number of rivers
- Derive up- and downscaling solution for the description of physical habitat conditions (e.g. mesohabitat – river reach)
- Derive Hydraulic Geometry relationships (e.g. for mean wetted width: $W = a * Q^b$; *a,b* empirical coefficients) for the river reach scale as function of known catchment and climate parameters (drainage area, land use, mean annual flood etc.; from Statens kartverk / NVE)
- Derive river-type specific duration curves for relevant physical parameters (e.g. wetted width);

Task 3.3: Ecological analysis and population simulation tools

- Application and further development of ecological population simulation tools, based on the input data provided in Task 3.1 and 3.2
- Model-based identification of bottle-necks
- ....

Task 3.4: Modelling of power production loss due to e-flow requirements

- Implement e-flow modules in hydro power production models
- Assess and optimize production loss and ecological flow requirements
- Develop a combined tool for research and administration
- ...

Task 3.5: Integration of new knowledge into WFD, links to WFD typology

- Suggestions for improvements and/or additional hydro-morphological parameters that should be integrated into the WFD river classification
- E-flow-norms/abstraction limits as function of WFD river types and regional factors (e.g. ecoregions)
- ...

The proposal will have a clear focus on re-licensing of hydro power plants. A pre-study will therefore identify the dominating WFD river types of the re-licensing-relevant river reaches (1.1. and 1.2 in Sørensen et al. 2013). This might result in a restriction to selected woodland and lowland river types within the project.

For Task 3.2., a sufficient number of unregulated and regulated rivers representing different river types and ecoregions should be included into the analysis, in order to provide large data set for the derivation of empirical correlations.

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