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Report

Setting environmental flows in regulated rivers

Implementing the EU Water Framework Directive (EU WFD) in Norway

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ABSTRACT
There is a clear need for identifying simple relations between changes in flow and ecosystem response for the improved management of rivers and the implementation of the EU WFD. Despite this, it appears very difficult to identify widely applicable relations between hydrological/hydraulic parameters and ecosystem response, and one specific water flow target/methodology could hardly be found nor recommended. The review of management practices of setting environmental/minimum flows in selected European countries, rather revealed that a number of approaches are used, most of them, however, ending up in minimum flow/environmental flows in the range of 5-10 % of mean annual flow. The authors would propose to use the building block methodology (BBM) as a conceptual framework for setting flow targets in regulated rivers. This would support the overall idea of the EU WFD of introducing ecosystem-based management with stakeholder involvement. This is in line with recommendations given to authorities in e.g. the UK where trials are currently undertaken. The authors believe the use of hydrological/hydraulic analysis still have an unleashed potential in the environmental management of regulated rivers in general and related to the EU WFD in particular, possibly supporting rapid assessment ecological status in rivers in the future.

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1 Introduction

1.1 The objectives of this study

The aim of this report is to provide an overview of the current approaches in Europe for setting minimum/environmental flows in general and in compliance with EU WFD in specific. Given the current trend and future scenarios for the further development of hydropower as a supplier of intermittent power, the topic of hydropeaking and possible environmental restriction of this pressure is discussed. Based on these findings and the authors' experience in river management, the report proposes approaches for implementing EU WFD in regulated rivers in Norway and for improved management of these rivers in a wider sense.

The project should by providing this information support of the following management tasks:

- Implementation of EU WFD in regulated rivers in order to meet the objectives of Good Ecological Status (GES) / Good Ecological Potential (GEP)
- Relicensing/revision of hydropower plants in Norway
- Setting flow targets in rivers with dramatically reduced flows due to the regulation, typically bypass sections
- Setting ecological-based limitations/thresholds for hydropeaking in regulated rivers

The findings in the project and documented in this report hopefully contribute to the ambitions of knowledge-based management of catchments and river system, hence providing a better basis for improved decision-making reconciling policies within the environmental and energy sector.

As the Norwegian electricity production is close to exclusively based on hydropower, the introduction of higher environmental standards in regulated rivers might cause loss in electricity production. Redefining the environmental requirements will hence be a delicate question of balancing the need for renewable electricity production (or even increasing according to EU RES directive) and the need for improving the environmental qualities in regulated rivers (to reach EU WFD's 'good ecological status/potential'). Relevant questions to raise are then:

- How much environmental quality can we gain/achieve without losing too much hydropower production?
- How to combine release of water with other mitigation measures in a cost-efficient/optimum way?

It could be useful to revisit the objective of defining good ecological potential (GEP) in heavily modified water bodies (HMWBs), being equivalent to good ecological status for natural water bodies, but taking into account the constraints imposed by social and/or economic uses. The scientific challenge in defining GEP in regulated rivers lies in:

1. quantifying the deterioration of ecological status caused by river regulation
2. quantifying the improvement which can be achieved by mitigating measures, and
3. weighting the deterioration and eventual improvements gained by measures against the socioeconomic costs in a transparent way.

Assessment of the so-called "ecological potential" (GEP) of HMWB is an important task, not only because it is legally required, but foremost to ensure a sustainable use of ecosystems. At the same time it should be ensured that the financial resources are spent in a cost-effective way. For defining GEP, it is therefore mandatory to apply a combined ecologic and socio-economic approach. Both scientifically and in practice, this has proven to be a challenging task. This is due both to lack of knowledge on the effect of river regulation on certain biological quality elements and lack of appropriate scientific-based (and transparent) approaches to balance biological and socio-economic perspectives.

This publication has a more limited scope than described above, but a newly submitted proposal to the Research Council of Norway's research programme Miljø2015 will address this more thoroughly, if approved. This project is titled EcoDEFINE - Developing criteria and tools for defining good ecological potential in regulated rivers and will deal with the process of defining GEP in selected case studies and establish a method and a set of criteria that can be used for defining GEP in regulated rivers. The project is highly relevant for the implementation of the EU WFD in Norway by developing biological and economic criteria and implementing these criteria into a Multi-Criteria-Analysis (MCA) framework which can be used for defining GEP in regulated rivers in a transparent way. By doing so, the project will contribute to a knowledge-based ecosystem management and a more sustainable use of ecosystems. EcoDEFINE will also include scenario-based analysis of discharge series as input to hydraulic and biological models, as a mean to investigate potential influences of climate change on mitigating measures in regulated rivers.

1.2 State of implementation of EU WFD in regulated rivers in Norway

The Water Regulation Act ('Vannforskriften') (Miljøverndepartementet, 2006) was adopted in late 2006 as Norway's main follow-up instrument of the EU Water Framework Directive (WFD) (OJEC, 2000) and entered into force on January 1st, 2007. Norwegian authorities selected 29 pilot areas with the common EU implementation, thereby being able to participate in the 'common European learning process' (http://www.vannportalen.no/enkel.aspx?m=40354) (accessed September24th, 2012). These 29 pilot areas cover approximately 20% of Norway's total areas within the jurisdiction of the WFD, and will follow the first planning cycle (2015), while the remaining 80% will follow the second planning cycle by meeting the environmental requirements by 2021. A large number of river basins in Norway are developed for hydropower production (many designated as heavily modified water bodies (HMWB)), and more than 2500 water bodies are considered being negatively impacted due to hydropower regulations (http://vann-nett.nve.no/innsyn/ (accessed September 24th, 2012). Hydropower production is of vital importance for Norway, providing close to 100 % of all electricity, thus forming a conflict of interest between energy production and improved environmental standards.

Implementation of the EU WFD in those water bodies designated as HMWB has in particular been difficult, both in Norway and in Europe. As stated in the background documents for the 3rd European Water Conference, Brussels, 24 – 25 May 2012 (http://waterblueprint2012.eu/conference-documentation) (accessed September 24th, 2012); "There are only few examples where heavily modified water bodies have been designated and good ecological potential has been defined in a transparent way following the WFD provisions and the Common Implementation Strategy (CIS) guidance", summing up the EU Commission's evaluation of the implementation EU WFD up to present day.

In Norway, there are two prior completed studies/reports of developing a methodology for the operationalization of GEP in regulated rivers (Skarbøvik et al. 2006; Finstad et al. 2007). These methodologies have, however, to a very little extent been used in the operational work, i.e. in the development of river basin management plans. A few very recent European studies (e.g. Mielach et al. 2011; Navarro et al. 2012) are considered very relevant and may propose possible ways forward for Norway. This study builds on both national and international studies in order to propose a strategy for the implementation of the EU WFD in regulated rivers.

1.3 Environmental flows (Eflows) versus minimum flow in the context of EU WFD

Environmental flows (Eflows or EF) can be defined as the amount of water that is left in an aquatic ecosystem, or released into it, for the specific purpose of managing the condition of that ecosystem (King & Brown 2003; Arthington et al. 2006). Navarro/Sánchez (CIS ECOSTAT - Hydromorphology Workshop, 12th and 13th June 2012 - Brussels), presented the following definition of environmental flows:

'Maintaining or partially restoring important characteristics of the natural flow regime (ie. the quantity, frequency, timing and duration of flow events, rates of change and predictability/variability) in order to maintain specified, valued features of the ecosystem is the concept known as environmental flows'.

Furthermore, environmental flows can also be understood as the 'flow regime necessary for achieving a certain level of conservation'.

The term minimum flow is the term traditionally used in legal processes of setting restrictions on water withdrawal, e.g. how much water should be left in the river (as a minimum) after withdrawal for a certain human purpose (for instance hydropower production). Minimum flow restrictions have historically to a limited extent been set based on ecological requirements. In Norway, the concept of assessing the minimum flow have, however, gradually been changed into assessing the minimum ecological requirements in order to sustain certain ecological qualities, typically acceptable conditions for salmonid fish and fishing.

At the same workshop in Brussels (June, 2012) Navarro/Sánchez state:

- The WFD does not specify the flow regime required to achieve the Good Status but requires that this flow regime should provide conditions 'consistent with the achievement of the values specified for the Biological Quality Elements'.
- GES is unlikely to be reached in a water body with significantly altered flows.
- A hydrological regime consistent with the GES must include:
    - the most relevant components of the hydrological regime,
    - must be based on the natural flow regime, and
    - must reflect a large proportion of such natural regime.

1.4 Used abbreviations

AHG	At-a-station hydraulic geometry
BBM	Building Block Methodology
CIS	Common Implementation Strategy
DC	Decrease
DHG	Downstream hydraulic geometry
EF	Environmental flow
Eflow	Environmental flow
EU WFD	European Union Water Framework Directive
EIA	Environmental Impact Assessment
FIS	Fluvial Information System
GES	Good ecological status
GEP	Good ecological potential
GIS	Geographical Information System
GWh	Giga-Watt hour
HG	Hydraulic geometry
HMU	Meso-habitat units
HMWB	Heavily modified water bodies
HPP	Hydropower plant
IC	Increase
LQ_d	Lowest daily minimum flow

MALF	Mean annual low flow
$MALQ_{d\ natural}$	Natural mean annual minimum flow
MALQd	Mean low discharge in a period and is the arithmetic average of the lowest annual mean daily flow (LQ) over a longer observation period
MAM(7)S	Mean annual 7-day minimum flow – Summer
MAM(7)W	Mean annual 7-day minimum flow - Winter
MFR	Minimum flow requirements
MQ	Mean flow
MW	Mega-Watt
R&D	Research and development
Q_{95}	The flow value exceeded 95 % of the time. Be aware that this is not consistently used in the literature (neither this report) as Q95 sometimes refer to flow value exceeded only 5 % of the time (upper end of the duration curve), i.e. 5 % probability that the flow will be larger than the given value. From the context, the understanding of the statistical term should be clear, but reading the figures with percentiles should anyhow be made with great care.
Q_{BF}	Bankfull discharge
Q_c	Common low flow
Q_{MF}	Mean annual flow
Q_{minA}	Locally adopted minimum flow
Q_{minEN}	Maximum acceptable minimum flow based on energetic and economic considerations
$Q_{minGÖ}$	Instream flow (minimum) based on ecological considerations
Q_{min0}	'Orientation minimum flow'
Q_{san}	Sanitary discharge
Q_{serv}	Servitude discharge
RBA	River basin authority
RBMP	River basin management plans
WFD	Water Framework Directive
W_M	Average river width

2 Practise in setting environmental flows and compliance with the EU WFD

A large number of methods exist for setting environmental flows in rivers from the pioneer work starting in the 1970's. Different authors have reviewed these methods (e.g. Navarro, 2012; Halleraker & Harby, 2006; Harby et al., 2009, Bakken et al. 2011). Although the techniques for assessing environmental flows can be categorized in a variety of ways, four basic groups of methodologies are widely recognised; hydrological methods, hydraulic methods, habitat simulation methods and holistic methodologies (e.g. Navarro, 2012, Halleraker & Harby, 2006). It has been estimated that some 200 different generic methods have been developed to derive 'environmental flows' (Tharme 2003, Arthington et al. 2006). The choice of method will determine the resources (costs, time, competence) to carry out an assessment, and a widely used approach for selecting method is determined by the 'acceptable risk'; meaning that cases with greater environmental, social or economic risks ask for more sophisticated methods to be applied. Furthermore, it is widely recognised that generic flow requirements are basically non-existing, and site specific data/assessments are required. It can therefore be stated that there is no one right way to assess environmental flows; the context is everything in this assessment (Navarro 2012).

As several reviews of methods to assess environmental flows have already been made (e.g. Navarro 2012, Halleraker & Harby, 2006), we would refer to these studies instead of presenting them in further detail in this report. In the following sections some of the historical and current practice of setting flow requirements (minimum flow, environmental flow) in selected European countries is presented.

2.1 Historical and current practise for setting minimum flow requirements (MFR) in Norway

Hydropower is key stone in the Norwegian energy supply and by far the dominant supplier of electricity. Hydropower resources have been developed more than 100 years, but environmental requirements were not introduced until late 60's – early 70's (Angell & Brekke 2011). The older regulations hence have no minimum flow requirements and any releases from these licences are based on voluntary releases by the hydropower producer. Typical wordings in the old licences are "the power plant should be operated such that floods are not increased. Otherwise the water can be managed as required by the power company" (from Steinar Sandøy's presentation at the WFT-workshop in Trondheim in April, 2012).

From the 1970's and onwards, minimum flow releases were typically required, with a gradual improvement with respect to improving the environmental conditions in the bypass section (see Figure 2-1).
Typical for requirements in the bypass section introduced in the 1970's to the late 1980's are:

- A low and constant minimum flow
- Difference between summer and winter flow

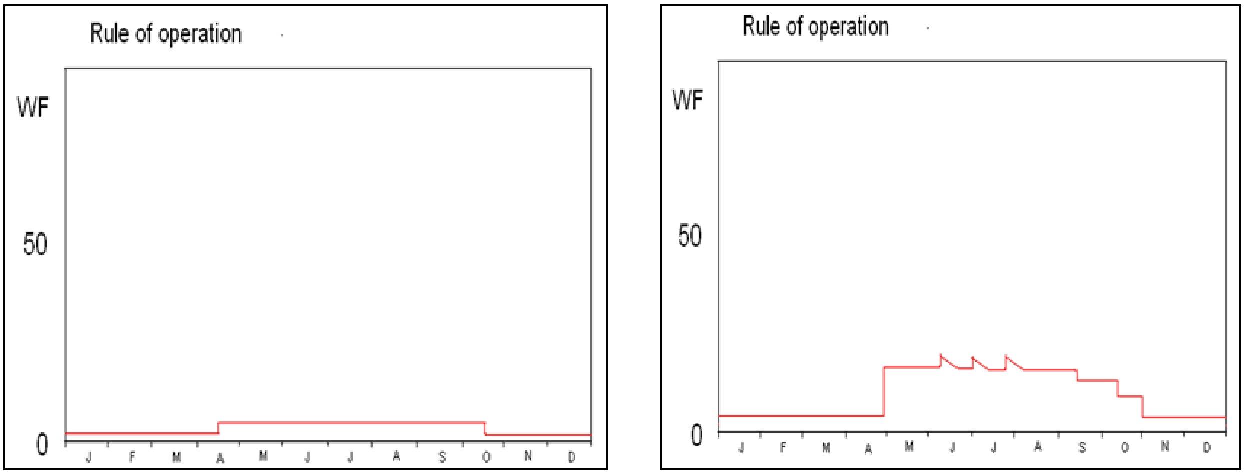


Figure 2-1. The figure to the left illustrate typical low flow regimes as required in the licencing process from the 1970's – late 1980's, with a low and constant minimum flow, possibly diversified with a higher summer flow than the winter flow. During the 1990's (to the right) the minimum flows were introduced as standard requirements in new licences and generally set higher. A stepwise decrease from summer to winter flow could be defined as well as artificial flood releases to trigger fish migration (from Steinar Sandøy's presentation at the WFT-workshop in Trondheim in April, 2012).

For the licenses permitted during the 1980's and later, the requirement is given in the license, based on an individual assessment in each case, with no standardized method. An environmental impact assessment study (EIA) is always required in the applications for power plants > 40 GWh. For small plants (1-10 GWh), a simplified environmental assessment is required. All new licenses are normally given a minimum flow requirement. The legislation allows for changes in practice due to new knowledge and priorities. In general, highest MFR are given in the salmon rivers, and lowest in many steep inland rivers/brooks.

The concept of common low flow (Q_c) is often a starting point to set residual flow when a license is needed, and it is used as the residual flow if a license is not needed. Calculation of the common low flow should normally be based on at least 15-20 years of data. The calculation algorithm of the common low flow value is as follows:

- remove the 15 smallest values every year in a daily streamflow record
- calculate the annual minimum series
- rank the values in the annual minimum series and remove 1/3 of the smallest values

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. Q_C is therefore closely related to the widely applied Q95 low flow index. Q_C is defined for all year. For Norwegian inland and mountain catchments, the low flow period will be during the winter caused by precipitation stored as snow. In lowland and coastal areas the low flow period is during the summer, mainly caused by higher evaporation losses. The Q_C calculated for a catchment with winter low flow, will therefore to a limited extent be useful for ecological purposes as it gives no information about natural low flow during the summer season. An alternative approach is then to calculate flow quantiles for the desired season (Engeland et al. 2006, Engeland & Hisdal 2009). The Q_C of Norwegian rivers ranges often between 6 and 12 % of mean annual flow (Q_{MF}) but can vary between <1 % and more than 50 % of Q_{MF} (Væringstad & Hisdal 2005).

Relationships have been developed between catchment characteristics and several low flow statistics including Q_C and MAM(7) (the mean annual 7-day minimum flow). In Krokli (1988), regression equations for estimation of the MAM(7) were established for all of Norway. Because of the highly seasonal flow patterns, MAM(7) was estimated for the summer and winter season separately, MAM(7)S and MAM(7)W. Skaugen et al. (2002) found high correlations between Q_C and min{MAM(7)S, MAM(7)W}. Engeland & Hisdal (2009) compared several methods and promoted the use of a regression method based on a relationship between the low flow index and an optimal set of catchment descriptors for low flow estimations in ungauged catchments.

Seasonal variations in the requirements are often introduced in rivers with significant seasonal variations in water flow. Q95 usually used for different seasons, diversified by summer (high flow) and winter (low flow). For rivers with salmonids, spawning flows in the autumn can be considered. For the small hydro power stations (< 10 MW), protection of landscape qualities is the most important reason for requiring minimum flow requirements.

For some large scale new hydropower plants in important salmon rivers, trial regulations have been applied. An example is Alta river in northern Norway, where a council of three parties (from NVE, the County Governor and a local fishing organization), have given advice to the hydropower company to limit damage to the famous salmon population, after a period where different flow regimes had been tested out and evaluated with respect to environmental response to various releases. In 2009 a permanent regulation system was set for Alta river, based on decades of trial and R&D. The process of setting this flow and the scientific basis for ending up with this flow regime as the permanent regime is presented in more detail in section 5, together with description of a similar process in two other important rivers in Norway (Mandelselva and Suldalslågen).

Table 2-1. The governing laws and regulation for issuing hydropower licenses in Norway briefly summed up. For further details on the institutional frameworks, including laws, regulations and licencing procedures, we refer to e.g. Knudsen & Ruud (2011).

Name of Act	**Regulating**
Water Resources Act (2000), § 10	Conditions on minimum water flow shall be based on a concrete assessment in each licensing case: - The assessment shall be based on relevant criteria, such as landscape, flora and fauna, water quality and groundwater. - For water extraction projects that do not require a license, release of minimum "common low flow" is a condition
Water Regulation Act (1917)	Modernize and demand minimum flow requirements (MFR) in "old licenses" with revision 30/50 years
Nature Diversity Act (2009)	I.a. principles for administrative decisions, similar to WFD art. 4.7.
Planning and Building Act (1985)	I.a. public hearings, mapping of interests

In cases with potential tense conflicts with various interests groups, which would typically be the case in regulated rivers with interests of salmon game fishing is very strong, studies from several and different research groups might be conducted in order to propose environmental flow conditions. In such cases, the outcome of the various studies might not be consistent in their recommendations and the selection scientific sources might form the basis of promoting various levels of environmental flows (Egeland & Jacobsen, 2012). The motivation for finding the optimum flow might be the same for all interest groups, but the scientific basis might not give clear and consistent recommendations.

It is not clear if the standardised way of setting minimum flows in Norway (environmental flow) is in compliance with the EU WFD-requirements of obtaining GES/GEP. This project is aimed at unveiling approaches that can be used to set environmental flow values in compliance with the requirements of the EU WFD.

We would also refer to section 5 and the cases from Norway for setting environmental flows that use a more sophisticated and comprehensive approach for setting flow regimes than the practise discussed in present section. All examples presented in section 5 are taken from real cases where flow regimes are set and R&D-projects aimed at testing out new approaches in a realistic situation.

2.2 Setting EFs in selected European countries - compilation of key figures

Table 2-2. Approaches and key figures for setting minimum/environmental flows and/or water releases in selected European countries[1]. The primary source for the information in the table is Mielach et al. 2011, with supplementary information by workshop participants.

Country	Minimum flow release
Austria	In Austria, Eflow is defined based on the Ecological Quality Objective Ordinance – Ecological Status of Surface Waters (BGBI.II NR. 99/2010 - Qualitätszielverordnung Ökologie Oberflächengewässer), which has to be applied for all surface waters with the exception of artificial and heavily-modified water bodies. The regulation defines objectives for the high hydro-morphological status and guiding values for the good hydro-morphological status. The guiding values describe conditions under which the values laid down for the good status of the biological quality elements can be reached with high probability. These values concern not only Eflow, but also other hydro-morphological pressures as impoundments and hydropeaking. In general, Eflow represents 20 % of the actual flow to maintain the natural flow variability and to ensure: - Natural relocation and composition of the natural bed-sediment. - Sufficient current/flow during spawning migrations - Consideration of different seasonal habitat demands of individual age classes of key organisms - Oxygen and thermal conditions typical for the respective water body However, Eflow is not allowed to undercut a permanent minimum flow rate in the streambed which a) is above the lowest daily minimum flow (Eflow $\geq LQ_d$) b) is at least on third of the natural mean annual minimum flow (Eflow $\geq 1/3\ MALQ_{d\ natural}$) for water bodies where $LQ_d < 1/3\ MALQ_d$. c) is at least half of the natural mean annual minimum flow (Eflow $\geq 1/2\ MALQ_{d\ natural}$) for water bodies with a mean flow below 1 m³/s (MQ < 1 m³/s) and where $LQ_d < 1/2\ MALQ_d$. Furthermore, thresholds for minimum depth and minimum flow velocity with regard to the fish region and slope have to be met in natural fish habitats (QZV 2010). Since it is assumed that these thresholds are met if Eflow $\geq 1/2\ MALQ_{d\ natural}$ is applied, a measurement and proof of compliance is not required in this case. As part of implementing the EU WFD, the main focus for rivers at risk is to improve the longitudinal connectivity (continuity), and the main factors support fish migrations and defining environmental flows for the improvement of habitats.
Finland	In Finland's environmental legislation the Water Act (27.5.2011/587) and national legislation related to implementation of WFD (Act on Water Resources Management, 1299/2004 and Government Decree on Water Resources Management Regions.

[1] The average low flow (as implemented as a requirement in Austria) is calculated based on the low flow values for a certain period, and comes out in the same range as the common low flow values in Norway. In Sweden, the average low flow values are in the range of 7-25 % of the mean annual flow.

	(1303/2004) lay down provisions on water resources management. There are no clear instructions for setting environmental flows in Finnish legislation and no standard method for assessing EF is used. EF is set case by case, the typical method used being Physical Habitat Modelling assessing changes from flow regulation to the amount of suitable habitat for juvenile salmonids. There is a standard method to integrate environmental considerations into projects affecting the environment, including water regulation (http://www.ymparisto.fi/default.asp?node=19742&lan=en). This process, Environmental Impact Assessment, is a part of the license process and is guided by Act and Decree on the Assessment of the Authorities' Plans, Programmes and Policies on the Environment (SEA Act (200/2005) & SEA Decree (347/2005)). Based on the information collected during EIA the authorities, State Administrative Agencies or Water Courts, set regulations for flow management. Many of the hydropower licenses are old and permanent, and have not been assessed by EIA protocol. Renewing the old licenses is under consideration.
France	The French Water Law imposes minimum values of flow from 5 % to 10 % of mean annual flow in 2014 for all dams and weirs. Locally, for each dams or weirs, the value of minimum flow can be increased based on study using microhabitat methodology (P. Baran – CIS ECOSTAT - Hydromorphology Workshop, 12th and 13th June 2012 - Brussels). Hydropower plants providing short-term regulated power normally have minimum flow requirements in the lower end of this range, i.e. 5 %.
Germany	The Federal Law (Wasserhaushaltsgesetz des Bundes, WHG, 2010) requires that hydropower utilization is only permitted if appropriate measures for the protection of fish populations are implemented. This also applies to existing hydropower schemes ("historic water rights"). Sufficient flows must remain in the river to protect the functionality of the river courses as a part of the ecosystem and to serve as habitat for animal and plant species. Furthermore instream flows must support the objectives of the WFD (lead to good ecological status with special regulations for heavily modified rivers). It is the responsibility of the respective state (provincial) authorities to apply suitable regulations. Individual state governments have their own provincial legal regulations (Wassergesetz, WG) some of which will have to be adopted following the new federal WHG. Almost all of them do require individual site assessments. The WG of Baden-Württemberg allows hydropower utilization only as long as "sufficient flows to sustain the ecosystem functionality" remain in the river bed. The state water agency sets the specific rules. Exceptions can be implemented under certain circumstances. For the practical application of the WG the "Landesanstalt für Umweltschutz B.-W." has published a guideline "Mindestabflüsse in Ausleitungsstrecken, 2005". This guideline is based on a 2 step approach. First, a hydrological method is applied to determine an "orientation minimum flow" Q_{min0} which is 1/3 MALF (MALF = mean annual low flow). In a second step this value can be locally adapted. For this adaptation different methods can be used: 1) hydraulic assessment, 2) habitat modelling, 3) field tests with different flows. The results of such methods can be used to determine the locally adopted minimum flow Q_{minA}. Q_{minA} may not be less than 1/6 MALF. Minimum flows can be seasonally adapted but in practice this is quite unusual. In Bavaria, the state with the highest hydropower utilization, there is a guideline named "Arbeitsanleitung zur Abschätzung von Mindestabflüssen in wasserkraftbedingten Ausleitungsstrecken" from 1993. According to this guideline, two different flows must be determined. An instream flow based on ecological considerations $Q_{minGÖ}$ and a maximum acceptable minimum flow Q_{minEN} based on energetic and economic considerations. While

	$Q_{minGÖ}$ is the first choice to be applied and is always applied to new hydropower plants it will be compared with Q_{minEN} which will overrule in the case of relicensing of existing small HPPs. The final instream flow rate to be determined is limited by a lower limit of 4% of the design flow and a maximum of 5/12 of MALF if $Q_{minGÖ}$ exceeds Q_{minEN}. For the determination of Q_{minEN} individual site specific assessments are required. Habitats for benthic species, requirements for the fish fauna, water quality and landscape aspects must be considered and field trials with flow tests are generally required. In some other states there is a focus on benthic habitats which have to be studied using FST hemisphere data for benthic preferences, some guidelines require certain flow depths and local flow velocities in the most critical reaches or along the thalweg of a diverted reach.
Italy	The Legislative Decree no. 152/2006 established that the rules for EF's calculation have to be defined in the regional WPPs (water protection plans), which are approved by the single regions in accordance with the general objectives proposed by the local RBA. For this reason in Italy there isn't a standard methodology in assessing EFs. Generally it consists of a basic hydrological component, proportional to the mean annual discharge, corrected by means of some coefficients that take different environmental aspects into account (morphology of the riverbed, functional uses, quality objectives defined by the Water Protection Regional Plans).
Romania	In Romania there is no legal regulation on computing the EF. Nevertheless, the Water Law establishes obligations on assuring EF and defines the following terms: • Sanitary discharge/EF (Qsan) is the minimum discharge required for continuous flow, in a section on a watercourse, to provide/assure the natural life conditions for the existing aquatic ecosystems. • Servitude discharge/flow (Qserv) is the minimum flow required to be continuously supplied in a section on a watercourse, downstream a dam, consisting of the sanitary discharge/EF and the minimum discharge necessary for the downstream water users. • The calculation of servitude discharge is done based on the sanitary discharge (see equation below) $Q_{serv} = Q_{san} + \Delta Q$ where: ΔQ = water required by the other downstream water uses. In general, Q95% (yearly minimum monthly mean discharge with 95 % probability of occurrence) is recommended as "guaranteed" flow. In the first RBMP (river basin management plans), standing on the available studies done by the research institutes, EF was considered to be the minimum between $Q_{95\%}$ (yearly minimum monthly mean discharge with 95% probability of occurrence) and 10% out of the mean discharge averaged on many years. The minimum release is approximately 10 % of mean annual flow or Q_{95}.
Slovenia	The first definition of minimum flows on running waters in Slovenia was defined as a quantity of water that enables the survival of water organisms. In the process to find out appropriate methods for EF assessment from existing methods it was recognised that approaches based solely on hydrological indices is 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 the use of basic hydrological data, and 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. EF is basically calculated on the basis of hydrological data and use of the following formula: EF = f * MALQd F is a factor defined by e.g. if the water abstraction is reversible or not, length of the river section, quantity of abstracted water, type of ecology and size of catchment. MALQd is given by mean low discharge in a period and is the arithmetic average of the lowest annual mean daily flow (LQ) over a longer observation period. This basically means that the minimum release varies from 8 % to 22 % of mean annual flow.
Sweden	The great majority of hydropower plants releases a minimum flow close to 5 % of mean annual flow or lower. A few tens of the hydropower plants release a flow close to 10 % of mean annual flow. There have been 53 revisions in Sweden since 1990. In 70 % of these cases the minimum flow required is set to 5 % of the mean annual flow and in 12 % of the cases to 10 % of mean annual flow. In two of the cases, the authorities required a minimum release of water in the range of 20-30 % of mean annual flow. In all cases, the requirements are constant over the year.
United Kingdom	As a general rule the Q_{95} is used, which corresponds with low flow values typically being within the range of 7-25 % of mean annual flow. See details on recommended allowable abstractions from rivers in order to meet the EU WFD requirements in section 2.4.

Based on this review it seems clear that there is no common European standard in setting the environmental flow values, which is also acknowledged and addressed by the EU Blueprint to Safeguard Europe's Water (http://ec.europa.eu/environment/water/blueprint/index_en.htm, accessed, October 8th, 2012). But as there are significant differences in terms of water availability, quantity, quality and efficiency, etc. the *Blueprint will not put forward a one size fit all straight jacket*, but rather try to put in place a tool box that Member States can rely upon to improve water management at national, regional and river basin level.

2.3 Setting environmental flows in compliance with EU WFD

It has been recognized that compiling the knowledge and experience gained from individual case studies into a scientific framework that supports the development of environmental flow standards at the regional scale is a key challenge (Acreman & Ferguson 2010). The ecological limits of hydrologic alteration (ELOHA) framework (Poff et al. 2010) synthesizes a number of existing hydrologic techniques and environmental flow methods that can support comprehensive regional flow assessment. The ELOHA framework comprises both a scientific and social process that includes the tasks shown in Figure 2-2. Scheme of the processes within the ELOHA framework (Poff et al. 2010)

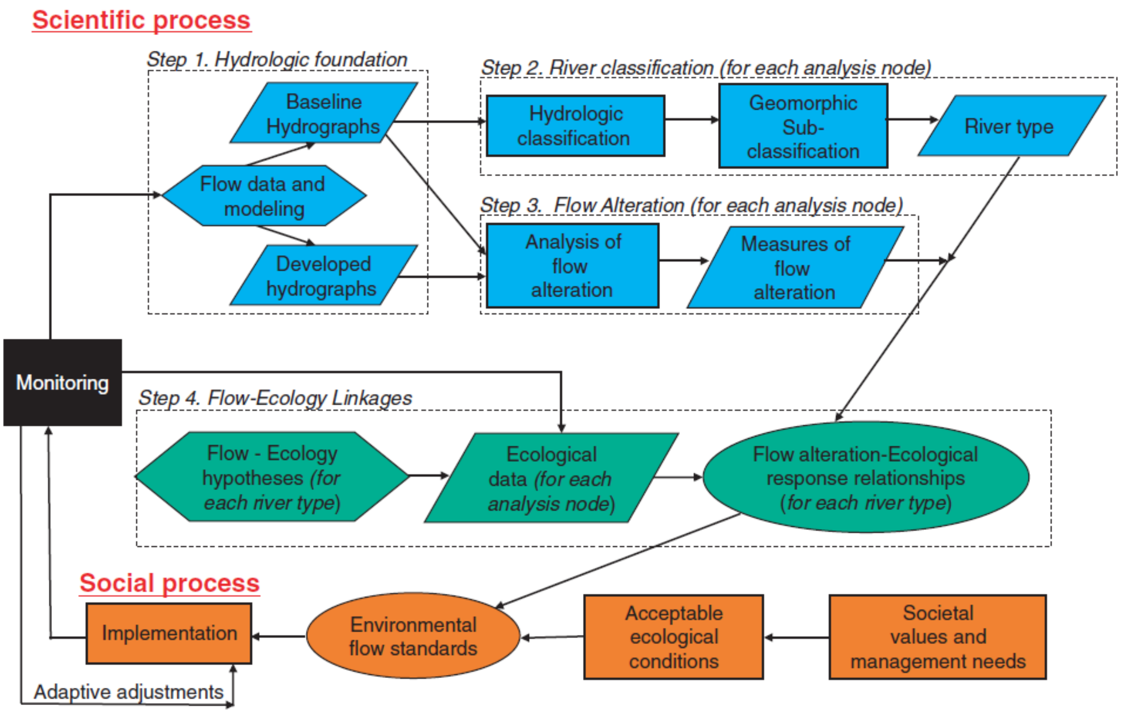


Figure 2-2. Scheme of the processes within the ELOHA framework (Poff et al. 2010).

In the following experiences from setting <u>environmental flow standards in regulated in line with the environmental objectives of the EU WFD</u> are presented. The experiences are presented country-wise and the information are mainly complied by scientists involved in the implementation of the EU WFD in the countries presented.

2.3.1 Finland

In Finland a criteria for hydromorphological changes has been developed (Keto & Aronsuu 2010, Vuori et. al. 2010). If river has been changed by damming, dredging, embanking or has been changed to a new river channel for at least half of its length or at least half of its natural head (loss) is developed; it can be directly named as heavily modified water body. Otherwise the hydromorphological status is defined by HyMo-points (Table 2-1). These are based on five variables, two of them referring to changes made in flow regime: 1) Upstream migration barriers (% of river length), 2) Constructed head (loss) (%), 3) Constructed part (%) of the river length (dredging, embankments, new channels, dry stretches), 4) The daily discharge variation compared with mean discharge (HQwk- NQwk)/MQ under normal water conditions and 5) Change (%) in the spring HQ compared with the natural discharge or the occurrence of the critical low flows. HyMo-points between 0-3 indicate excellent hydromorphological status, whereas 6-10 indicate moderate to bad status. If a water body is given more than 10 points it can be classified as heavily modified.

Setting EF differs between heavily modified and natural water bodies. In regulated natural water bodies the reference condition is the natural flow regime, whereas in heavily modified rivers the aspects of important water use are taken more into account. The GEP is measured after the effect of all economically sustainable mitigation measures is taken into consideration. There is no general method of setting EF in Finland. Together with expert judgment habitat modeling is typically used at different scales on a case-by-case basis. The principle of habitat modeling is to combine information on the physical state of the study site with information on the biological needs of the organism being studied, typically juvenile salmonids, to create a presentation of the suitability of habitats. The scale of work varies from single rapids to river reaches or bypass channels of several kilometers. The results can cover salmonids at all age-groups in the river, including spawning habitat. Seasonal aspects are included to reveal the possible bottlenecks in habitat availability (e.g. Lahti & Auvinen 2009). Habitat modeling is used also to assess suitable flows needed to attract ascending fish to fishways. Whether Finland will adopt another strategy in setting environmental flows is under discussion. The environmental authorities recently established a working group to consider if other methods are needed in setting environmental flows.

Table 2-3. Criteria for evaluating hydromorphological changes in Finnish rivers (Keto & Aronsuu 2010).

	1. Upstream migration barriers	2. Constructe d head loss (%)	3. Constructed part (%) of river length (cleaning, embanking, new channels, dry stretches) and its effects	4. The magnitude of short-time regulation [1] (HQwk- NQwk)/MQ under normal water conditions or frequency of 0-discharge	5. Change (%) in the spring HQ compared with the natural discharge
Very high (4 points)	Completely closed [3] (90-100 %)	Over 50	over 50, This has caused destruction/significant negative changes in natural underwater habitats (e.g. rapids)	Case-specific evaluation [2]	Over 75
High (3 points)	50-90 % closed	>30-50	30-50 Natural underwater habitats largely destroyed / significantly changed	Case-specific evaluation[2]	> 50-75
Moderate (2 points)	25-50 % closed	>15-30	15-30 At maximum third of natural habitats destroyed/ significantly changed	Case-specific evaluation[2]	>25-50
Slight (1 point)	10-25 % closed	5-15	5-15 Minor negative changes in natural habitats	Case-specific evaluation[2]	10-25
No change (0 points)	Less than 10 %	Less than 5	Less than 5 Natural habitats	Case-specific evaluation[2]	Less than 10

[1)] Short-time regulation contains weekly and annual regulation. HQ-NQ can be calculated from a weeks period.
[2)] The effects on the water levels on down stream water courses shall be taken into account.
[3)] Excluding the short period possibilities to upstream migration. Can be evaluated in several discharge situations if necessary.

2.3.2 Austria

The Austrian Regulation on ecological quality objectives of surface waters (BGBI.II NR. 99/2010) defines quality objectives for the high and the good hydromorphological condition (QZV 2010).

Therefore, the previously discussed Austrian Eflow approach is based on this regulation. Although the definition of the minimum flow is based solely on hydrological data (LQ_d, $MALQ_d$ and MQ), Eflow is defined to represent 20 % of the actual flow (QZV 2010). Thus, the Austrian Eflow method considers flow variability over time.

Not only is the quantity of discharge decisive for suitable Eflows, also the timing plays an important role. Discharge dynamics are of high importance for sustaining and conserving the native species diversity and the ecological integrity of rivers and for fulfilling the EU WFD requirements and objectives. Poff et al. (1997) stated five important flow characteristics which are: magnitude, frequency, duration, timing and the rate of change.

Mielach et al. (2012) performed a comparison of different Eflow approaches (i.e. Austria, Italy, Slovenia and Romania) using daily flows of two case study rivers, the Oplotnica river in Slovenia and the Missiaga river in Italy. The comparison used the legally defined Eflow thresholds (see "country-code"_legal in Figure 2-3) and the modelled Eflow with regard to the actual flow conditions (see "country-code"_actual in Figure 2-3). For modelling of actual Eflow it was assumed, that as soon as the hydropower plant reaches its maximum capacity, the surplus water can be added to the legal Eflow. Furthermore, at times when the natural discharge falls below the legal threshold, the entire discharge has to be released as Eflow resulting in an actual Eflow below the legal Eflow threshold (Mielach et al. 2012). The results are exemplarily provided for the year 1999 at Missiaga river (see Figure 2-3), where the black line indicated the actual flow and the coloured lines represent the legal (dashed) and actual (solid) national Eflows.

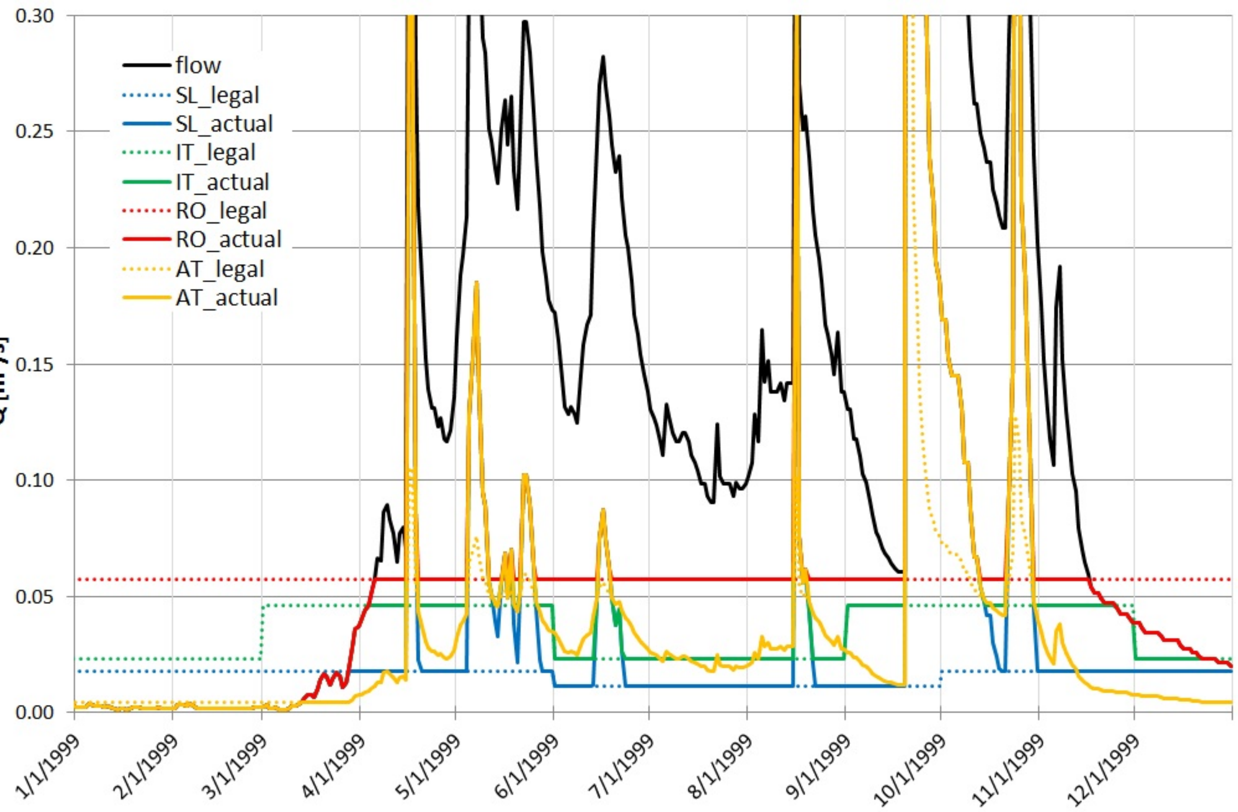


Figure 2-3: Eflow (legal and actual) comparison at Missiaga river for the year 1999 (flows above 0.3 m³/s are not indicated to increase the visibility of Eflows) (Mielach et al. 2012)

The theoretical comparison showed that, even in cases where Eflow is defined as a fixed threshold, natural variations over time are present. However, the degree of variability depends on the natural flow conditions, the defined Eflow thresholds and the hydropower capacity (Mielach et al. 2012).

2.3.3 Germany

The German Wasserhaushaltsgesetz WHG from 2010 refers to the goals and objectives of the WFD and basically requests that instream flows must be set as such that they are in agreement with the requirements of the WFD. It is left to the states to develop their own laws and guidelines to implement this. The "water laws" of the individual states rarely go into more detail but rather refer to "guidelines" that have to be developed. The guidelines being used today are older than the WHG. Still some of the states, such as Baden-Württemberg, have guidelines that can generally be applied or easily modified as such that they are in agreement with the WFD, other states will have to develop new guidelines over the next years.

Germany has 16 States of which about half have significant hydropower resources. 90 % of all hydropower generation is concentrated in Bavaria and Baden-Württemberg.

2.3.4 U.K.: Abstraction of water from rivers – standards in compliance with EU WFD

The focus in this study is how much water is required to release (from the dam) in order to gain a certain environmental standard, i.e. going from the low end and release increasingly more water. A common concern is going the other way – how much water can be abstracted without causing any significant negative impact on the environment? In the U.K. standards for water abstraction (maximum values/limits) ('look-up tables') have been developed aimed at meeting the environmental requirements of GES set by the EU WFD (Acreman et al., 2010). The tables are fairly simple to use as the limits are defined only by river type, season and flow rate (see table 2-4). A typical picture is that higher abstractions can be accepted in lowland/meandering rivers than in the headwaters. As far as the authors know, U.K. is the first and only country in Europe where such a clear standard is developed for the purpose of meeting the EU WFD-requirements.

Table 2-4. The table presents standards for U.K. river types⁄sub-types for achieving GES given as % allowable abstraction of natural flow (thresholds are for annual flow statistics). Details on the coding of the river types can also be found in the same publication. Source: Acreman et al. 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

Based on a simple illustration of one type of a river cross-section, it can easily be understood that the severity of the reduction in flow will very much depend on the how much water there is presently in the river, i.e. where on the water flow/water level curve the reduction in flow occurs (as well as the geometry of the cross-section) (see figure 2-7). The geometry of the individual transects and the possibilities to generalise on transect types will be important in order to transfer water flow/level-relations from one location to another.

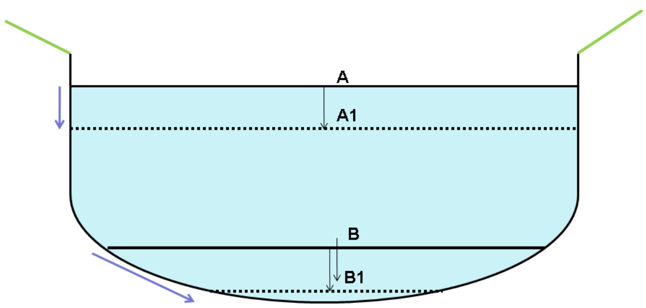


Figure 2-4. The figure illustrates a simplified cross-section of a river where the levels A and B are natural flow conditions (typically wet and dry periods) where A1 and B1 illustrate the water level after

certain abstraction of water (from Acreman's presentation in WFT-workshop in Trondheim April, 2012).

3 Hydrology and river hydraulics as the basis for assessing ecosystem response

3.1 Introduction

In order to assess the magnitude and dynamics of flow releases from dams for environmental purposes, the relation between water flow or other hydrological/hydraulic parameters elaborated from flow and the corresponding ecosystem response, would be very useful to investigate. Use of hydrological or hydraulic data/parameters to define good ecological status/potential (GEP/GES) in regulated rivers would simplify the process of characterising these water bodies and define measures involving water releases. Linking GEP/GES to hydrology would also make it possible to calculate the loss of energy production introduced by a certain requirement of the flow regime, both for the individual plant and nationally. Linking good ecological potential/status to certain releases of water would also allow detailed and fairly precise cost estimates of the measures to be calculated.

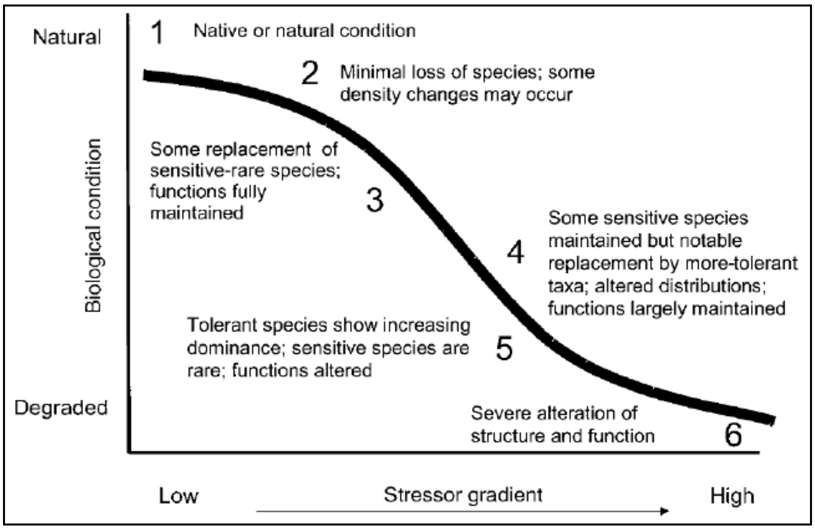


Figure 3-1. The Biological Condition Gradient to show conceptually the degradation of ecosystems determined by given levels of stressors (USEPA 2005).

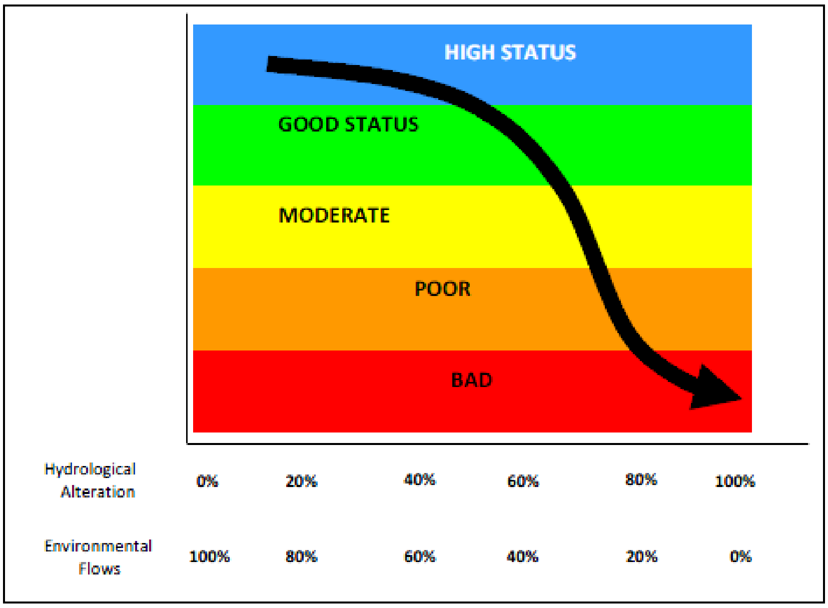


Figure 3-2. Conceptual and theoretical relationships between environmental flows and ecological status classes following the EU WFD principles (Navarro et al. 2012).

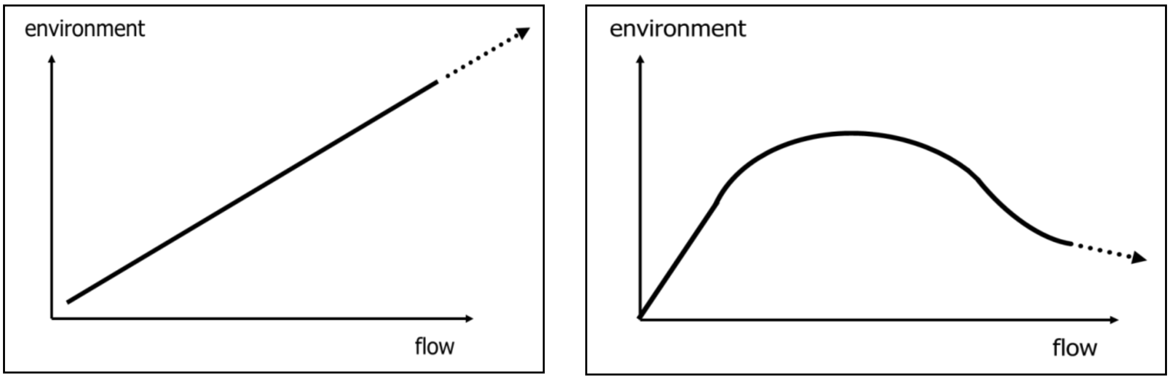


Figure 3-3. 2 different conceptual and theoretical relationships between releases of minimum flow (environmental flow) versus achieved environmental qualities (presented by Harby in WFT-workshop in Trondheim April, 2012).

The Figures 3-1 to 3-3 are all conceptual figures aimed at illustrating the relation between a change in water flow and environmental stress/degradation or increase on flow (from a dry river) and the environmental improvements. Transforming these conceptual relations into precise quantification of changes in environmental qualities is, however, more difficult. A large number of attempts have been made do investigate and develop robust correlations between hydrological indices and ecosystem response, and a dedicated software package has even been developed to calculate a large set of probably ecological relevant hydrological indices, called IHA (Indices for Hydrological Alterations) (Richter et al. 1997). Similar and dedicated tools to calculate hydropeaking indices have also been developed (Sauterleute & Charmasson, 2012).

It is certainly not trivial to find these relations and the review of hydrological indices by Poff & Zimmerman (2010) concluded that:

"The quantitative analysis provided some insight into the relative sensitivities of different ecological groups to alteration in flow magnitudes, but robust statistical relationships were not supported. Our analyses do not support the use of the existing global literature to develop general, transferable quantitative relationships between flow alteration and ecological response; however, they do support the inference that flow alteration is associated with ecological change and that the risk of ecological change increases with increasing magnitude of flow alteration".

A review by Lloyd et al. (2003) reported:
"Despite the unequivocal evidence for ecological responses to flow change, the relationship between these two measures was not simple. Small flow changes could produce large ecological responses and no simple thresholds were detected".

Findings from the Norwegian research project "HydBioUpscale" - Upscaling biological data, processes and models in relation to hydrological processes and models to catchment scale (Research Council of Norway, contract no 183286) were not very encouraging in terms of establishing relations between hydrological indices and ecosystem response based on Norwegian data (unpublished, SINTEF/NINA). The project tested the relations between a selected set of hydrological indices and fish data (from electro fishing) by use of regression analysis. For Alta River it was found that 7-day minimum flows during winter were significantly positively correlated with fish density (corrected for recruitment and flow). In Orkla River it was found a weak negative correlation between 7-days maximum flow in June and smolt production. No other significant relations were found. Lack of long timeseries of fish data and moderate/poor quality of the electro-fishing data made the results uncertain. It can also be disputed if those findings being significant in this study are general findings valid for a large number of rivers or being exclusive relation for the specific study sites.

Frame 3-1. Hydraulic parameters and ecosystem response.

There is a clear need for identifying simple relations between changes in flow and ecosystem response for the improved management rivers and the implementation of the EU WFD. Despite this, it appears very difficult, and dangerous, to apply widely and on general basis relations between hydrological/hydraulic parameters and ecosystem response found in one study in one specific river, without knowing the inherent assumptions and limitations of the found relations.

The authors believe that a potentially promising way forward would be to investigate the possibilities of using hydraulic parameters (e.g. wetted areas / width) as proxies for ecological status in rivers and relate these hydraulic parameters to habitat requirements of aquatic species. These hydraulic analyses should preferably be driven by data that are easily accessible, for instance map-based data from public databases, aerial surveys or measurement campaigns covering larger areas, and applicable in a scale (extent) relevant for supporting management of regulated rivers.

The major parts of section 3 focus on the possibilities of using hydraulic parameters for the environmental management of rivers.

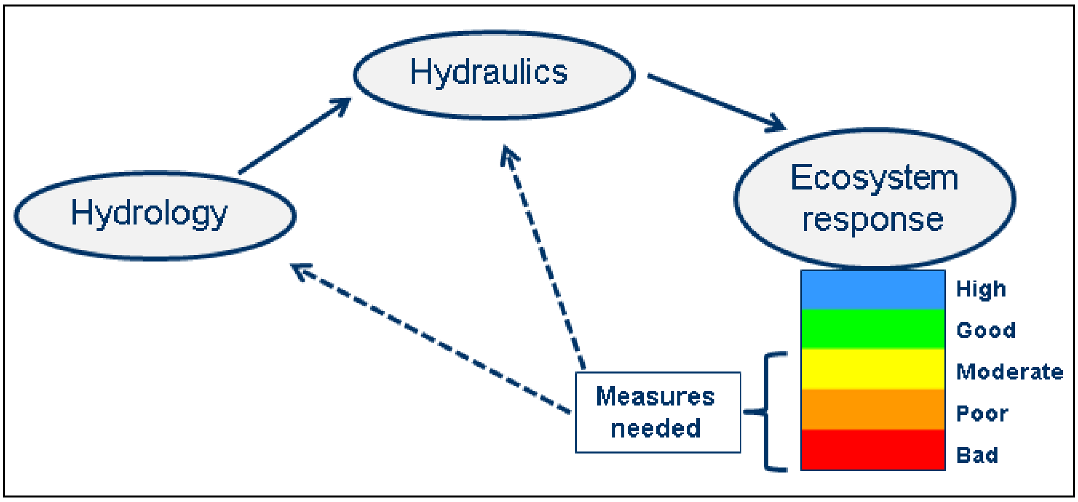


Figure 3-4. Conceptual relation between hydrological parameters, hydraulic parameters and ecosystem response within the context of regulated rivers and EU WFD, assuming that the ecosystem response is exclusively determined by physical factors. In the case of ecological state lower than good, measures must be introduced.

3.1 Actual trends in river research and implications for setting environmental flows

3.1.1 Actual trends in river research

River morphology and habitat has traditionally been sampled either with highly localized point sampling methods or broadly spaced surveys yielding average trends in river response at watershed scales. This has led to the widely-accepted view that the environment along a river's course changes relatively smoothly and predictably through space, with characteristic gradual, averaged, variation of parameters like width, depth and grain size (e.g. Leopold & Maddock 1953). The conceptual frameworks for characterizing river forms and processes throughout entire basins include hydraulic geometry (Frame 3-2) and the river continuum concept.

Frame 3-2. Hydraulic geometry.

Relationships between channel characteristics (e.g. mean depth, water-surface width, and mean velocity) and discharge, known as hydraulic geometry (HG), have been in use by hydrologists and geomorphologists since Leopold & Maddock (1953). In the simplest form, hydraulic geometry of river channels for example in relation to width has been described using empirical power laws

$$W = aQ^b \qquad \textbf{Eq. 3.1}$$

where W is wetted width, Q is discharge, and a, b are empirical coefficients. This relationship has been applied separately to describe a) how hydraulic conditions change as flow increases in one location ("at-a-station hydraulic geometry", AHG) and b) how hydraulic conditions change in stream-wise direction at a specific reference flow such as bankfull discharge Q_{BF} ("downstream hydraulic geometry", DHG). The empirical coefficients in Eq. 3.1 have been calibrated for a range of environments, leading to different values around the world for example depending on bed substrate, channel pattern, and stream size (Park 1977, Singh 2003). The AHG exponents systematically depend on scale (i.e. the size of the catchment area) and the DHG exponents on discharge frequency (Dodov & Foufoula-Georgiou, 2004). Semi-empirical DHG relationships were derived by combining fundamental equations for flow rate, flow resistance, bed material mobility, and secondary flow in bends, allowing calculating channel width W as function of discharge Q, mean size of bed particles d_S, channel friction slope S, or Shields parameter (Julien & Wargadalam 1995, Lee & Julien 2006). Recent studies estimated hydraulic geometry coefficients using multiple-linear regression models and highlighted the importance of additional regional factors such as catchment climate, elevation, land use for the HG relationships (Booker & Dunbar 2008, Booker 2010). In steep headwater streams, the AHG exponents were found to be mainly controlled by roughness area and bed gradient (David et al. 2010).

This continuous view of river systems has been strongly challenged by findings which suggest that discontinuities and variations rather than smooth changes are the key to characterizing river systems (Ward & Stanford 1983, Fausch et al. 2002, Thorp et al. 2006). There is an increasing recognition that fluvial systems are complex to degrees that can defy process explanations or predictive models that apply over a wide range of scales (Murray & Fonstad 2008). Rivers are viewed as holistic systems where process scales range from small micro-habitats to entire watersheds. This led for example to the concept of "riverscapes". It portrays rivers as combination of broad scale trends in energy, matter, and habitat structure as well as local discontinuous zones and patches (Ward 1998, Carbonneau et al. 2012). In this context, a "patch" is an area of similar physical and biological properties from the standpoint of an individual organism, i.e. the scale of the organism determines what is considered a patch. Thus, multi-scalar mapping systems are needed to capture the patchiness of the river. The application of the riverscape concept requires information on the spatial distribution of organism-scale habitats throughout entire river systems.

Recent technical and methodological developments (remote sensing techniques such as LIDAR, optical imagery, thermal imagery) allow to gain high-resolution data for entire rivers at reasonable costs (Fonstad & Marcus 2010, Carbonneau et al. 2012). Together with an advanced data base and geographical information system ("Fluvial Information System"), such data can be used for the extraction of primary fluvial variables such as width, depth, particle size and elevation from raw data (Figure 3-5). From these first-order variables, second-order variables including velocity, Froude number and shear stress can be derived and habitat patches can be analysed.

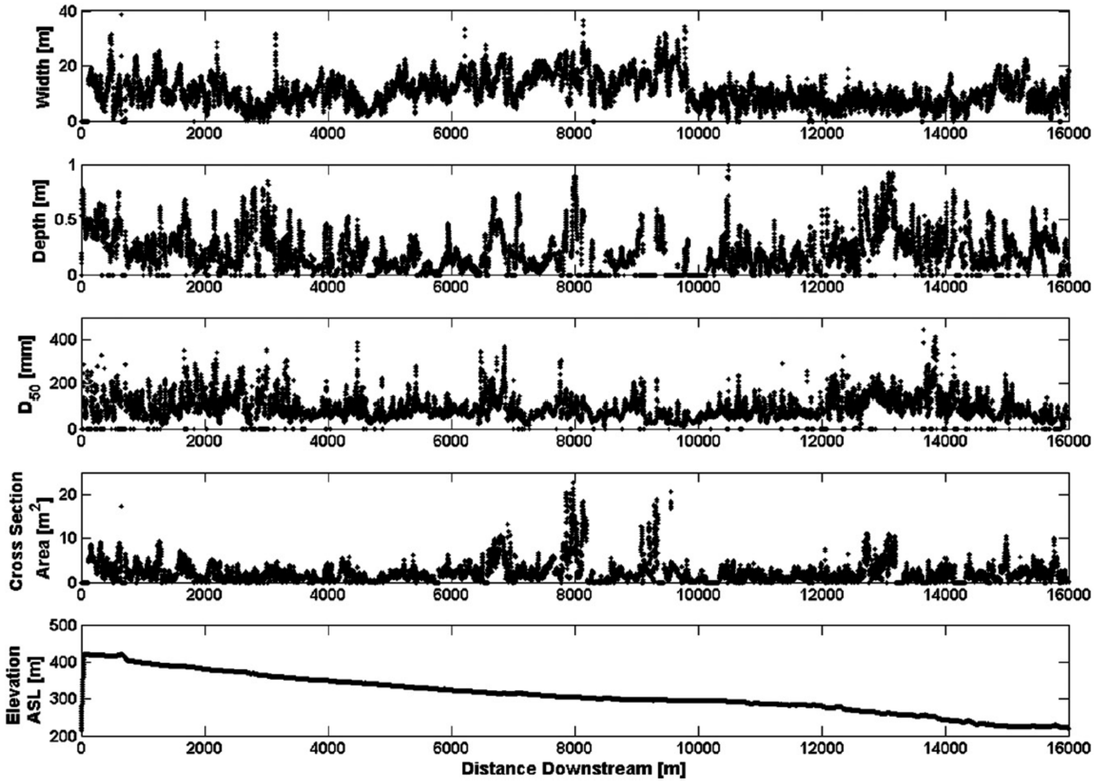


Figure 3-5. Downstream plots of width, depth, grain sizes, cross-sectional area, and elevation for River Tromie in Scotland. White is habitable (0.1 m < depth < 0.6 m, 25 mm < D50 < 250 mm), black is not habitable. Resolution 1 m. From Carbonneau et al. (2012)

High-resolution data is also increasingly used in mesohabitat investigations, where it supplements or replaces field investigations based on visual assessments. Hauer et al. (2009) developed a conceptual mesohabitat evaluation model that uses a functional linkage of three parameters (velocity, depth and bottom shear stress) to distinguish six different mesohabitat types (riffle, fast run, run, pool, backwater and shallow water). The study documented that the accuracy of the river geometry had a significant impact on mesohabitat distribution especially for shallow water habitats. The mesohabitat-units vary and change under different flow conditions, and there can be differences for the same mesohabitat in different rivers or sections (Clifford et al. 2006, Hauer et al. 2011).

The Norwegian mesohabitat classification (Borsanyi 2006) distinguishes between 10 mesohabitat (HMU) types which traditionally have been assessed by field estimations of the parameters water depth, surface velocity, surface gradient and surface pattern. Escudero-Uribe (2011) showed that a 1D hydrodynamic model can be used as predictive tool for the analysis of the HMU, hereby applying a threshold of the Froude number to separate water surface patterns. On-going research at SINTEF/NTNU aims at testing out this approach in Norway by use of HEC-RAS as the computational tool and combine these modelling results with the classification system developed by Borsanyi (2006).

The locations of riffles and pools in gravel-bed rivers are closely associated with the spatial pattern of river corridor morphological variability, in particular valley width variations (White, et al., 2010). Glacial history and relief structure (i.e. large-scale features) appear to be first-order controls on substrate grain size and habitat quality in two North American Atlantic coastal streams (Wilkins & Snyder, 2011).

Upscaling-downscaling techniques are necessary to transfer information between different scales and to identify correlations between key parameters from different scales. Upscaling-downscaling approaches have been successfully used to determine the hydraulic parameters of a river reach before looking for representative areas required for biological sampling (Le Coarer 2007). It was also tested whether cross-sectional based hydromorphological parameters were related to mesohabitat characteristics in riffle-pool reaches. However, only an increasing hydraulic radius was correlated to an increase in fast run and a decrease in run habitats (Hauer et al. 2011).

3.1.2 Implications for setting environmental flows in Norway

Environmental flows are usually defined for rivers or river reaches, but they affect processes on-going and interacting at different scales. This is illustrated in Figure 3-6, including traditional areas of application for hydrodynamic models. Increasing computational capacities allow for using high-resolution models on steadily increasing scales (e.g. 2D modelling of entire rivers). The analysis of high-resolution data from a large number of rivers worldwide may lead to some new paradigms in fluvial theory in future. At the moment, however, the interplay between the different spatial scales is not fully understood yet, and the development of up- and downscaling methods is topic of on-going research. In practice, we recommend to combine some well-established methods such as HG relationships with the knowledge about the large variations of fluvial variables.

In many cases and especially for the European Water Framework Directive, environmental flow standards have to be developed at a regional scale and for many rivers simultaneously, with limited resources for the single case. On a short run, high-resolution data acquisition throughout all relevant river systems for this purpose is not feasible. However, physical data of various spatial resolution (ranging from 1D modelling transect data to high-resolution bathymetry data from side scan sonar investigations) exists already from several site studies and rivers. New data is permanently gained within on-going research projects or studies for other purposes. Together with additional detailed investigations of selected sites, these data should be brought together, analysed and generalized to provide empirical parameters that allow for the estimation of hydraulic parameters on the regional (reach to catchment) scale.

This requires the creation of an adequate river classification system for Norway. River classification for environmental flows includes hydrologic and geomorphic classification. According to Poff et al. (2010), it serves two important purposes in the ELOHA framework (see Figure 2-2).

- By assigning river or river segments to a particular type, relationships between ecological metrics and flow alteration can be developed for an entire type based on data obtained from a limited set of rivers of that type within a region.
- A river typology facilitates efficient biological monitoring and research design, i.e. monitoring sites can be strategically and cost-efficient placed throughout a region to capture the range of ecological responses.

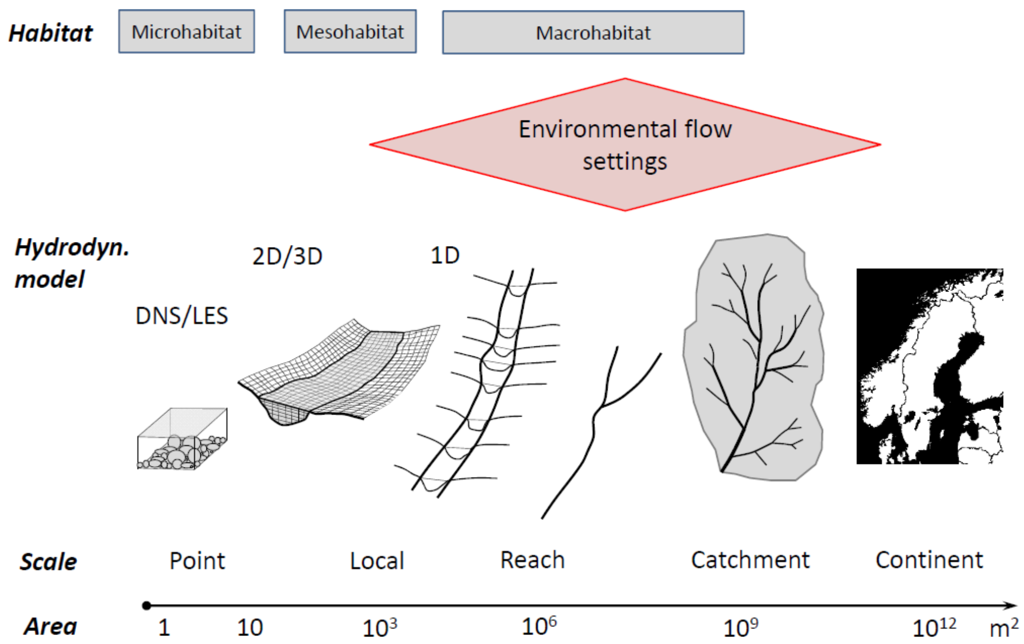


Figure 3-6. Scheme illustrating the spatial scales.

Some large-scale hydrologic classifications of Norwegian rivers are available. Roald et al. (2006) distinguished for example between the following river regions when they investigated the effect of climate change on streamflow in Norway: River Trysilelv and upper River Glomma, high alpine basins, basins around the Hardanger-vidda plateau, coastal basins in South Norway, basins in Trøndelag and North Norway. The Norwegian Nature Type Classification (Halvorsen, et al., 2009) works on a smaller scale and includes both hydrologic and geomorphic attributes. It defines 24 base types on the spatial level of a landscape-part, ranging from "clear chalk-poor slowly flowing river" ("klar kalkfattig roligflytende elv") to "humous moderately chalk-poor river at waterfalls and fast waterfall runs" ("humøs moderat kalkfattig elv i foss og fossestryk"). In this classification, some threshold parameters were defined based on the Rosgen river classification (Rosgen 1996), but the description of the units is not sufficient from a hydraulic and geomorphological point of view.

As a part of the EU Water Framework Directive, Norway was divided into eleven water regions, in addition to five water regions that are shared with Sweden and Finland. These regions are further divided into smaller units based on criteria such as catchment borders and the location of larger lakes. However, to the author's knowledge, a river classification system for the river reach to regional scale in Norway which could be readily used within the ELOHA framework does not yet exist. It has to be developed. Experiences from the UK (Acreman & Ferguson 2010) show that a number of eight to ten different water reach types allowed for a sufficient characteristic in the context of environmental flow settings.

The following tasks are recommended:

1. Establish a Norwegian fluvial information system (FIS) that allows for managing and analysing large amounts of fluvial data including high-resolution data from remote sensing surveys. Feed the FIS in cooperation with the partners that are willingly/obligated to contribute to and to use the FIS.

2. Establish a Norwegian river classification system working at the river reach scale using available information (aerial images, hydrological/geological/chemical/biological data, climatic zones, catchment area parameters etc.) and additional field investigations. Integrate the system (i.e. the respective maps/attributes) into the FIS.
3. Analyze the river data with respect to hydraulic parameters (i.e. wetted width) as function of discharge and other variables. Derive empirical functions that can be used for the estimation of environmental flow standards on a regional scale (if possible).

The FIS should be established as a part of the NVE database or at least linked to it, in particular to NVE's river network ("elvenettverk", ELVIS).

3.1.3 Example: determination of wetted area

The wetted area (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 (Figure 3-7). 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., u.d.) require the mean wetted area for river section lengths of 50 m as input parameter.

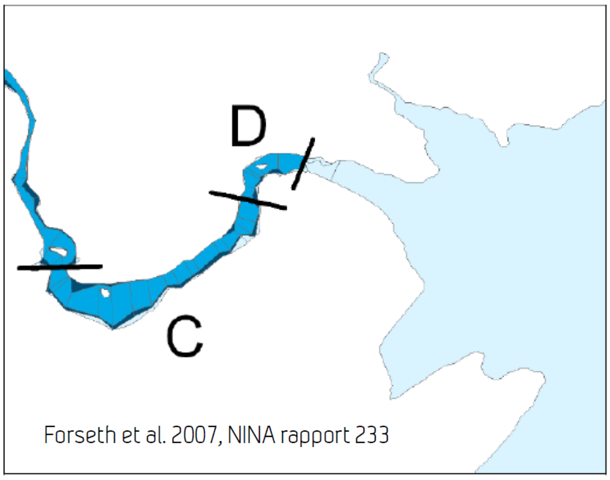


Figure 3-7. Wetted area of the Åbjøra river in sections C and D. Blue colour represents water covered area at low discharge (2 m^3/s), while dark blue zones are areas which are additionally wetted at high discharge (30 m^3/s). Source: Forseth et al. (2007).

Most rivers have a width that is much larger than their depth. Then the wetted width has nearly the same value as the wetted perimeter. Wetted width and wetted perimeter have 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. However, 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 3-8 shows the threshold values (break points) for two river cross-sections from the UK. The threshold value seems to appear at Q_{95} and Q_{85}, respectively. The figure on the left has a less clear threshold than the figure to the right. Figure 3-9 summarizes a number of studies from river cross-sections in the UK, where thresholds in the wetted width-discharge relationship have been defined (Acreman 2012).

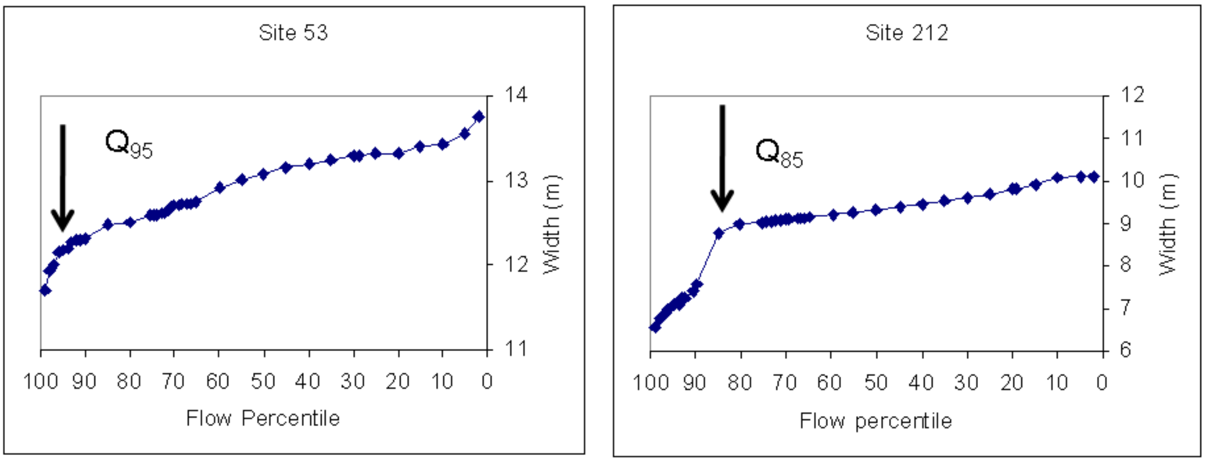


Figure 3-8. Threshold flow percentile for two different cross-sections (Acreman 2012).

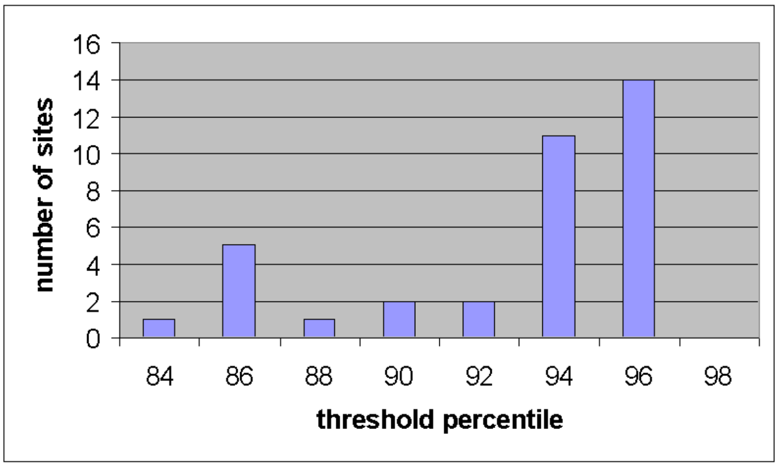


Figure 3-9. Threshold percentile for a number of studies from rivers in the UK (Acreman 2012).

In some Norwegian rivers, the relationship between wetted width and discharge has been investigated in detail for selected reaches and different purposes, usually based on field surveys and hydrodynamic modelling. Figure 3-10 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 the 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 & Hisdal 2005; NVE 2012):

- $Q_C / Q_{MF} = 0.092$
- $MAM(7)_S / Q_{MF} = 0.127$
- $MAM(7)_W / Q_{MF} = 0.149$
- $Q_{BF} / Q_{MF} = 5.2$

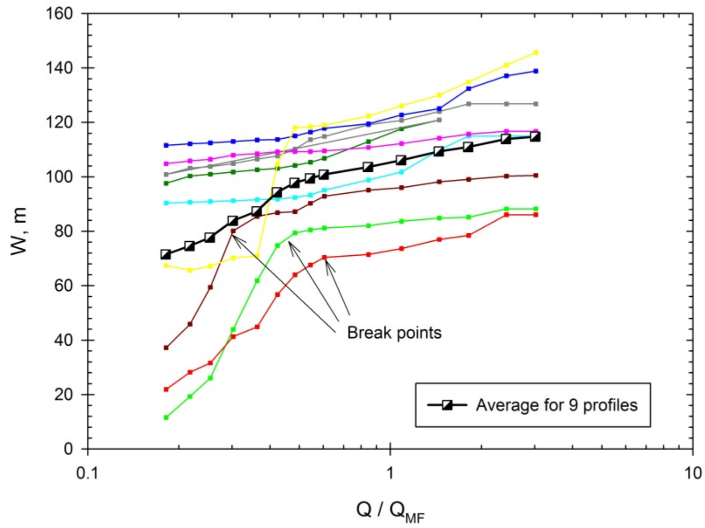


Figure 3-10. Wetted width W against discharge ratio Q/Q_{MF} for a river reach near Krossen at Mandalselva in southern Norway. Data of a 1D hydrodynamic modelling study by Sauterleute (2012).

For five of the cross-sections, the wetted width increases nearly monotonic between $Q/Q_{MF} = 0.2$ and $Q/Q_{MF} = 3$. In contrast, four of the nine cross-sections show a breakpoint. However, the relevant low flow statistics (Q_C, MAM(7)) range between $Q/Q_{MF} = 0.09$ and 0.15 and are not covered by the graph, because the modelling study was performed for a different purpose.

Figure 3-10 illustrates that the variations between river transects may be large even within short river reaches. High resolution measurements for river widths throughout entire catchments show high width variations along the rivers over short distances (Fonstad & Marcus 2010, Carbonneau et al. 2012). In Figure 3-11, the measured river widths for a river in Texas (USA) were shown together with DHG curves which were calculated using the basin as independent variable. DHG captured the central tendency of width variations along the river. However, the magnitude of reach-scale and local variability generally far exceeded the DHG-predicted trend (Fonstad & Marcus 2010).

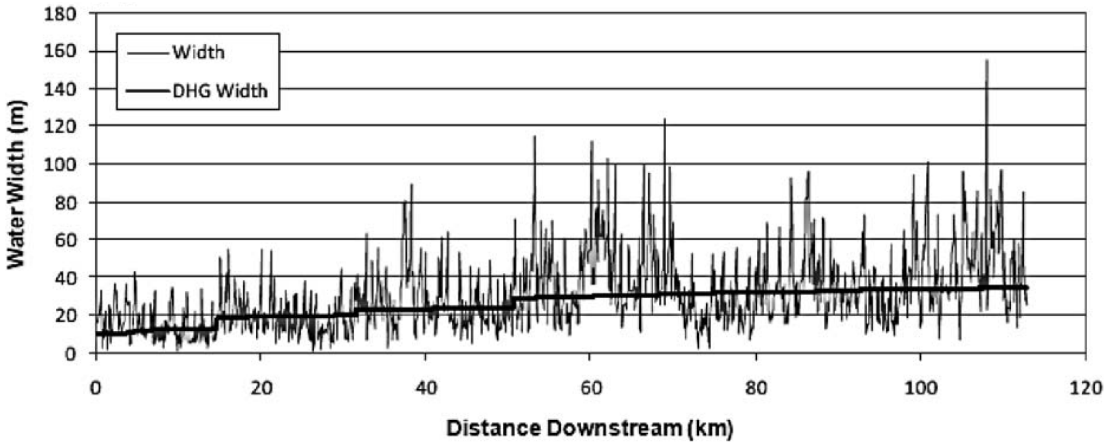


Figure 3-11. The low-flow downstream water width variation for the Nueces River, Texas. From Fonstad & Marcus (2010).

For Norwegian rivers, wetted width analyses based on high-resolution data for entire river are not yet available. In the following, the methods and first results of a pilot-study based on a simplified data collection by an internship student at SINTEF (Carnerero, 2012) are reported.

In this study, information about river width was obtained from publicly available aerial images (www.norgeibilder.no). At 29 sites situated close to gauging stations of the Norwegian Water and Energy Directorate (NVE), the wetted width was measured at selected transects for different flow situations. The sites were chosen because they were covered by at least 2 or 3 aerial images of <1 m spatial resolution from different dates and the discharge data for these flight dates was available in the NVE data base. The rivers belonged to various geographic regions including the northern, central and southern part of Norway (Table 3-1). The catchment areas of the investigated sites ranged between 88 and 6257 km^2 according to the NVE data base. Most of these rivers are affected by flow regulations due to hydro power production.

Transects were extracted over reach lengths ranging between about 200 and 2500 m where the discharge of the gauging station was regarded as representative and constant (no tributaries). The distance between transects was approximately half of the bankfull width, hereby covering the longitudinal width variations in the investigated reach. The data was processed using a Geographical Information System (GIS). Figure 3-12 illustrates the extraction of wetted area transects for Mandalselva. In addition, some available data from 1D hydrodynamic models of Norwegian rivers made by SINTEF or NTNU was systematized and analyzed with respect to the hydraulic geometry parameters.

Table 3-1. Rivers and gauging stations included into the study.

Name	Region	NVE stations	Note
Alta	Finnmark	212.9, 212.10, 212.11, 212.44	
Gaula	Sør-Trøndelag	122.2, 122.9, 122.11, 122.24	Not regulated
Mandalselva	Vest-Agder	22.4, 22.20, 22.23	
Neiden	Finnmark	244.2	
Numedalslågen	Buskerud, Vestfold	15.23, 15.61, 15.79	
Nærøy	Sogn og Fjordane	71.1	
Orkla	Sør-Trøndelag	121.9, 121.22, 121.23, 121.25, 121.39	
Otra	Vest-Agder, Aust-Agder	21.11, 21.15, 21.21, 21.22, 21.43, 21.69	

Surna/Rinna	Møre og Romsdal	112.8, 112.27	

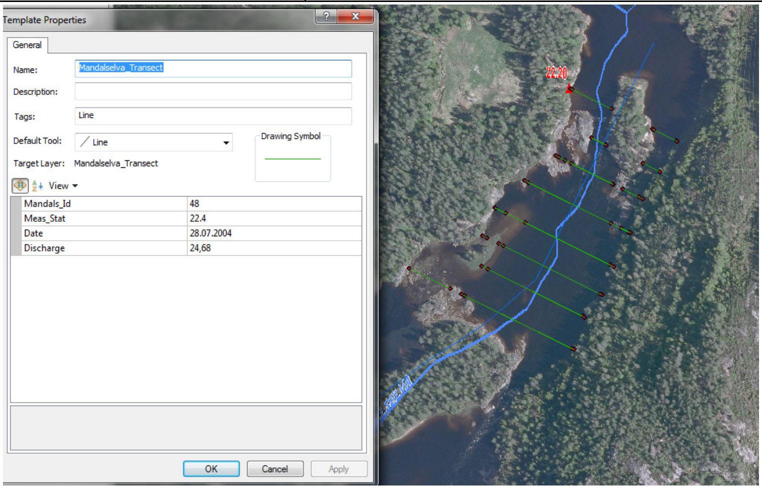


Figure 3-12. Extraction of wetted-width transects from aerial images for a given data and discharge at Mandalselva (Carnerero 2012).

Figure 3-13 shows the pairs of observed width and discharge from all investigated transects. For discharges ranging between 1.2 and 600 m^3/s, the wetted widths ranged between 2 and 400 m. In Figure 3-14, the data is presented in terms of the flow rate per unit width Q/W, and discharge data is scaled using the bankfull discharge Q_{BF}. Bankfull discharge is the discharge at which flow overtops the river banks and spills from the channel onto the floodplain. In alluvial rives, it represents the channel forming discharge mechanism since over long periods it transports the majority of sediment volume (Wolman and Miller 1960, Wormleaton et al. 2005). In rivers under quasi-equilibrium conditions, the mean annual flood equals or slightly exceeds in frequency the bankfull discharge which usually has a recurrence interval of 1.5-2 years (Leopold et al. 1963).

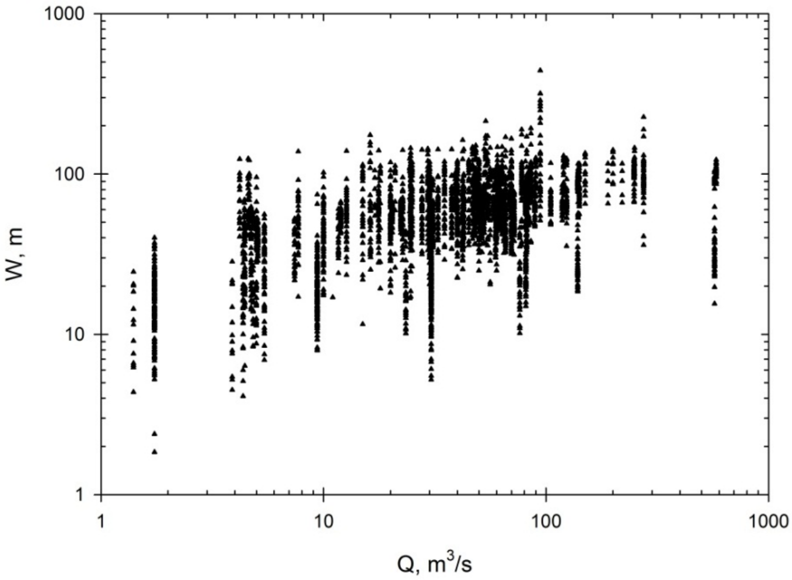


Figure 3-13. Width against flow for all investigated transects.

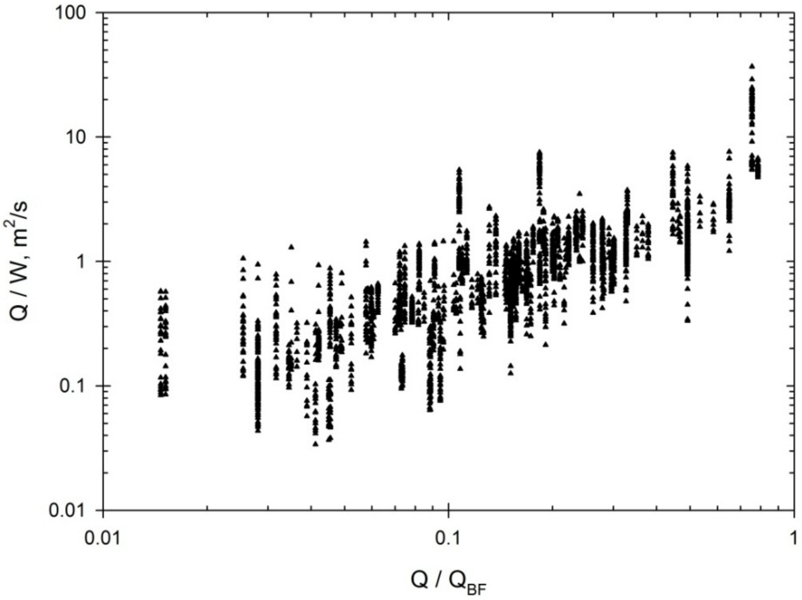


Figure 3-14. Flow rate per unit width Q/W against discharge ratio Q/Q_{BF} for all of the investigated transects where data for the Q_{BF} was available.

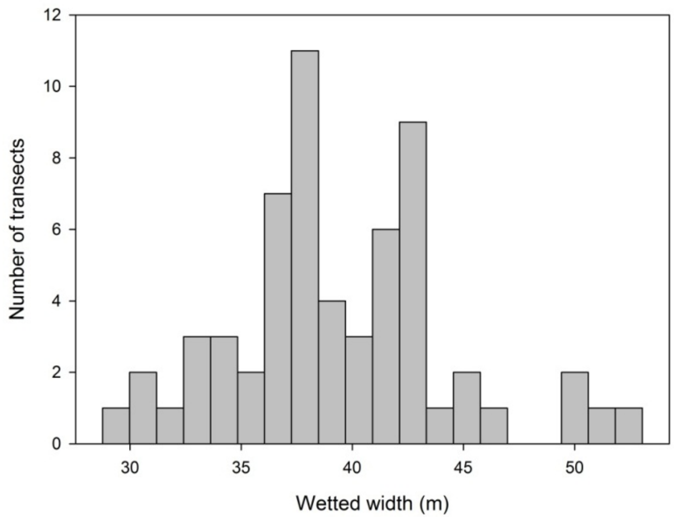


Figure 3-15. Extracted transects (left) and histogram of wetted widths (right) for Orkla, station 121.25, discharge 5.07 m^3/s, based on the aerial image from 30.05.2004. The site is influenced by small weirs.

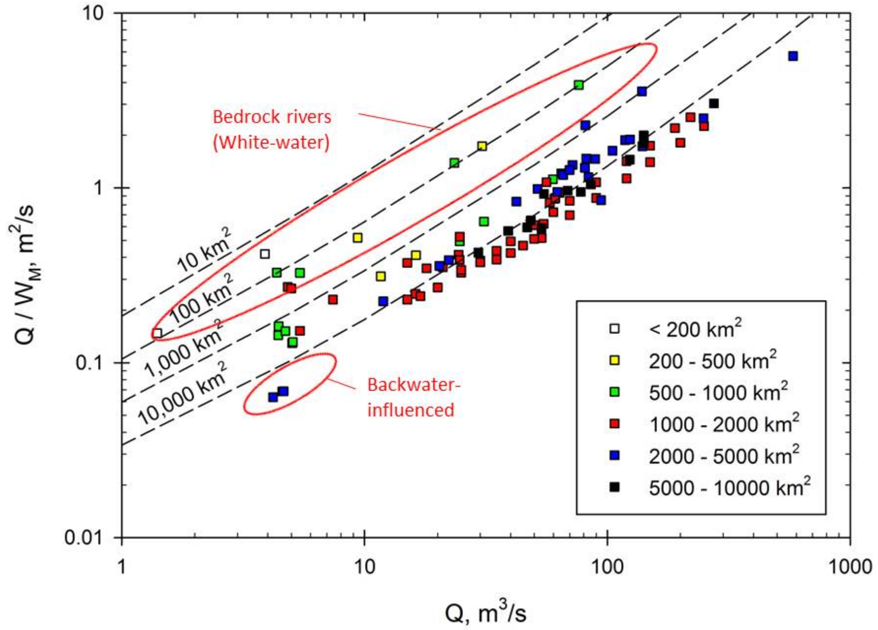


Figure 3-16. Flow-width-ratio against flow for the average site widths W_M for different catchment areas. The dashed lines indicate the AHG relationships found by Booker (2010) for 326 gauging stations across New Zealand, given the catchment area only.

Figure 3-13 and Figure 3-14 illustrate that the wetted width for a given discharge and river reach can vary very widely, depending on the longitudinal width variation within the reach. Figure 3-15 shows the histogram of the wetted widths for one site at the regulated Orkla river. It suggests that the width variation within a reach can be described by distribution functions and their statistical parameters (e.g. the mean value).

In Figure 3-16, the mean of the observed widths for all cross-sections at each site was calculated to obtain the average site width. The different colors indicate different sizes of the catchment areas. Booker's (2010) AHG-relationships for rivers in New Zealand are shown for comparison. He suggested a multilevel model to quantify the at-a-station width-discharge relationships as function of several available explanatory variables. In his work, all AHG coefficients were found to have statistically significant relationships with catchment area. Great improvements were made when climate was added as predictor variable, and further improvements were achieved by including station elevation, channel slope, flow source and land cover. Rivers with larger catchment areas were found to be wider than rivers with smaller catchment areas, even when the same discharge was occurring. River width was generally higher for rivers with cool-extremely wet catchments.

The results in Figure 3-16 underline a dependency of the catchment area also for Norwegian rivers, but they show that information about the catchment area only is not sufficient for the estimation of the mean wetted river width of a given reach. Therefore it is necessary to look into correlations with other parameters. For methodical reasons (use of available aerial images for a given discharge), the presented pre-study did not cover low-flow discharges ranging about Q/Q_{MF} = 0.1, which are the most relevant for minimum flow settings. Much more data has to be acquired to cover also this discharge range. This should be done in field investigations, where the wetted area, discharge and some other parameters (substrate, slope) are measured at low-flow conditions for a large number of river sites. The inclusion of low-flow data will probably reveal a non-linearity in the log-linear model for a given river or river type. Its analysis can be used to detect the break points in the relationship between discharge and wetted area (Navratil & Albert 2010).

It has to be investigated whether it is possible to describe wetted width based on HG coefficients and typical wetted width histograms as function of a specified river type within a new Norwegian river classification system. For this, a representative large number of river reaches has to be analyzed and additional field data (slope, roughness) has to be gained.

3.2 Ecological status classification directly based on hydrological/hydraulic data

In order to classify the ecological status, quantitative limits between the ecological classes must be defined. Sandlund et al, (2012, in progress) aims at developing a classification system for fish and proposes to use minimum 7-days minimum flow as one of the supporting parameters. More specific, the classification uses 7-days minimum flows in Summer and Winter, respectively, in relation to the natural flow in the same periods. The rationale for proposing this hydrological parameter is based on the findings in "HydBioUpscale" (see section 3.1), but can also be explained by the fact that fish tend to stand physical stress for a certain period and that climatic/hydrological events typically can last for a week (Harby, pers. comm.)

In the same report it is questioned, however, if a shorter time period would be a better indicator, for instance the 1-day minimum flow. The proposed classification is presented in Figure 3-18.

Ecological status tilstand	Very good	Good	Moderate	Poor	Bad
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

Figure 3-17. The figure outlines a possible classification of ecological status of fish based on the supporting parameter minimum 7-days in rivers based on water covered area. Source: Sandlund et al. (2012 – in progress).

As water covered area might be a physical factor more directly linked to an ecological response than water flow, it is of relevance to know the relationships between flow and water covered areas, as discussed in earlier sections. Furthermore, water covered areas should be linked with an ecological response. Figure 3-18 presents a proposed classification based on reduction in water covered area and reduction in fish production. The figure was presented by Halleraker at WFT-workshop in Trondheim April, 2012, taken from an early version of Sandlund (2012, in progress), but left out from the latest draft available. For this reason, the use of this figure should be done with great care and not without thoroughly checking its validity. From figure 3-19 it could be read that the ecological status will always stay bad if the reduction in water covered area is > 25

% of water covered area in an unregulated river. The river will never come into the class "good ecological state" unless at least 90 % of the water covered area is intact after any kind of hydromorphological change. Again, this is taken out of the most updated draft of the report by Sandlund et al. (2012, in progress).

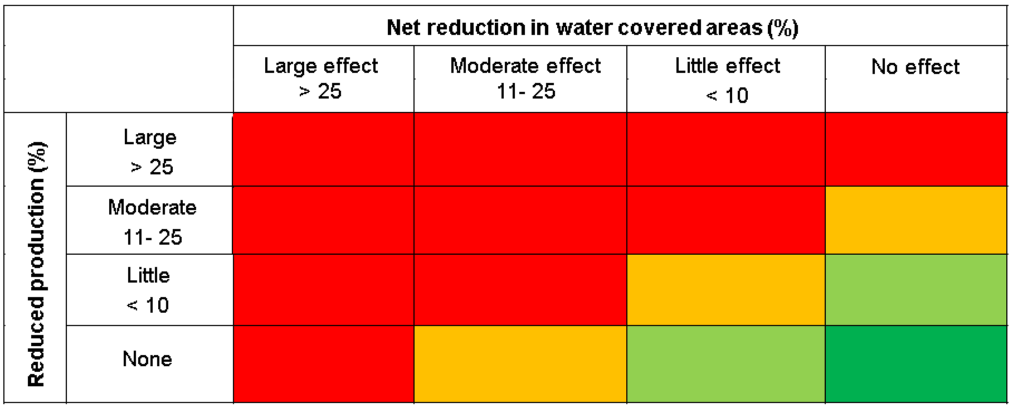


Figure 3-18. The figure outlines an ecological classification based on net reduction in water covered areas and loss in fish production (Anon 2011).

Limitations in the use of the relations in figure 3-19 are that:

- Additional water covered areas due to building of weirs are not accountable
- Additional water covered areas due to building of fish ladders are not accountable
- Cultivation outside anadromous river reaches are not accountable

The European Standard “CSN EN 15843 - Water quality - Guidance standard on determining the degree of modification of river hydromorphology”) provides guidance on appraising the quality of rivers based on a suite of hydromorphological features described in EN 14614, including the hydrological regime (Navarro et al. 2012). The standard allows for a simple approach of classification of rivers into 5 classes based on changes in water flow from natural conditions, thus having many similarities with the conceptual approach of the EU WFD. It can, however, be argued, that this approach is too simplistic for management of Norwegian rivers, but could possibly provide some basis a more sophisticated approach could be inter-calibrated against.

Table 3-2. Quantitative criteria to assess the departure from naturalness of the flow regime. Source: CSN EN 15843.

% days flow different from natural in spring, summer, autumn or winter (worst)	<20	20-<40	40-<60	60-<80	≥80
<5% decrease or <10% increase in flow	1	1	1	2	2
5-<15% decrease in flow or 10-<50% increase in flow	1	2	2	3	3
15-<30% decrease in flow or 50-<100% increase in flow	1	2	3	3	4
30-<50% decrease in flow or 100-<500% increase in flow	1	2	3	4	5
≥50% decrease in flow' or ≥500% increase in flow	2	3	4	5	5

SINTEF

3.3 The effect of mitigating measures

Revisiting the theoretical concept presented in figures 3-1 – 3-3, it is clear that the concepts in these figures illustrate how increased release of water in bypass sections would improve the environmental state in these rivers with very limited water available. If we combine release of water with additional mitigating measures, like changes in the hydromorphology, the conceptual curves for reversing the degradation might look different (see conceptual illustrations in figure 3-19), hence a combination of release of water and other measures would probably be the preferred strategy in order to improve the overall environmental state to reach GES/GEP.

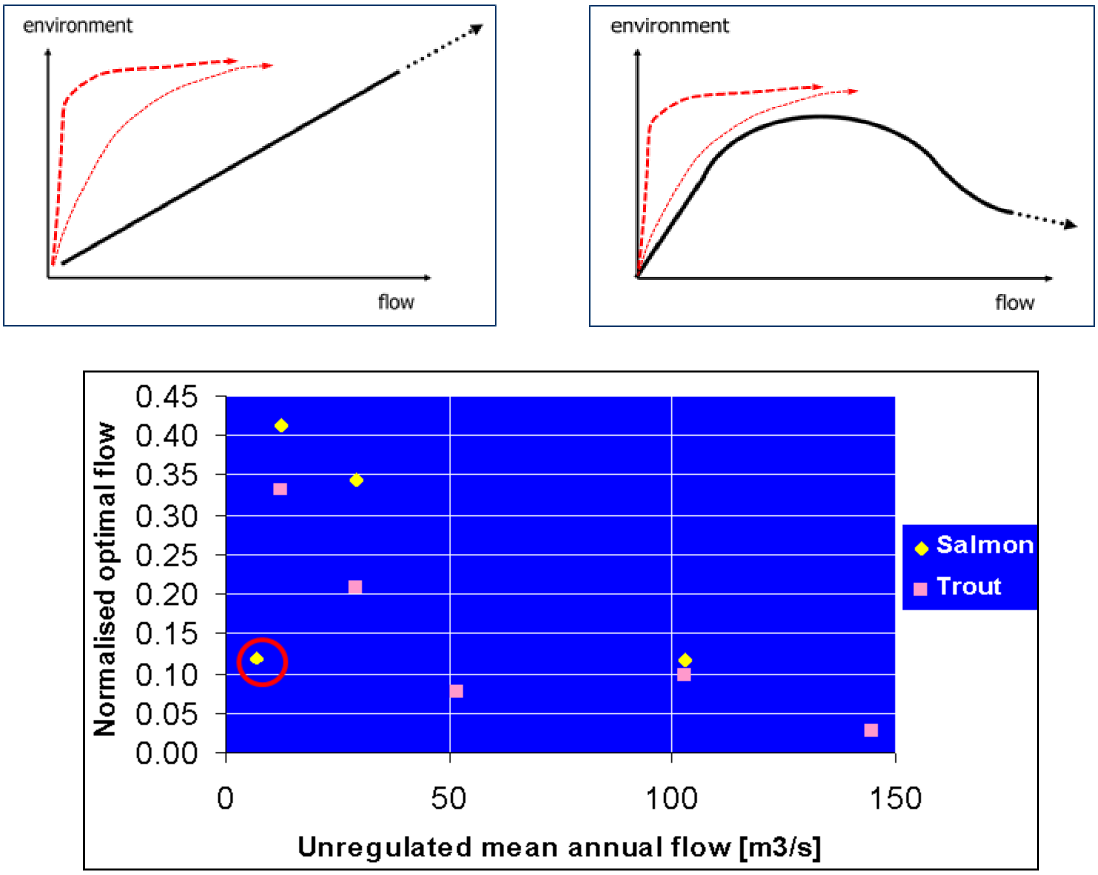


Figure 3-19. Conceptual and theoretical relationships between releases of minimum flow (environmental flow) versus achieved environmental quality (upper left and right). The red curves illustrate how 2 additional packages of mitigating measures (e.g. changes in hydromorphology) would improve the environmental state with smaller releases of water than with the additional measures. This concept is supported by the single data with a red ring in the lower figure (Harby 1999) (see details in the text below).

The lower part of Figure 3-19 (Harby 1999) illustrates the optimal flow versus the unregulated mean annual flow, based on 9 large datasets in Norway. This part of the figure basically indicates:

- Optimal flow varies from 3 to 41 % of mean annual flow for 9 large data sets in Norway. This indicates that the optimal flow decreases with increased mean annual flow.

- The single data point with a red ring is from the location Øyvollen, a reach on a tributary to Stjørdalselva with only minimum flow releases (bypass section). At this part of the river, mitigating measures have been introduced in the form of physical habitat changes ('a river within the river'). The single result support the concept that introducing measures might reduce the needs for water releases as the optimal flow is found at a lower flow level than expected.

For further details on mitigation measures and their effects in rivers being exposed to 'traditional hydropower regulation impacts', we refer to Glover (2006). For mitigation measures related to hydropeaking as a specific type of pressure, please see the extensive review by Charmasson & Zinke (2012) of a large number of publications (including so-called grey literature) in English, German and French.

3.4 Categorization of transects and rivers – generalization of results

As a preliminary approach to establishing an adequate Norwegian river classification system (as referred to in chapter 3.1.2), this chapter sums up possible international classification systems which can be used as a basis, and also possibly be implemented in a Norwegian system.

When reviewing river modelling analysis results from a specific river it can be equally important to transfer the knowledge to a broader range of rivers. The transferability of such knowledge can be defined by the similarity or difference between two rivers. In order to be able to use analysis results from one river in another river, the two rivers need to be compared in detail. Regarding river modelling results, the comparison must be based on physical characteristics/variables. The same principles are valid for the transfer of transect analysis results within a river or between rivers. Within a river the categorization and classification of river sections (and indirectly) transects can help picking out which areas with higher or lower risk of being influenced by severe changes in the flow regime.

Defining river or transect classes can be a tool for management groups to indicate within which category a specific river or transect falls into. This can be in relation to potential anthropological influence and how this will influence the specific river or transect type. Regarding transects (within a specific river type), the physical variables will determine how it (the transect) responds to i.e. a declining wave created by a shutdown in an upstream hydropower plant.

Three alternative methods of categorization and classification of rivers have been examined and summarized. The methods evaluated are:

- Rosgen classification
- Montgomery and Buffington classification
- Whiting and Bradley classification

3.4.1 Rosgen classification

Organization of the classification

The first step in the Rosgen classification (Rosgen 1994) defines 9 major stream types. The last step leads to 18 different minor types of stream, all characterized by a specific range of delineative criteria. The classification is based on three "levels". The two first are the most relevant to describe the characteristics of the channel, while the third one focuses on additional parameters in order to describe the stability and the further evolution of the channel.

Level I (Geomorphic characteristics) is a qualitative description that provides a general characterization of valley types and landforms (basin relief, landform, valley morphology, channel dimension). Many of the criteria can be determined from maps and aerial photos.

Level II (Morphological description) is a more detailed morphological description extrapolated from field measurements. This step provides a consistent quantitative assessment.

Level III (Stream conditions) incorporates additional factors (i.e. hydrological, biological, and ecological) as an overlay to the morphological template (*Level II*) in order to further describe the existing stream condition or state.

The following table describes delineation criteria/description of parameters of interest.

Table 3-3. Level II parameter overview in the ROSGEN classification of river types.

Parameter	*Formulae*	*Description*
Entrenchment	FLOOD-PRONE Width / BANKFULL Width	• Ratio of the width of the flood-prone area to the surface width of the bankfull channel. • Computed value index used to describe the vertical containment of a river and the degree to which it is incised in the valley floor. • Describes the relationship of the river to its valley and landform features. The flood-prone area width is measured at the elevation that corresponds to twice the maximum depth of the bankfull channel as taken from the established bankfull stage.
Width/depth ratio	WIDTH / DEPTH	• Ratio of the bankfull surface width to the mean depth of the bankfull channel • Key to understand the distribution of available energy within a channel, and the ability of various discharges occurring within the channel to move sediments.
Sinuosity	Stream LENGTH / Valley LENGTH	• Ratio of stream length to valley length, or ratio of valley slope to channel slope • Meander geometry characteristics are directly

		related to sinuosity

Slope	SLOPE (M/M)	• Difference in water surface elevation per unit stream length • Determinant of river channel morphology, and of the related sediment, hydraulic and biological function
Channel material	SIZE (M)	• Refers to surface particles that make up both the bed and banks within the bankfull channel • Refers to the D50 particle size, which means that 50 % of the particles measured by a pebble count are type X. • Surface particles are referred to as the "pavement" of the channel. The sub pavement is indicative of the range of sizes of sediment that are likely to be mobilized when stream flows are approaching or are at bankfull discharge levels.

Figure 3-20 shows a graphical overview of Level I stream types. The major stream types are separated into 9 different classes. Figure 3-21 shows the classification key for the Rosgen method. The parameters in Table 3-3 are indicated on the left hand side. The specific classes for each parameter are listed in the middle/right end of the table. As indicated by figure 3-25 each major class can be parted into several sub-classes.

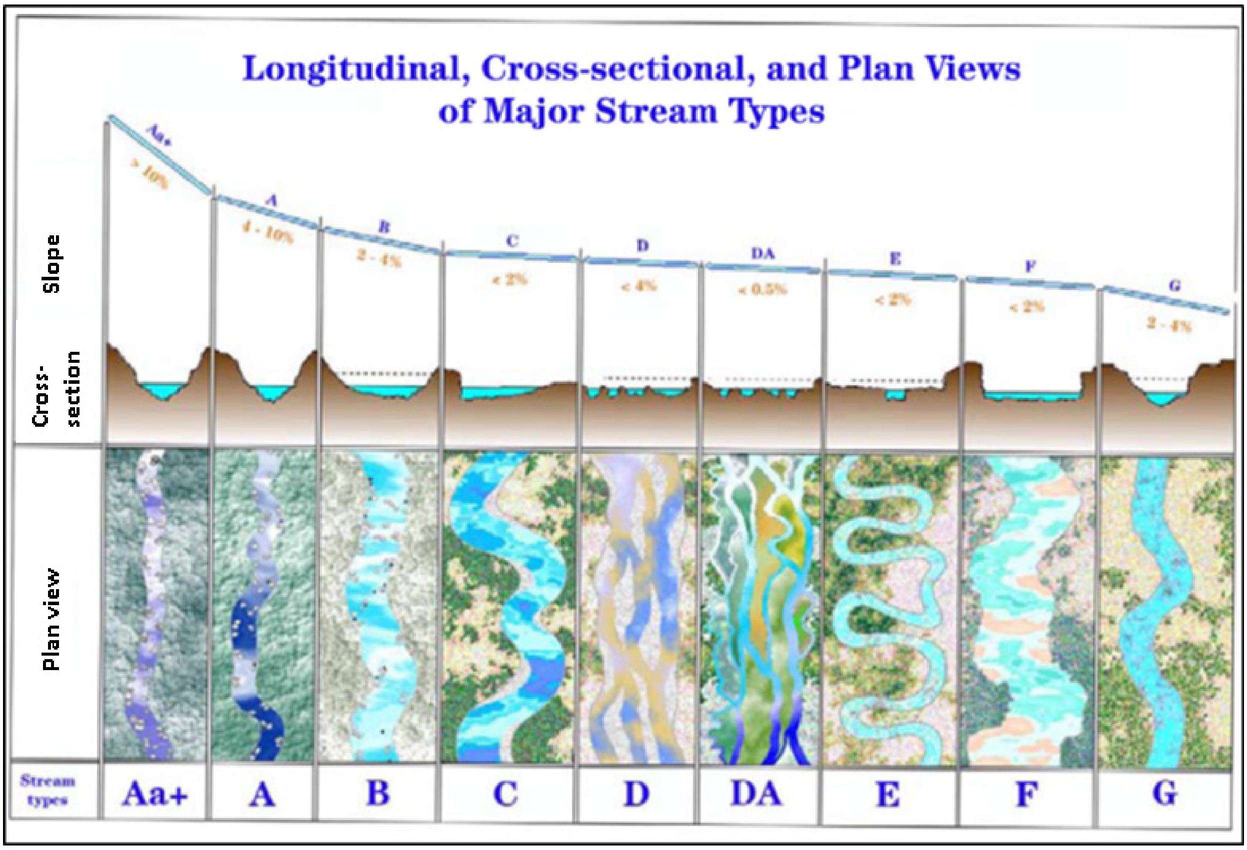


Figure 3-20. Broad-level stream classification delineation showing longitudinal, cross-sectional, and plan-views of major stream types (Rosgen 1994 - http://www.stockton.edu/~epsteinc/rosgen~1.htm) (Accessed September 24th, 2012).

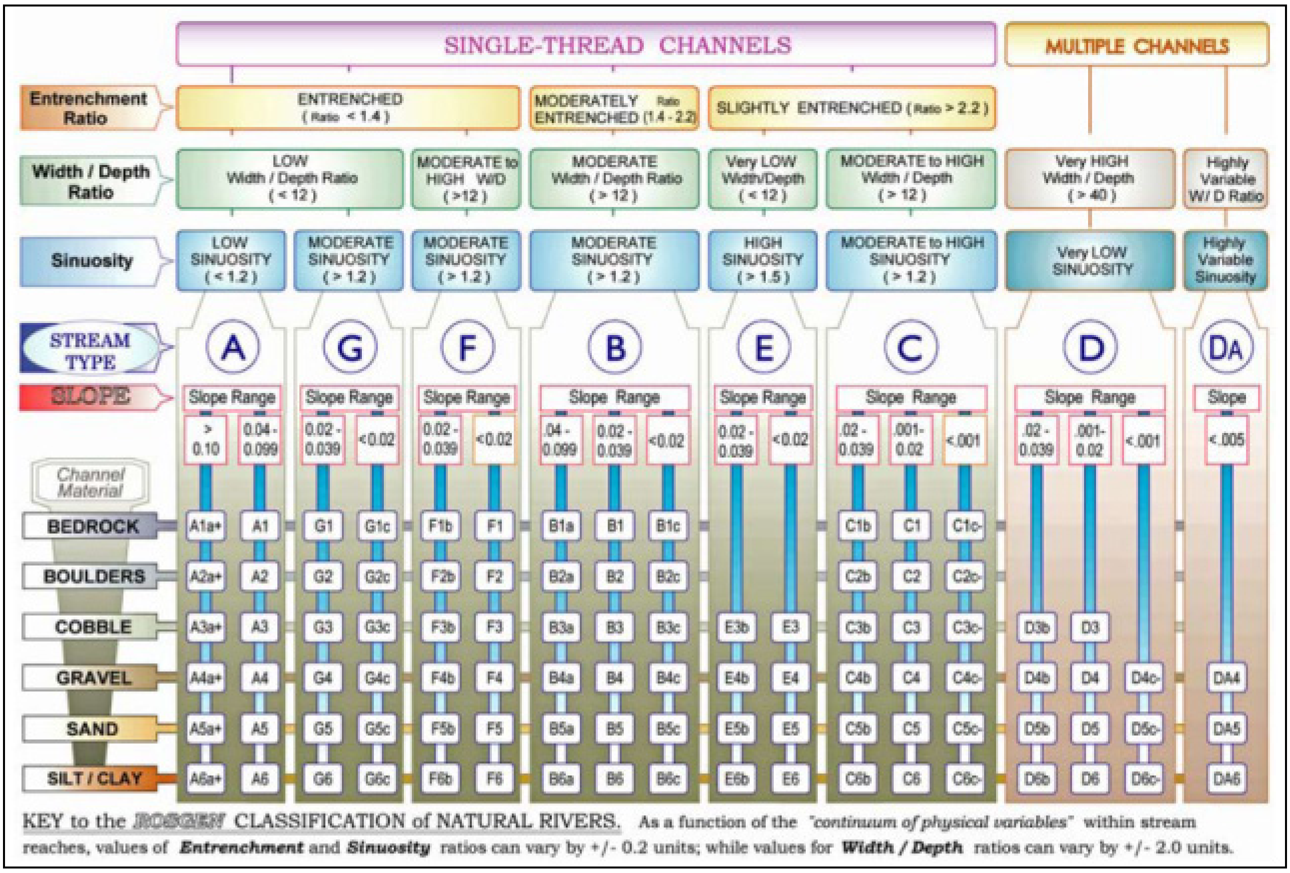


Figure 3-21. Classification key for natural rivers (Rosgen 1994).

3.4.2 Montgomery and Buffington classification

Organization of the classification

This channel classification provides 7 distinct stream types (Montgomery & Buffington 1997). The classification is based on channel substrate, bed form, transport capacity and sediment supply. The channel types are related to both qualitative and quantitative parameters. The characteristic value of criteria for the channel types was provided trough extensive field work in mountainous areas. The literature on the specific classification type provides ranges of value for some criteria and some stream types, but not for all.

The following table describes delineation criteria/description of parameters of interest.

Table 3-4. Parameter overview in the Montgomery and Buffington classification of river types.

Parameter	*Formulae*	*Description*
Slope	SLOPE (M/M)	• Difference in water surface elevation per unit stream length
Relative roughness	d90/D (ratio)	• Ratio of the 90-percentile grain size to the bankfull flow depth [d90/D] • Pool-riffle channels: relative roughness less than about 0.3 and occur on slopes <0.03; • Plane-bed channels exhibit relative roughness of roughly 0.2 to 0.8 on slopes of 0.01 to 0.04; • Step-pool reaches occur on steeper slopes and have relative roughness of 0.3 to 0.8
Shear stress	FORCE/AREA	Bedrock channels occur in reaches with the greatest shear stress; cascade and step-pool reaches plot at lower values, which in turn are greater than those for plane-bed and pool-riffle channels.
Grain size distribution	SIZE DISTRIBUTION (%)	• Refers to the composite bed-surface grain-size distributions for pebble counts from different channel types. • Literature provides the aggregated cumulative grain-size distributions (graphical view only) for 4 alluvial channels of reaches with different bed morphologies in the Finney Creek watershed.

Transport capacity and sediment supply	-	• Transport capacity generally decreases downstream due to the slope decreasing faster than the depth increases, whereas total sediment supply generally increases with drainage area, even though sediment yield per unit area often decreases
		• Channel morphologies reflect the relative magnitude of transport capacity to sediment supply, which may be expressed as the ratio $q_r = Q_c/Q_s$.
		• Colluvial channels are transport limited ($q_r \ll 1$), as indicated by the accumulation of colluvium within valley bottoms.
		• Bedrock channels are supply limited ($q_r \gg 1$), as indicated by the lack of an alluvial bed.
		• Alluvial channels, however, probably represent a broad range of q_r
		  ○ steep alluvial channels (cascade and step-pool) have higher shear stresses and thus higher Q_c and q_r values for a given drainage area and sediment supply;
		  ○ the lower-gradient plane-bed and pool-riffle channels are transitional between

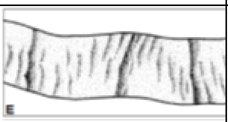
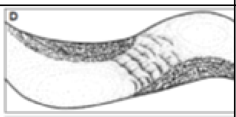
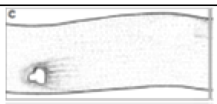
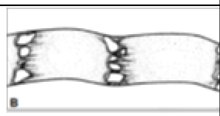
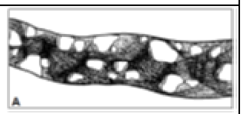
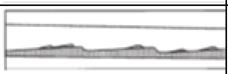
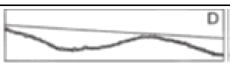
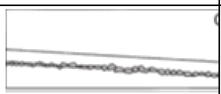
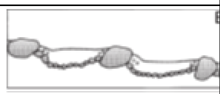
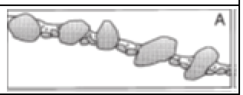
		qr >1 and qr≈1, depending on the degree of armoring and the frequency of bed-surface mobility; ○ the live-bed mobility of dune-ripple channels indicates that qr ≤1

Figure 3-22 gives an overview of all classes within the Montgomery & Buffington classification, including bedrock and colluvial river types. The two latter river types are not frequent in Norwegian watersheds and table 3-5 seems more relevant for Norwegian river systems.

	Dune ripple	Pool riffle	Plane bed	Step pool	Cascade	Bedrock	Colluvial
Typical bed material	Sand	Gravel	Gravel-cobble	Cobble-boulder	Boulder	Rock	Variable
Bedform pattern	Multilayered	Laterally oscillatory	Featureless	Vertically oscillatory	Random	Irregular	Variable
Dominant roughness elements	Sinuosity, bedforms (dunes, ripples, bars) grains, banks	Bedforms (bars, pools), grains, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Boundaries (bed and banks)	Grains
Dominant sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Hillslope, debris flows
Sediment storage elements	Overbank, bedforms	Overbank, bedforms	Overbank	Bedforms	Lee and stoss sides of flow obstructions	Pockets	Bed
Typical confinement	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Typical pool spacing (channel widths)	5 to 7	5 to 7	None	1 to 4	<1	Variable	Unknown

Figure 3-22. Diagnostic features of each channel type (Montgomery & Bufferton 1997).

Table 3-5. Excerpts from characteristics of the stream types in the Montgomery and Buffington classification of river types.

Valley segment	Alluvial				
Channel reach	**Dune-ripple**	**Pool-ripple**	**Plane-bed**	**Step-pool**	**Cascade**
General features	Dune and ripple forms as viewed through the flow	Exposed bars, highly turbulent flow through riffles, and more tranquil flow through pools	Single boulder protruding through otherwise uniform flow	Sequential highly turbulent flow over steps and more tranquil flow through intervening pools	Nearly continuous, highly turbulent flow around large grain
View from above					
Longi-tudinal view					

3.4.3 Whiting and Bradley classification

Organization of the classification
The channel classification (Whiting & Bradley 1993) provides 7 major stream types, based on the degree of hillslope interaction with the channel. Based on the characterization of the transport of material in the channel 6 sub-categories are defined for each stream type, providing 42 stream sub-types. 6 qualitative variables are used to build the classification. Physical laws and morphologic relationships are used to define domains in which various processes dominate and therefore to distinct channel types.

The following table describes delineation criteria/description of parameters of interest.

Table 3-6. Parameter overview in the Whiting and Bradley classification of river types.

Parameter	*Formulae*	*Description*
Hillslope gradient	SLOPE (M/M)	Determines in large part the possibility of a shallow transitional slip.
Channel gradient	SLOPE (M/M)	Related to the gravitational force acting to carry water and sediment.
Valley width	WIDTH (M)	Defined as the distance between opposing valley side slopes at the base of these slopes. Controls the hydrologic regime and controls whether debris flows coming off adjacent slopes enter streams.
Channel width	WIDTH (M)	It is the other indicator of the degree to which the hillslope contributes material directly to the channel.
Channel depth	DEPTH (M)	Channel depth multiplied by channel slope and the unit weight of water determine the force applied to the channel bed that entrains sediment, and erosion and deposition caused by variation in shear stress creates channel topography.
Sediment size	SIZE (M)	The median size of sediment in the channel.

Figure 3-23 and Figure 3-24 provide an overview of all classes within the Whiting and Bradley classification, indicating the diversity of the river types. The main focus is on the channel description and a focus on channel bed composition and not on the transect shape, when compared to the Rosgen classification.

Stream class	Channel/hillslope susceptibility to landslides	Valley aspect	Channel description
DE0	eroding in-channel debris flows	typically narrow	debris chute often on bedrock
DE1		"	scoured bouldery debris chute, w/LOD?
DE2	"	"	scoured bouldery debris chute, w/LOD?
DE3	"	"	****
DE4	"	"	****
DE5	"	"	****
DD0	depositing in-channel debris flows	typically narrow	debris chute
DD1		"	bouldery debris chute w/LOD
DD2	"	"	aggrading gravelly debris chute w/LOD
DD3	"	"	****
DD4	"	"	****
DD5	"	"	****
AD0	adjacent hillslopes prone to failure by debris flows	very narrow; VW–CW < 25 m	ephemeral debris chute
AD1		"	irregular bouldery cascades
AD2	"	"	gravelly shallow channel
AD3	"	"	unarmoured, shallow gravel channel, $T > 3T_{cr}$
AD4	"	"	infilling sandy shallow channel
AD5	"	"	silty multi-strand? shallow channel
MD0	"	narrow; 25 m < VW–CW < 50 m	ephemeral debris chute
MD1	"	"	bouldery cascades
MD2	"	"	locally armoured gravel
MD3	"	"	unarmoured, shallow gravel channel, $T > 3T_{cr}$
MD4	"	"	sandy shallow channel
MD5	"	"	silty shallow channel

Figure 3-23. Classes in the Whiting and Bradley classification (1/2).

Stream class	Channel/hillslope susceptibility to landslides	Valley aspect	Channel description
OD0	"	moderate; 50 m < VW–CW < 250 m	ephemeral channelway
OD1	"	"	bouldery stepped bed w/fines
OD2	"	"	armoured gravel
OD3	"	"	unarmoured gravel, $T > 3T_{cr}$
OD4	"	"	sandy shallow channel
OD5	"	"	silty channel with flat bottom
SD0	"	wide; VW–CW > 250 m	ephemeral, poorly defined channelway
SD1	"	"	bouldery stepped bed
SD2	"	"	armoured gravel
SD3	"	"	unarmoured gravel, $T > 3T_{cr}$
SD4	"	"	sandy well-formed channel
SD5	"	"	silty channel with pools, bars
NF0	hillslopes stable	variable, often narrow	ephemeral, relict?, coarse? channelway
NF1	"	variable, often narrow	bouldery bars and pools
NF2	"	variable	armoured gravel channel with bars
NF3	"	variable	unarmoured gravel, $T > 3T_{cr}$
NF4	"	commonly wide	sandy stable channel with deep pools
NF5	"	commonly wide	silty channel with deep pools, bars

CW, channel width; VW, valley width; ****, rare, unlikely, T, boundary shear stress; T_{cr}, T at initial motion

Figure 3-24. Classes in the Whiting and Bradley classification (2/2).

3.4.4 Relevance for management of Norwegian river systems

The three classification systems as mentioned above all have their specific methods for separating river types into classes. The focus is mainly on natural rivers, but half of the parameters will be influenced by river regulation:

1. Width/depth ratio (Rosgen)
2. Channel material (Rosgen)
3. Relative roughness (Montgomery and Buffington)
4. Shear stress (Montgomery and Buffington)
5. Grain size distribution (Montgomery and Buffington)
6. Transport capacity and sediment supply (Montgomery and Buffington)
7. Channel depth (Whiting and Bradley)
8. Sediment size (Whiting and Bradley)

The channel width and depth of a river (*point 1 and 7*) will be influenced by the degree of regulation. Channel material composition and dynamics (*point 2, 3, 4, 5, 6 and 8*) will depend on the redistribution of sediments after regulation, and also influence the shear stress dynamics. This indicates that the classification systems need to be considered in the light of the relevant river regulation.

The comparison of rivers will aid to the *transferability of environmental responses to flow* between rivers. Often the similar rivers, in terms of large scale classification, will have a similar output in regards to physical consequences of river regulation. This might be within the following fields (excerpts):

- Change in sediment supply and transport capacity
- Change in water temperature regimes and indirectly changes in ice dynamics
- Response to rapid drawdown of water level and corresponding drying of river bed areas
- Erosion of river banks

Two of the three classification systems mentioned above, Rosgen and Montgomery, includes a stronger focus on the transect shape dynamics (point 1 and 7 in the list above). Transect shape is vital in the process of comparing two rivers, with an emphasis on how a transect responds in terms of changes in flow regime or even more short term changes. There is currently work being done at NTNU to compare a selection of transects in several regulated rivers in order to investigate the similarities and which transect parameters which are most important in describing the influence and dynamics of river regulation. This work will also focus on the internal differences in rivers (bottleneck approach).

The Rosgen classification system would at the moment be the primary choice as a basis for the Norwegian system based on the following arguments:

- Focus on transects (i.e. cross-sectional) which is supposed to be the most appropriate level (scale) and might allow transferability of river sections within and between rivers
- Many mentioned river types are valid for Norwegian watersheds
- Easy approach to classification using a three level step method
- Also including multiple channel classes

Parameterization in regards to defining ecological status in rivers, as mentioned in chapter 3.1, should be based on a possible adjustment of the Rosgen classification method to Norwegian river systems. The emphasis should be put on river reaches more than whole river systems, and specifically on bottleneck river sections. Hydraulic parameters like wetted perimeter (width and depth), bankfull width and environmental flow width/depth in relation to the transect geometry would be good indicators of a river's potential sensitivity to anthropogenic influences (hydropower production, water outtake, etc.).

4 Rapid changes in flow and ecosystem response (hydropeaking)

In contrast to the chapters 1-3 and 5 discussing assessment of environmental flows in bypass sections, this section deals with the sections downstream the outlet of the hydropower plant, which are those sections of the river potentially affected by hydropeaking. Extensive research is carried out on hydropeaking in Norway (e.g. in CEDREN – www.cedren.no – accessed September 24th, 2012), as increasing use of hydropower plants to produce peak power is expected in the future, due to an expected higher share of unregulated power production. The activities in CEDREN are carried out in close co-operation with partners from Austria, considered being in the front of the research on ecological impacts from hydropeaking and the implementation of the EU WFD. It is hence considered relevant to draw on the experiences in particular from Austria.

Many river stretches in Austria are considered as impacted by hydropeaking and residual flow, due to water storage affecting the hydrological flow regime (NGP 2010). This chapter provides a comparative analysis and general overview of hydropeaking impacts for Austria and Norway and is structured in the following sub-chapters:

4.1 The relation between hydrological indices and ecological response
4.2 Overview of ecological status in hydropeaked rivers in Austria
4.3 How does Norway fit into this picture? A comparative analysis and of hydropeaking characteristics for Austria and Norway
4.4 Hydropeaking, ecological consequences and mitigating measures

4.1 Hydropeaking and the ecological response

The critical feature of hydropeaking is the impact on the natural flow regime. The hydrological characteristics of the flow regime determine the habitat quality and life-supporting capability of the river ecosystem. Controls on hydropeaking rates go some way towards reducing the velocity of the peak wave. The natural flow regime is the primary boundary condition for regulating the hydropower plant operating cycles.

An extensive review was made from 30 research articles, out of 180 preselected papers, dealing with case studies involving fish species, macro-invertebrates, hydro-morphology and hydropeaking. Constrained ramping operations resulted in changes to the flow regime that was generally ecologically protective. Invertebrate abundance and diversity, fish biomass, fish condition and food web length were all equal to, or greater than, the unaltered system. Some metrics that differed between rivers, specifically isotope signatures, were attributed to the presence of the reservoir and not to flow alterations. Whether protection is afforded simply by minimum flow restrictions or the combination of minimum flow and ramping rate restrictions still remains unclear.

Unrestricted ramping operations had significant impact on river morphology and benthic macro-invertebrate composition and diversity. Small fish and fry taking refuge along ramped shoreline might be impacted by lack of profitable forage or feeding areas and forced into deeper water (predation and metabolic demand) – habitat switch, with fewer and smaller forage and juvenile fish. Most studies looked at the flow discharge effects from the falling limb of the peak hydrograph. The falling limb of the peak hydrograph (rapid flow decreases caused by hydropeaking) caused drift or stranding of organisms (desiccation). With the rising limb of the peak hydrograph (peak velocity as a critical factor), there was a significant relationship between species richness and peak velocity.

Table 4-1. Potential impacts of hydropeaking.

Loss of species and biomass	Temperature change	*Diurnal temperature fluctuations*
	Flushing Drift	*(Young) fish* *Invertebrates* *nutrients (Algae, CPOM, FPOM)*
	Increased turbidity	*Disabled breathing,* *stress, migration*
	Habitat change	*Flushing of fine sediments,* *erosion of bank- and bed sediments,* *change of bed morphology*
	Desiccation of bed sediments	*Death of benthos organisms and fish,* *falling dry of spawning habitats*
	Residual flow	*Habitat loss, habitat alteration*
	Behavioural change	*Increase of drift, catastrophic drift,* *disturbed feeding,* *habitat change*

Peak velocity was the significant environmental variable (flushing) leading to macro-invertebrate depletion. Unregulated river had highest density near the shore. Both river channelization and hydropeaking had negative effects on both riparian arthropods and fish. Channelization significantly increased inundation frequency and hydropeaking increased substrate embeddedness. Analysis strongly supported natural flow reconstruction. Sites that were affected by both hydrological and morphological modifications together were almost devoid of arthropods. Restoration of riverbank morphology and mitigation of hydropeaking would benefit riparian arthropods. Unregulated river had the highest species density near the shore, regulated rivers had a low density closer to the shoreline, while deeper offshore areas had greater density and diversity. Unrestricted ramping significantly decreased invertebrate density.

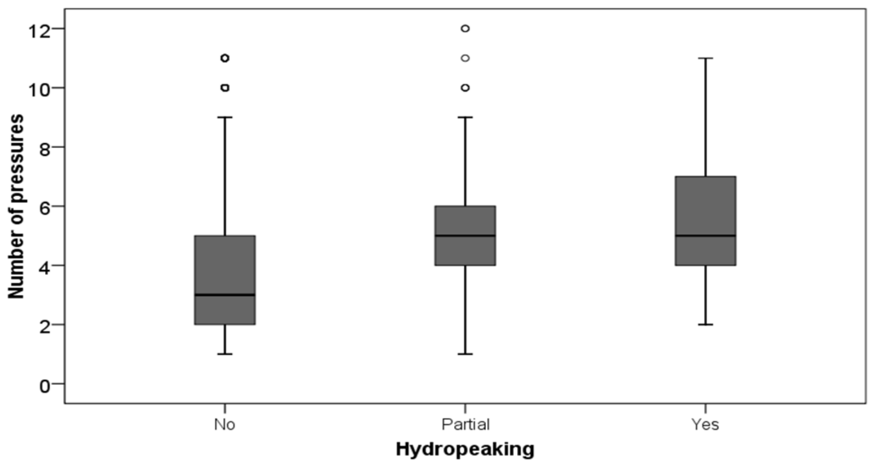


Figure 4-1. Hydropeaking and the number other pressure types in Europe (data source: EFI+, http://efi-plus.boku.ac.at/) (Accessed September 24th, 2012).

Figure 4-1 explains multiple pressure impacts on European rivers (EFI+ Manual and data source: http://efi-plus.boku.ac.at/, accessed September 24th, 2012). Pressure types with their effect on aquatic organism were assessed using the following categories: Hydrology (n pressure types = 4), Morphology (n=3), Water quality (n=3) and river connectivity (n=2). Particularly hydropeaked river reaches (n=632) are affected by a mean of 5.5 impacts (Melcher et al. 2012). In general a huge number of investigated sites all across Europe (n = 8444) are influenced by many pressures, on average 3.5 (see also Schinegger et al. 2011). In Austria research on multiple pressures on river systems, including channelization, land use as well as flow regulation involved the use of multi-metric fish assessment systems (Schmutz et al. 2008) and recently finalized case studies focuses additionally on hydropeaking (e.g. Unfer et al. 2011).In these Austrian impacted sections the ecologically-based flow regime is now controlled by the Austrian Qualitätszielverordnung (QZV 2010) as described above. At present the relations between the hydrological indices (e.g. Q95, winter low flow, etc.) and corresponding ecological responses are explained by the QZV.

4.2 Overview of ecological status in hydropeaked rivers in Austria

Austria consists mainly of four eco-regions, the Alps, the Central Highlands, the Hungarian Lowlands and the Dinaric Western Balkans. The alpine eco-region dominates the main part. Mountains with altitudes up to 3700 m provide the characteristic topography of its rivers systems and associated aquatic organisms.

Approximately 60% of Austria's electricity production is based on hydropower using about 70% of the energy potential of Austrian rivers topography, where one third of that hydropower production relies on hydropeaking. Consequently hydropeaking has become one of the most significant impacts on river ecosystems, especially for large to medium-sized Alpine rivers (Figure 4-2), including Alpenrhein, Bregenzerach, Ziller, Inn, Salzach, Drau, Möll and Enns (from west to east).

The national water monitoring programme (NGP Nationaler Gewässermanegment Plan 2010, BMLFUW Article 5, WFD) describes a total river-length of 31000 km that is divided into approximately 7000 water bodies.

Water bodies affected by hydropeaking were identified by the ratio between low flow and peak flow. Ratios of more than 1:3 were considered to affect biota in small and medium-sized rivers. Hydropeaking in larger rivers was always taken into account.

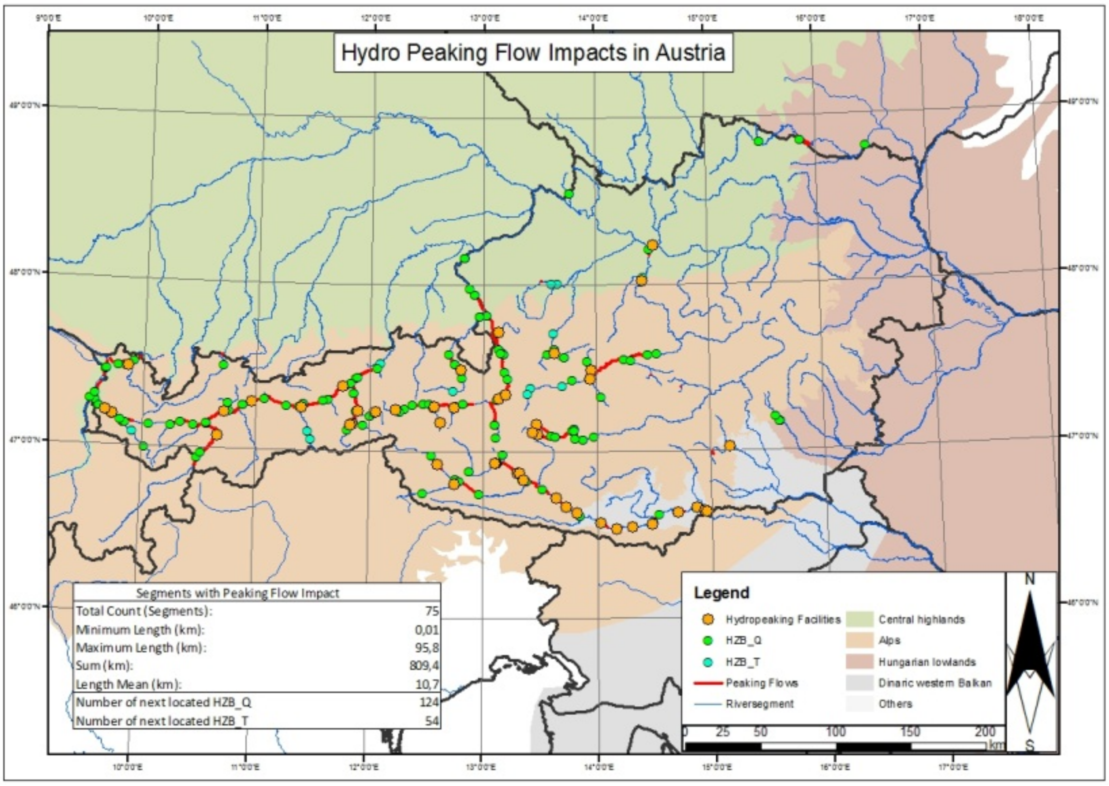


Figure 4-2. Hydropeaking in Austrian rivers partitioned into the various eco-regions (Alps are in pink colour).

In total, a river length of about 800 km is impacted by hydropeaking that represents about 10 % of smaller rivers (catchment size >100 km^2) and about 30% of larger Austrian rivers (catchment size >1 000 km^2). The entire length of the water body (mean length 8.4 km) is affected in 71 % of the by water bodies impacted by hydropeaking (N=114). This demonstrates that hydropeaking is not only a local pressure, but can affect long river stretches. The ecological status in river sections with hydropeaking varies from good to bad, with most sections having a poor status (NGP, 2010). Whereas hydropeaking mainly occurs in the grayling and trout zone, which are characterized by few species occurrence, but "dominated" by endangered European grayling (*Thymallus thymallus*) and brown trout (*Salmo trutta*) (Figure 4-3).

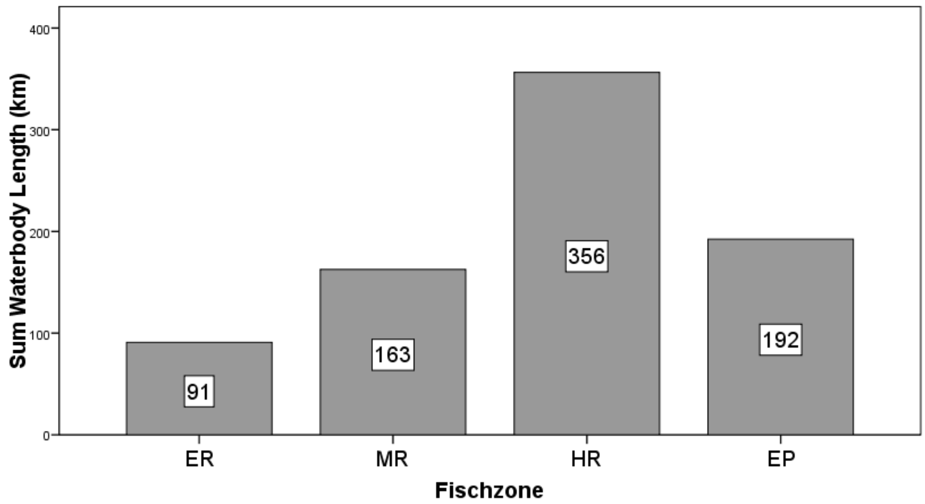


Figure 4-3. Frequency (n = 802 km) of fish-zones (i.e. Trout zone - Epirithral Metarhithral; Grayling zone - Hyporhithral; Barbel zone - Epipotamal) affected by hydropeaking (flow ratio >1:3) in Austria.

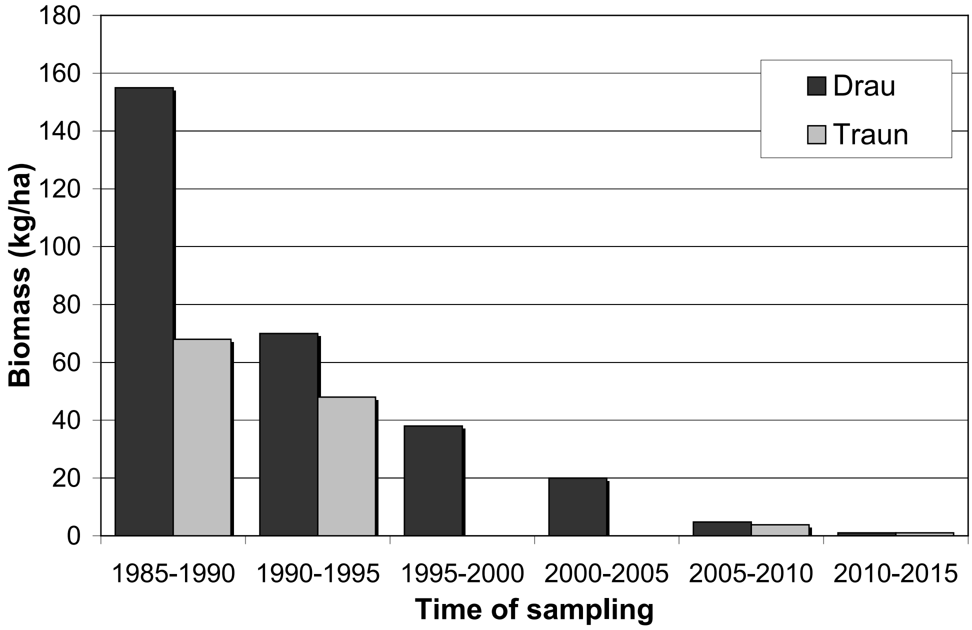


Figure 4-4. The key species grayling (*Thymmallus thymallus*) is disappearing.

Previous studies in the large Traun and Drau rivers showed a decrease of the key species grayling over the last 25 years (Fig. 4-4). Especially the Drau biomass affected by hydropeaking was reduced dramatically from 160 kg/ha to below 10 kg/ha. In 1989 the hydropower plant "Strassen Amlach" in the upper reach close to the Italian border started its operation. Both hydropeaking and channelization were the main reasons for the loss of biomass and abundance (Unfer et al. 2010).

The scientific basis for determining the ecological status of water bodies is based on a multi-metric approach, the Fish Index Austria (FIA), developed and published in 2006 by Haunschmid et al. (2006) to fulfil the requirements for the EU Water Framework Directive (WFD). During the WFD inter-calibration process, the FIA was validated and compared to other European assessment methods (Jepsen & Pont 2007).

The FIA employs nine metrics as percentages: (1) dominant species, (2) subdominant species and (3) rare species; number of (4) reproduction guilds and (5) habitat guilds; (6) index of fish region; (7) biomass and population age structure of (8) dominant species and (9) sub-dominant species. Reference conditions are defined for seven different fish assemblage types along the longitudinal zonation. Deviation from reference conditions is used to assess the ecological status by means of combining metrics into a single index ranging from 1 (high status) to 5 (bad status). A minimum of one site was monitored within each water body used for the analyses.

The ecological status of fish in 22 alpine rivers and 133 hydropeak-impacted sites were assessed using the FIA method. The standardized electric fish sampling, in accordance to the WFD, was done by wading or from a boat (De Lury 1947; Seber & Le Cren, 1967; Schmutz et al., 2001).

In general the fish-based assessment indicated a poor ecological status for water bodies affected by hydropeaking (mean index 4.16), which is a significant lower status than in water bodies not affected by hydropeaking (mean index 3.16). Also the fish biomass was significantly lower in hydropeaked stretches (mean 38.9 kg/ha) versus stretches with no hydropeaking (mean 95.4 kg/ha). Finally 47 hydropeaking samplings (i.e. 54 %) showed a bad status and more than 80% were either in poor or bad status – far below the required goal of good ecological status (Figure 4-5).

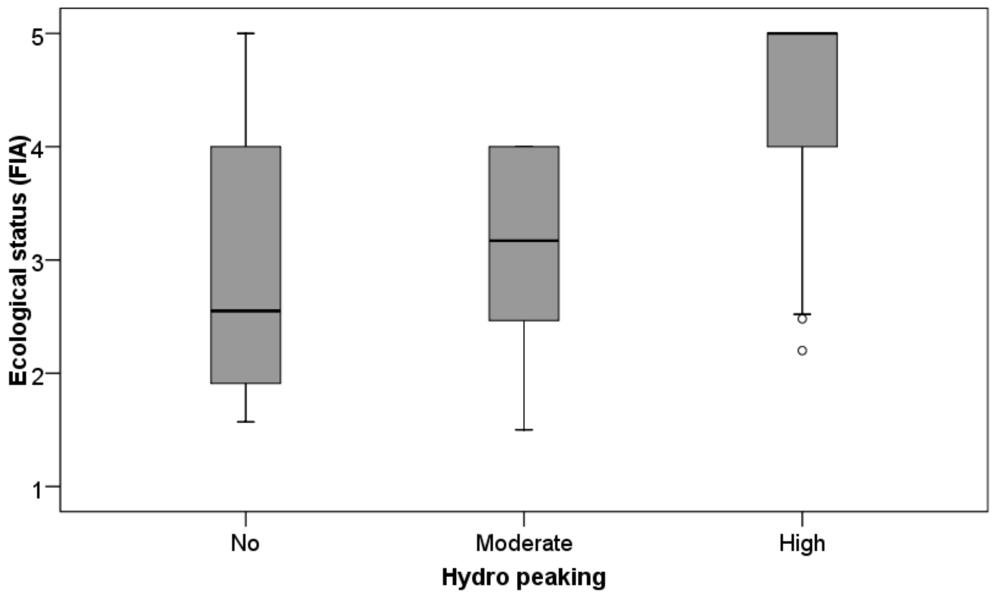


Figure 4-5. Fish Index Austria (FIA) classes and ecological status (1… excellent, 2 … good, 3 … moderate, 4 … poor, 5 … bad) of sampling sites with no (n=30), moderate (n=16) and high (n=87) hydropeaking intensity.

All sampled stretches showed low abundance and biomass, as well as a poor population structure for most species. Consequently there was a significant lower ecological status compared to water bodies unaffected by hydropeaking. In most cases a comparison between reference and hydropeaking sites showed a difference of at least one class of the FIA. In some stretches with hydropeaking, populations of fish species are largely dependent on stocking. Furthermore we were able to demonstrate that rivers with intense hydropeaks characterised by a high ramping rate, peak frequency and fast decreasing duration (e.g. Ziller in Tyrol) showed the greatest negative impacts on fish assemblages and their life stages (Tab. 4-2).

Table 4-2. Number of fish species and ecological status of selected Austrian rivers.

River	Fishzone		Species		FIA
		Total N	Dominating pot.	Dominating act.	
Ziller	MR	4	1	1	5,0
Ziller	HR	5	4	1	5,0
Inn	HR	4	3	1	4,0
Salzach	HR	5	4	2	4,6
Drau	EP	9	5	4	4,7
Drau	EP	11	5	4	3,3
Enns	EP	10	6	4	4,5
Enns	EP	6	3	3	2,4
Großache	HR	4	2	2	3,1
Zemmbach	MR	3	1	1	2,3

4.3 How does Norway fit into this picture?

A comparative analysis and of hydropeaking hydrological characteristics for Austria and Norway

We compared eight Norwegian and eight Austrian rivers. To analyze hydrological parameters, Greimel et al. developed 2012 a method for automated analysis of time series using basic data from 2008 with a time resolution of 60 minutes for Norwegian and 15 minutes for Austrian rivers. For each single peak the parameters maximum and minimum flow, mean increase IC/ decrease DC ($m^3/s/min$), Maximum IC/DC ($m^3/s/min$) and total IC/DC dQ_IC/DC ($m^3/s/event$) are determined by the tool (Fig. 4-6).

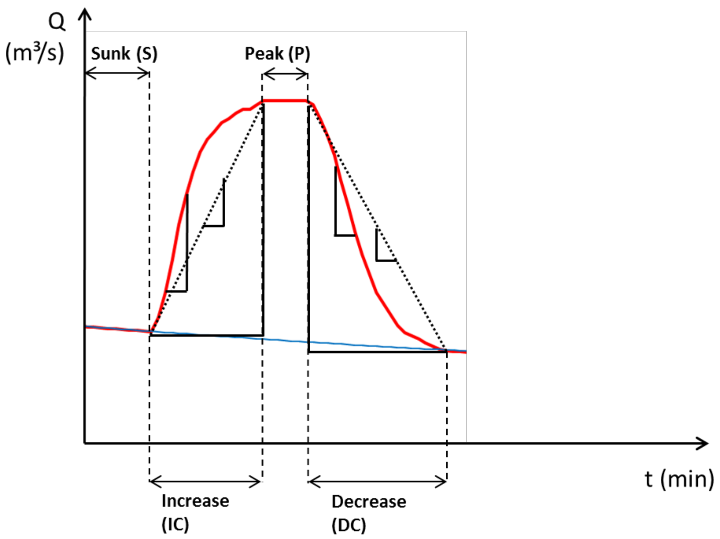


Figure 4-6. Criteria to determine hydropeaking characteristics (Greimel et al. 2012).

The different peaking parameters can be statistically described and illustrated for different seasons. Furthermore in a second step the program is generating the base flow without hydropeaking at the gauging station. Thereby it`s possible to compare the hydropeaks with natural floods caused by long term rainfall events or snow melting. The maximum flow range of hydropeaks in Austria is about 110 m^3/s, released in less than 15 minutes. Flow ratios between minimum and maximum flow exceeding 1:25 are observed. As shown above the overall ecological status is mainly bad in Austrian peaked rivers. The results are considered relevant also for Norwegian rivers, given similar hydropeaking/hydrological characteristics, with respect to fish and other organisms (invertebrates).

As shown in Figure 4-7 below, the Mean Q (MQ) of Norwegian rivers (40 m³/s) is generally smaller in comparison to the Austrian hydropeaked rivers (72 m³/s). Austrian rivers without hydropeaking (e.g. Kitzbühler Ache and Ötztaler Ache) are quite similar to Norwegians. Note that the River Lech has an error in the data (Fail) with no hydropeaking influence and will not be discussed in detail.

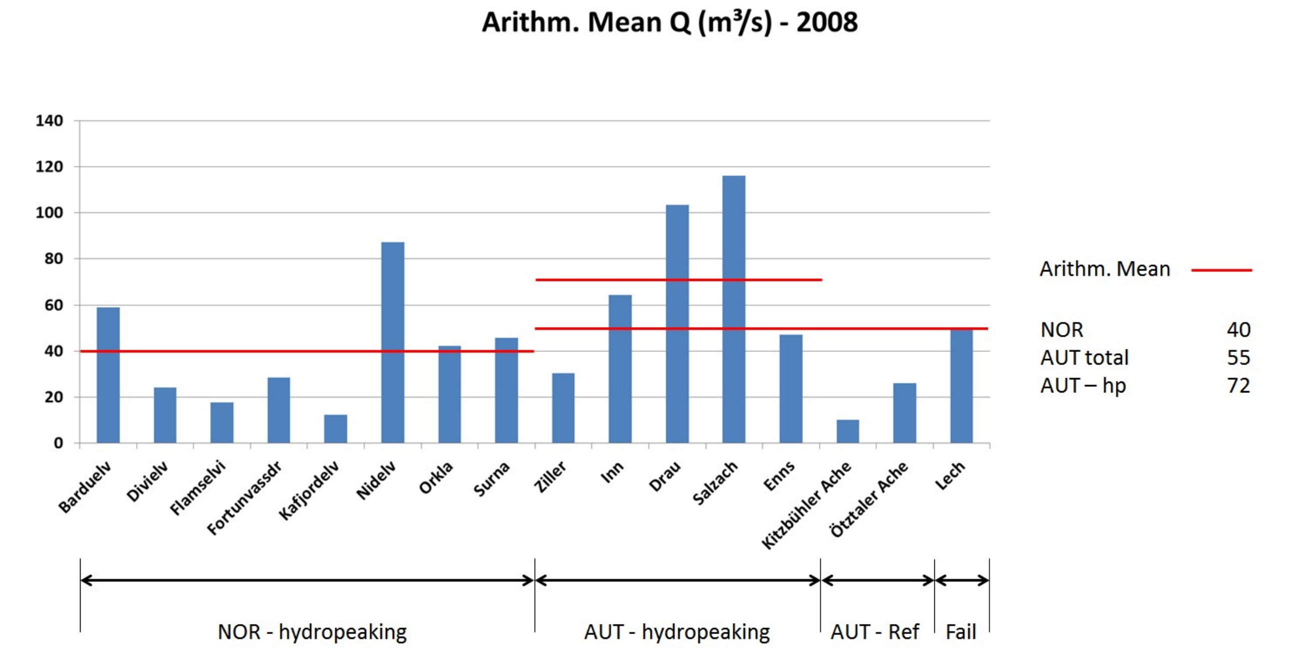


Figure 4-7. Mean MQ characteristics for Norwegian and Austrian rivers from 2008.

As the time resolution to measure the flow was for Austrian rivers more precise (finer time resolution) the mean number of events in 2008 for Norwegian rivers (n=1120) was the same as the Austrian references (n=1095); those for Austrian hydropeaking was nearly three times higher (Figure 4-7). It has to be stated here, that some of the reported Norwegian rivers are hydropeaked, but in a moderate way; maybe because of mitigation measures to improve the abundance of salmon.

To compare the hydropeaking characteristics for both countries, we made further analyses of all 500 waves per gauging station and year. It was also possible to distinguish between waves caused by flood (HQ) or hydropeaking for different time scales. This was done for Austria automatically by using direct references, which are missing for Norway. Therefore Norwegian waves were selected graphically for the 99% percentile of the fastest waves – analyzing 500 waves these are the five highest.

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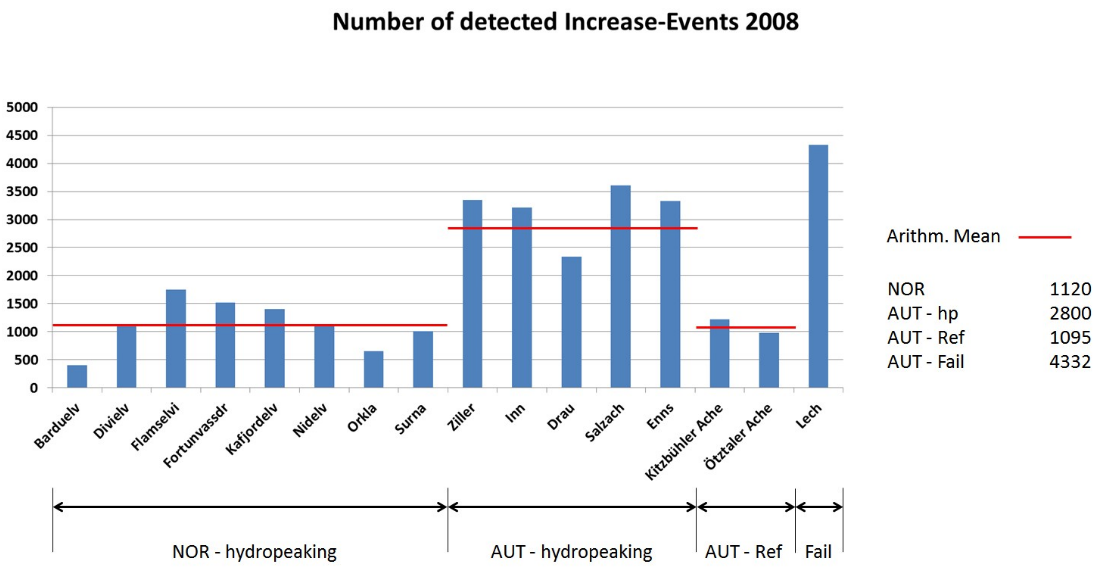


Figure 4-8. Total number of detected IC events for Norwegian and Austrian rivers from 2008.

In contrast to Figure 4-8 above, Figure 4-9 below gives a comparative representation of river hydrology characteristics in Norway and Austria. The sum of discharge fluctuations (increase events) in Austrian hydropeaked rivers is considerably higher than Norwegian rivers. The only exception in Norway is the Nidelva river, which reaches values similar to Austria. Some of the Norwegian river flow characteristics are comparable to Austrian references.

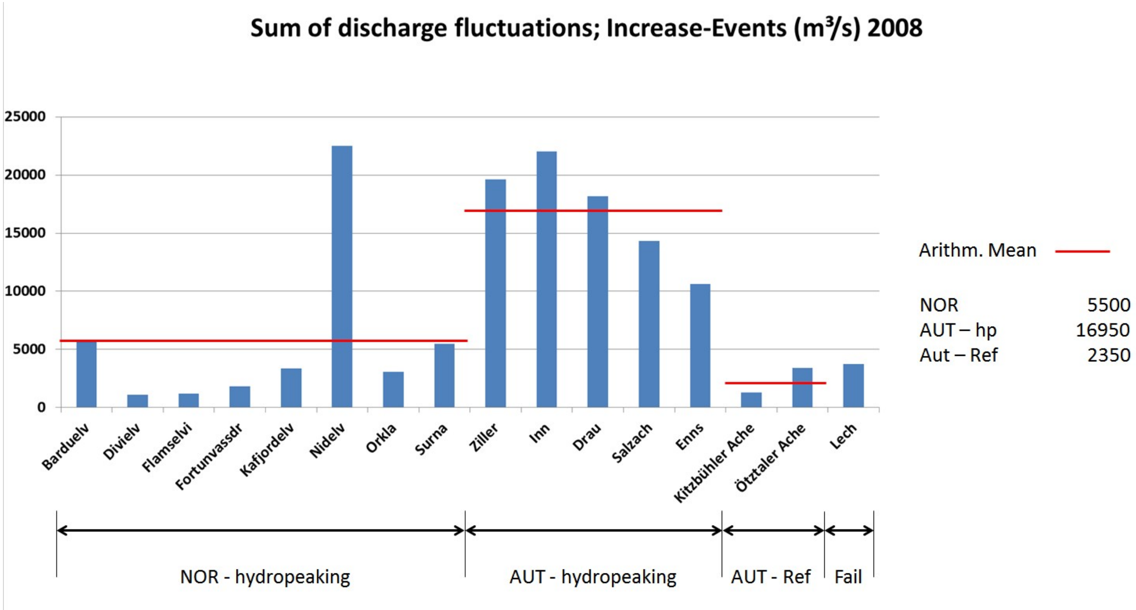


Figure 4-9. Sum of 500 most relevant detected IC events (discharge fluctuations) for Norwegian and Austrian rivers from 2008.

All fast events in Austrian reference rivers occur in summer, with the main peaks (fastest events) from Mai to July (Fig. 4-9). They are mainly naturally induced by rain glacier and snow melt. In contrast the high discharge fluctuations in Austrian hydropeaked rivers are always a combination of natural and artificial (hydropeak) flood waves (Figure 4-11). In Norway Barduelva, Kafjordelva und Nidelva river exclusively show hydropeaking, whereas the others are a mixture like in Austria (Figure 4-12).

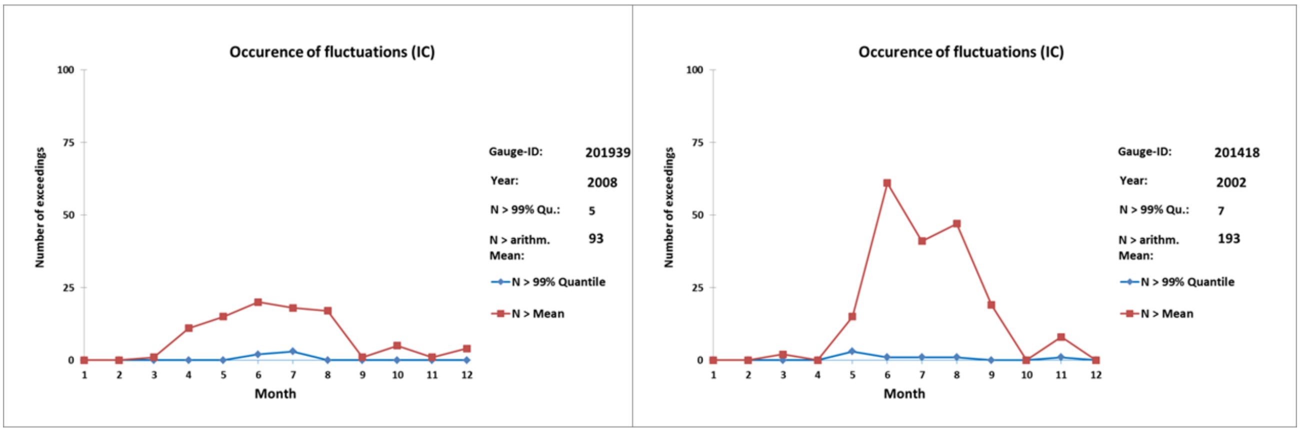


Figure 4-10. Number of IC events (discharge fluctuations) for two Austrian reference rivers from January to December 2008.

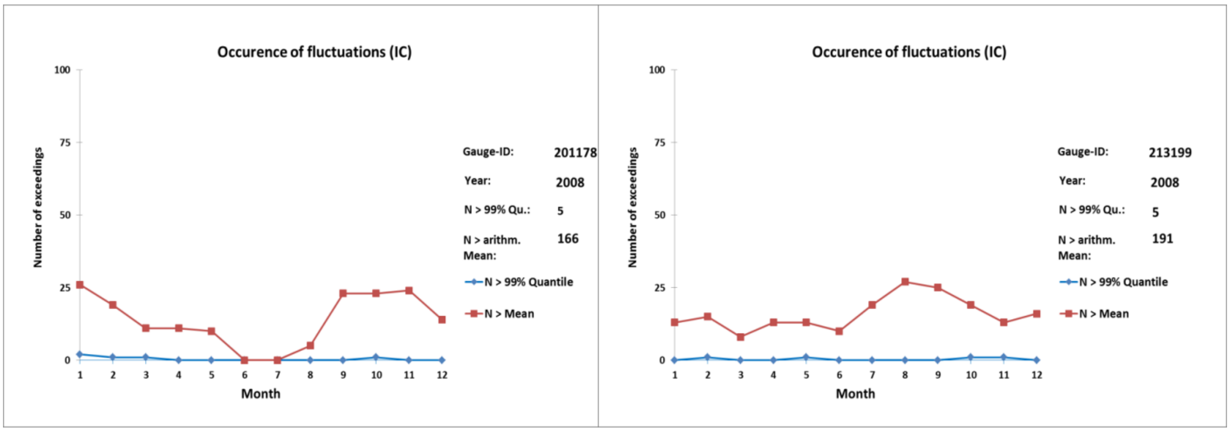


Figure 4-11. Number of IC events (discharge fluctuations) for two Austrian hydropeaking rivers from January to December 2008.

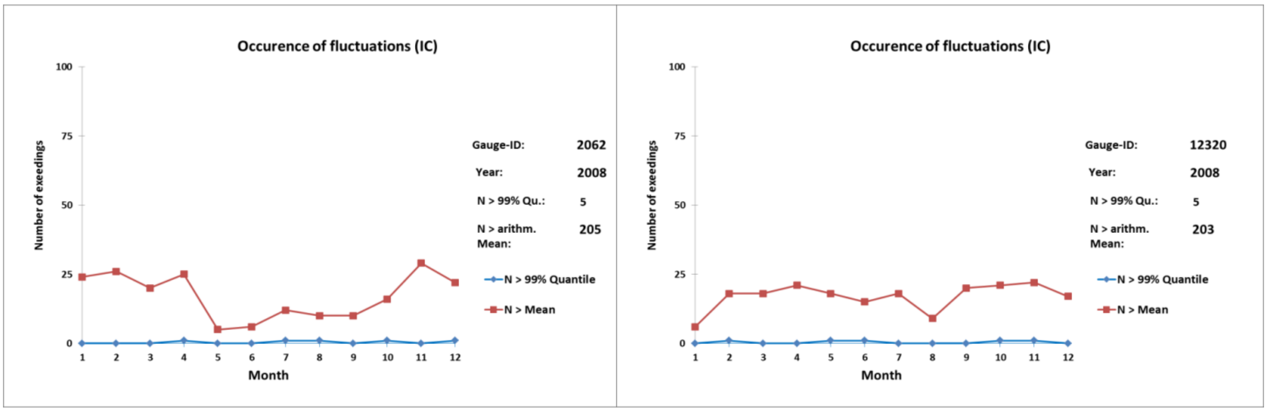


Figure 4-12. Number of IC events (discharge fluctuations) for two Norwegian hydropeaking rivers from January to December 2008.

The Nidelva river and all Austrian hydropeaked rivers show similar values regarding the highest discharge fluctuation values at approximately 100 m³/s. In contrast, the other Norwegian rivers and Austrian references are between 60 and 40 m³/s (Fig. 4-12). In addition also the parameters sum of dQ_IC and its standard deviation determine the Nidelva and Barduelva as rivers with the highest hydro peaking impact, which is similar to the Austrian situation.

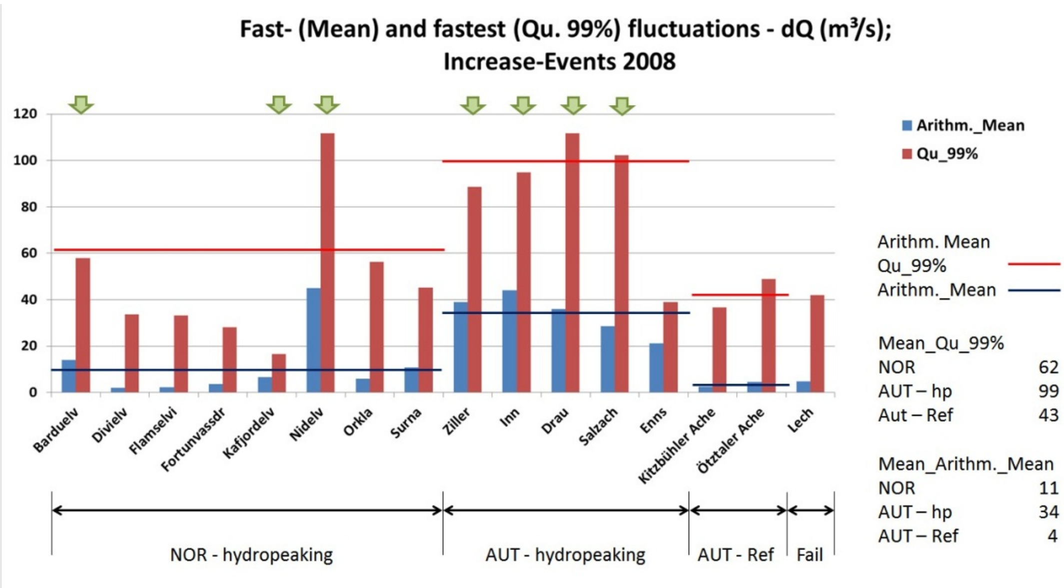


Figure 4-13. Number of fast discharge fluctuations IC events (dQ) for Norwegian and Austrian rivers from 2008. Green arrows are stations with hydropeaking only.

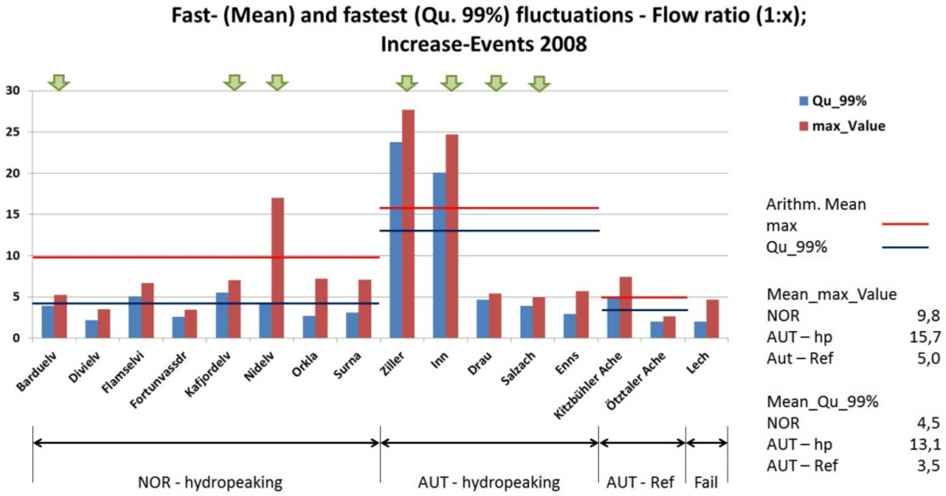


Figure 4-14. Flow ratio fluctuations (IC events, 1:x) for Norwegian and Austrian rivers from 2008. Green arrows are stations with hydropeaking only.

Finally we also compared the flow ratio (Figure 4-14). In comparison to the references (mean Qu 99 % flow ratio 1:3.5), extremely high hydro peaking was analysed for the rivers Ziller (1:24) and Inn (1:20). The average for Norwegian rivers is constantly between a flow ratio of 1:4 and 1:5. Both values, the mean and the maximum, are always nearly the same with one exception, the Nidelva. The absolute maximum value (1:17, red bar) could be a measurement error. A possible reason is the metric itself, which is commonly used but may not be ideal to describe hydropeaking - this has to be further investigated. Nevertheless the flow ratio metric shows nearly no significant difference between artificial floods in Norway and natural floods in Austria. This metric is able to characterise very strong (high) peaking impacts, but not the same ability to determine low flow ratios.

What we have learned from the available data (flow fluctuations, rates of increase and decrease over time), is that the impact of hydro peaking in Norway is much lower than Austria. Nevertheless hydropeaking activity was clearly detected for Barduelva, Kafjordelva, Surna und mainly Nidelva. In this report no analyses for decrease are shown, because the results are quite the same. In addition it was possible to distinguish between natural flood and artificial hydropeaking in Austria by using reference rivers (gauging stations); for more detailed analyses it is necessary to include also Norwegian references. A determination of hydropeaking characteristics is not possible without clearly distinguishing natural from artificial peaking. A comparison of different time resolutions also biases the results, whereas more detailed data do not miss short acting flow actions.

The aim to combine and analyse hydrological data with biological data directly will be realistic after developing a method to interpolate the flow for a specific monitoring site along river reaches (Figure 4-14). Appling such a method and integrating the morphological status information, it will be possible to better understand the intensity and effects of peaking impacts. Mitigation measures should be conveyed in a holistic approach.

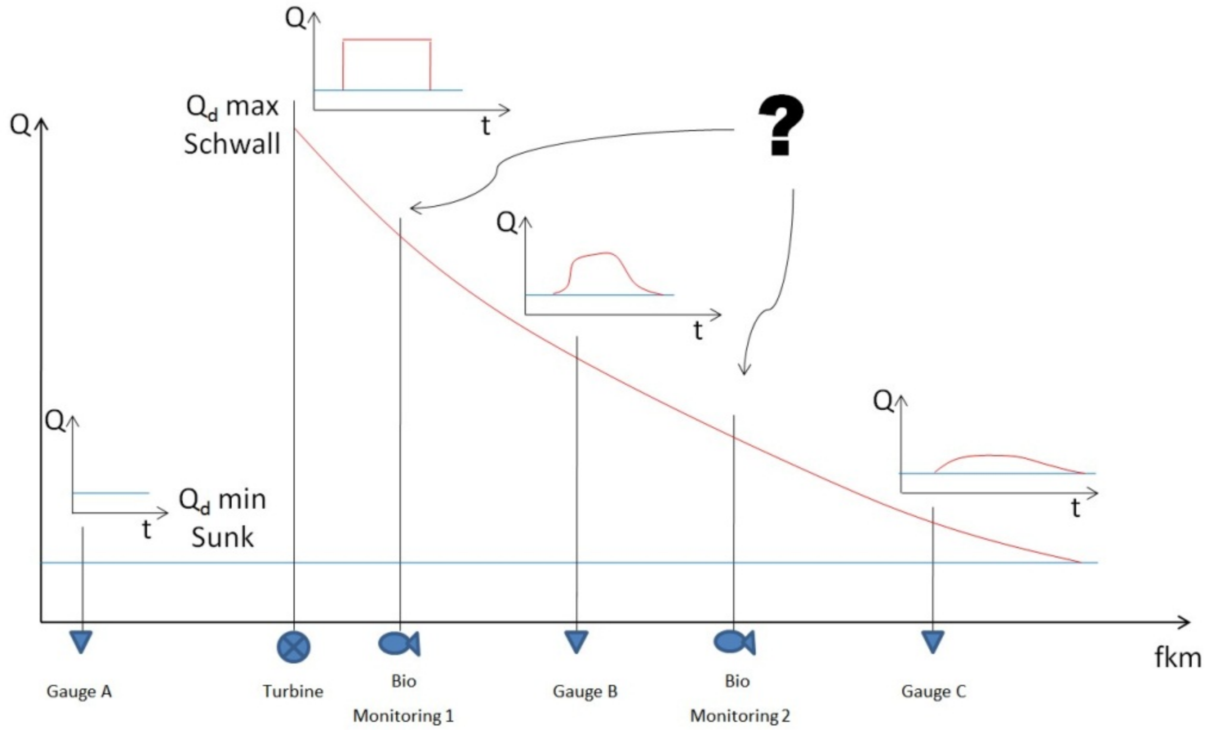


Figure 4-15. Concept to determine peaking intensity at a specific monitoring site.

4.4 Hydropeaking and mitigating measures of ecological impacts

Nearly all river reaches affected by hydro peaking are in poor or bad ecological status. In Austria all reaches with a flow ratio higher than 1:3 are considered to be affected by peaking. Detailed case studies have also shown that a natural flow larger than 1:5 could lead to a bad ecological situation, if happens in a sensitive period (e.g. spawning, development of larvae). The more often such a critical event happens the greater the environmental impact. It has to be clearly stated that the flow ratio as the parameter to characterize hydropeaking impacts must be described accurately, because it is very much dependent on the river dimensions. The flow ratio affects smaller rivers much more than larger ones. Nevertheless actions have to be taken to achieve the objective of a good ecological status according to the WFD. The following measures to mitigate hydro peaking effects on fish have been considered so far:

- altered operation of hydropower plants, (e.g. Dampening the peak -magnitude, -increase, -decrease, -frequency.)
- increasing amount of low flow (e.g. Alpine Rhine),
- morphological improvement of river channels,
- downstream diversion of peak flow to lakes or impoundments (new power plant needed), and
- building of compensation reservoirs downstream of power stations (new power plant needed).

Dampening reservoirs will reduce the flow ratio and the ramping rates, but also other measures related to fish behaviour (spawning) and ecology (mainly larvae and juveniles), would help to improve the ecological. For example the timing of the peaking – specific sensitive periods of day and year were suggested in a case study at the river Drau by Unfer et al in 2011.

Key species in this study are the brown trout and grayling as both are indicator species and form a large part of the fish ecosystem in their affiliated fish regions. Also these fish regions in the upper reaches of the rivers are most affected by hydropeaking respectively (Fig. X). Furthermore the two species differ in their habitat use, therefore provide a wider perspective on the effects of hydropeaking on various habitats. As most negative impacts are expected on eggs, larvae and juveniles the following hypothesis were developed and investigated by UNFER et al., 2011:

Hypothesis 1: Young larvae of the grayling strand during low flow and are drifted away during peak flow, decimating total number early in the year.

Yes. During all samplings in spring and summer (17 samplings) stranded larvae could be found (up to 500 ind. per 100m shoreline). Quantification however remains difficult. During the samplings in autumn (3 samplings) no fish could be found. The risk of stranding was significantly higher during nighttime.

Hypothesis 2: During the time with increased base flow (June - September) the development of juvenile graylings in different areas affected by hydropeaking is similar regarding growth and condition.

Yes. Direct comparison of fish lengths showed that the largest juveniles can be found on gravel banks, while fish in bays and structures tend to be smaller. The difference decreases during the summer months. However the abundance of juveniles is much higher in bays and structures along the shore during June, indicating the importance of these structures as nursery habitat.

Hypothesis 3: Structures increase survivability. Habitats differ significantly regarding their quality for juvenile grayling in river stretches with hydropeaking.

Yes. Habitat use between emerging from the gravel bed and autumn differs significantly: Until June the fish stay in very shallow areas along the shoreline with low flow velocities. Later in June and July bay areas are densely populated while in late July the juveniles switch to gravel banks, going into deeper areas in fall. Sensitive periods with high losses are the switch from the bays to the gravel banks and in September with increasing hydropeaking.

Hypothesis 4: Between late autumn and spring energy deficiencies lead to increased mortality during winter.

No. Between late autumn and spring flow variations impact the energetic status of the juveniles. Mortality increases during winter with decreasing energy level, according to the total fat content of the fish.

Hypothesis 5: Reduced availability of food sources and temperature changes in stretches with hydropeaking are responsible for low survival rates of juvenile graylings (during winter).

Maybe yes – in autumn. Samplings showed no significant differences regarding biomass and drift of benthic organisms between the stretches with and without hydropeaking. However the abundance and biomass of benthic organism in the shallow areas most affected by hydropeaking and highly important for juvenile fish showed very low numbers. The water temperature, although recognizable, changes very moderately and within the tolerance parameters of the native biocenoses. Therefore it can be assumed that its impact is negligible in the Drau.

Summary of required actions to mitigate hydropeaking effects on biota:

- Identification and characterization of hydropeaking sites following a consistent methodology including rivers morphology.
- Determination of effects on the aquatic system caused by hydropeaking - need for new methods and experiments.
- Research on ecological hydropeaking criteria and related thresholds.
- Knowledge of interactions with other pressures (morphology, continuum, ...)
- Development and future monitoring of mitigation measures, like compensation reservoirs, change of operation, damping of ramping rate, reduction of peaks, improvement of river morphology etc.

In situations where hydropeaking discharges cannot be regulated or controlled with an ecologically-meaningful approach, the alternatives include the restoration and on-going management of riparian buffers, associated wetlands, backwaters and floodplain refuges for aquatic biota. This is a mitigation of the loss of the natural flow regime and would require an annual compensation system for the use of adjacent agricultural land to achieve this purpose. Annual compensation would be paid to the landowners by the hydropower plant operator. It would be an income for restoration purposes, similar to EU and national funding to farmers for agroecosystem initiatives. Similar measures have been the subject of extensively discussions in Switzerland (Baumann et al., 2012). A combination of various measures, adjusted to the local situation, should be the best practice for most river reaches.

5 BBM – a possible approaches for setting environmental flows

An important part of this project was to convey a workshop with international experts working within the field of science covering environmental studies in regulated rivers, setting environmental flows and management of water resources (see details on participants and affiliations in section 7). During the workshop there was a consensus that application of the so-called Building Block Methodology (BBM) (King et al., 2000) was a possible way forward. The development of the BBM originates from South-Africa and dates back to the early 1990s (Tharme & King 1998). The approach was developed as a workshop-based method to assess environmental and downstream flows, by including the needs of water flow for a variety of species or ecological functions (Hughes et al., 2007) and taking into consideration the dynamics in the aquatic system, i.e. the variation in flows and needs between seasons and years. The method is considered to be a holistic approach to setting environmental flow. The proposal by the Norwegian and international experts are, thus, in line with the recommendations from the articles published by e.g. Acreman et al. (2009) and Navarro et al. (2012).

The rationale for considering BBM as the approach for setting environmental flows (EF) is;

- Knowledge-based management is the a priori approach – BBM would hence provide the ideal framework.
- Due to a constant development of new knowledge, more knowledge on specifying the right magnitude, timing, duration, etc. of each of the 'boxes' within the BBM framework will become available.
- The ecosystems in running waters are clearly dynamic and requirements for environmental flow releases should hence better 'mimic' the natural hydrology, which is in line with the BBM concept.
- BMM provides a better basis for defining environmental flows according to the ecosystem needs than the traditional (or at least historical) way. This could possibly also save water for energy production, providing win-win solutions.
- BBM has been proposed/recommended as the approach for setting EF in line with the EU WFD requirements also by other authors (e.g. Acreman 2009 & Navarro et al., 2012), and trials are downstream of large dams currently undertaken in the UK.
- The BBM approach is in line with the overall goals of the EU WFD as introducing an ecosystem-based management of water in Europe.

There are, however, only limited examples that such approaches have been used in real management of regulated water courses (Gravem et al. 2006). In the following sections, the concept of the BBM is introduced and those cases known from Norway are described. All the presented cases can not be defended as following the procedures of a full BBM (Tharme & King 1998), but all of them could be considered having clear elements from the BBM by taking the documented flow needs of the ecosystem as the basis. In Norway, most of the cases where elements of BBM have been used are related to re-licencing of hydropower plants where new flow regimes in bypass sections are defined. Furthermore, those cases where elements of the BBM have been used are rivers with potentially high level of conflict, where the conflict typically lies between hydropower production and salmon game fishing.

5.1 The Building Block Methodology (BBM)

The Building Block Method (BBM) approach was developed as a workshop-based method to assess environmental and downstream flows, by including the needs of water flow for different species or ecological functions (Hughes et al. 2006) and taking into consideration the dynamics in the aquatic system, i.e. the variation in flows and needs between seasons and years. The method is considered to be a holistic approach to setting environmental flow as classified by Halleraker & Harby (2006). The basic data/information on the different water flow requirements can come from various sources, ranging from detailed and comprehensive model simulations to rough estimates set by experts ('expert judgements'). By bringing together all the experts and stakeholders representing specific water needs, optimum flow conditions are set in a process that is supposed to end in consensus. The typical way of using the BBM-approach is to invite a number of experts, covering different user interests and sciences related to water needs, species and their ecological functions, to set the environmental flow conditions (King 2000). The organizers of the workshop should provide all relevant data. The water flow requirements are defined individually for all essential components and functions on a monthly basis, also taking into concern the uncertainty in the requirements. Alfredsen et al. (2009) reported the application of the BBM concept in a demonstration case in a Norwegian river regulated for hydropower production, but the stakeholder participation was, unfortunately, limited. This case is described in more detail in section 5.5.

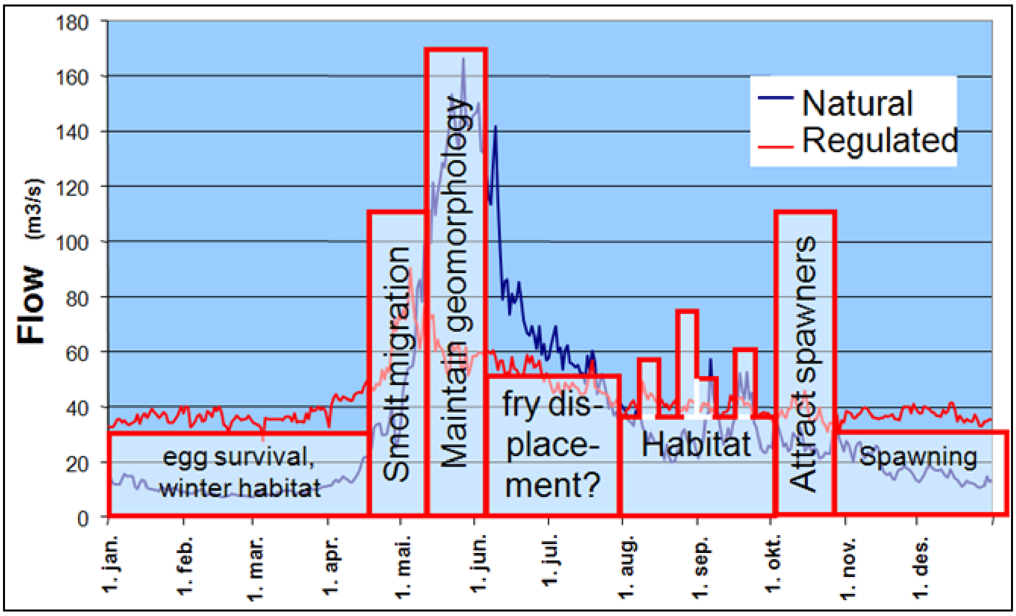


Figure 5-1. The figure illustrates the concept of the BBM as the 'blocks' of water flow releases are determined by the various life stages of the species or ecosystem of concern (presented by Harby in WFT-workshop in Trondheim April, 2012).

More specific, the application of the BBM in a real management situation would then be to define the size and duration of the various building blocks. Each block would typically represent a specific life stage of specific species. Figure 5-1 shows typical typically life stages of salmonid fish to allocate specific volumes of water for. The sources of information could be prior research from the same river or other rivers allowing transfer/generalisation of findings, new studies including model simulations and expert judgements. Figure 5-1 would, however, represent a simplification of the far more complex situation taking into account all relevant ecological elements and not only salmonids, the whole river system with varying hydrological, morphological and biological characteristics and the inter-annual requirements.

5.2 Experiences with the BBM-approach in Suldalslågen

Suldalslågen is probably the first river where elements of the BBM-approach were used to design the water flow regime in a regulated river in Norway. Suldalslågen is an important river with respect to salmon game fishing due to its large fish and catches. A large part of the scientific basis for defining the flow regime was developed during a large R&D-programme initiated by the hydropower company (Statkraft), which included investigations on hydro-physical processes, water chemistry and biological processes/conditions. The objective of the programme was to develop knowledge in order to propose the optimum mitigating measures, including water flow regime. The authorities and relevant interest groups were invited into the Board of the programme.

As discussed earlier, the old way of specifying minimum flows in bypass sections was represented by constant flows, possibly with different flows during summer and winter. During the 1990's these flows were generally larger than before due to a higher focus on ecological conditions. In parallel, research documenting the relations between physical and biological conditions was carried out, including relations between water flow, water temperature and light and various biological life-stages. As an example, hydrological events like floods and changes in water temperature could possibly trigger migration of fish or development of eggs and larvae. Regulated rivers will, despite their regulation, also have a component of natural inflow and temperature variations, depending on the size of the unregulated part of the catchment. Experiences from Suldalslågen showed that the water flow regime should be designed to follow natural hydrological variation. In Sub-alpine regions, the spring flood will determine a number of biological processes and the operational water flow regime should include such hydrological events. The timing of such events might vary from year to year depending on climatic conditions and operation/water release to the bypass sections should, thus, not be specified to fixed dates, but follow the actual climate, which is the traditional way of specifying the water release.

In Suldalslågen, a number of important biological factors were focused, including:

- Smolt migration
- Timing of the spawning
- Egg development
- Swim-up of larvae
- Juvenile fish growth
- Quality of the spawning and rearing habitat
- Composition of invertebrates
- Biomass of and composition of water vegetation

Within the R&D programme these biological factors and their relation to physical factors were studied, and especially the relation to different water flow regimes. Various water flow regimes were tested under different climatic conditions and biological response registered. A monitoring programme for basic hydrological and biological data was established, as well as on water quality. The investigations gave both river-specific knowledge and more basic understanding about relevant processes. Game fishing has been very important, and this interest was in particular important, alongside other economical interests, such as the hydropower production, when the final water flow regime was decided.

Periode	Vannslipp ved Suldalsosen	Utfyllende kommentarer
Vinterperiode		
1/12-10/4	12 m^3/s	
Vår og forsommer		
11/4-24/4	20 m^3/s	
25/4-30/4	20-200 m^3/s	Vannføring økes til 200 m^3/s i løpet av to døgn (25-26/4). Holdes 4 døgn (27-30/4) for så å bli redusert.
1/5-5/5	20 m^3/s	Vannføringen reduseres fra 200 til 20 m^3/s.
5/5-14/5	20-100 m^3/s	Vannføring økes til 100 m^3/s i løpet av to døgn (5-6/5). Holdes 7 døgn for så å bli redusert
15/5-30/6	42 m^3/s	
Sommer		
1/7-30/9	60 m^3/s	Pendle mellom 40 og 80 m^3/s. Det totale slippvolum skal tilsvare et gjennomsnitt på 60 m^3/s i perioden.
Høst		
1/10-15/10	50 m^3/s	
16/10-30/10	35-200 m^3/s	Innenfor perioden 16. oktober til 30. oktober skal det slippes to flommer på 200 m^3/s, begge med varighet på 24 timer. Mellom og etter flommene skal det slippes 35 m^3/s.
1/11-14/11	35 m^3/s	
15/11-30/11	19 m^3/s	

b) Det foreslåtte pendlingsmønster i perioden 1/7-30/9 kan justeres av en representant for de fiskeberettigede etter avtale med regulant.

c) Alle vannføringsreduksjoner skal foretas med maksimalt 6 cm pr. time målt ved Stråpa

1. oktober ved utløpet i Suldalsvatn ikke underskrider 0,5 m^3/s.

Figure 5-2. Water flow regime for Suldalslågen, where the first column defines the period, the second the volume of water, while the third column describes further details on the water release. The requirements for water flow are set at the upstream end of the river (Suldalsosen), see graphical presentation in figure 5-3. Source: Statkraft.

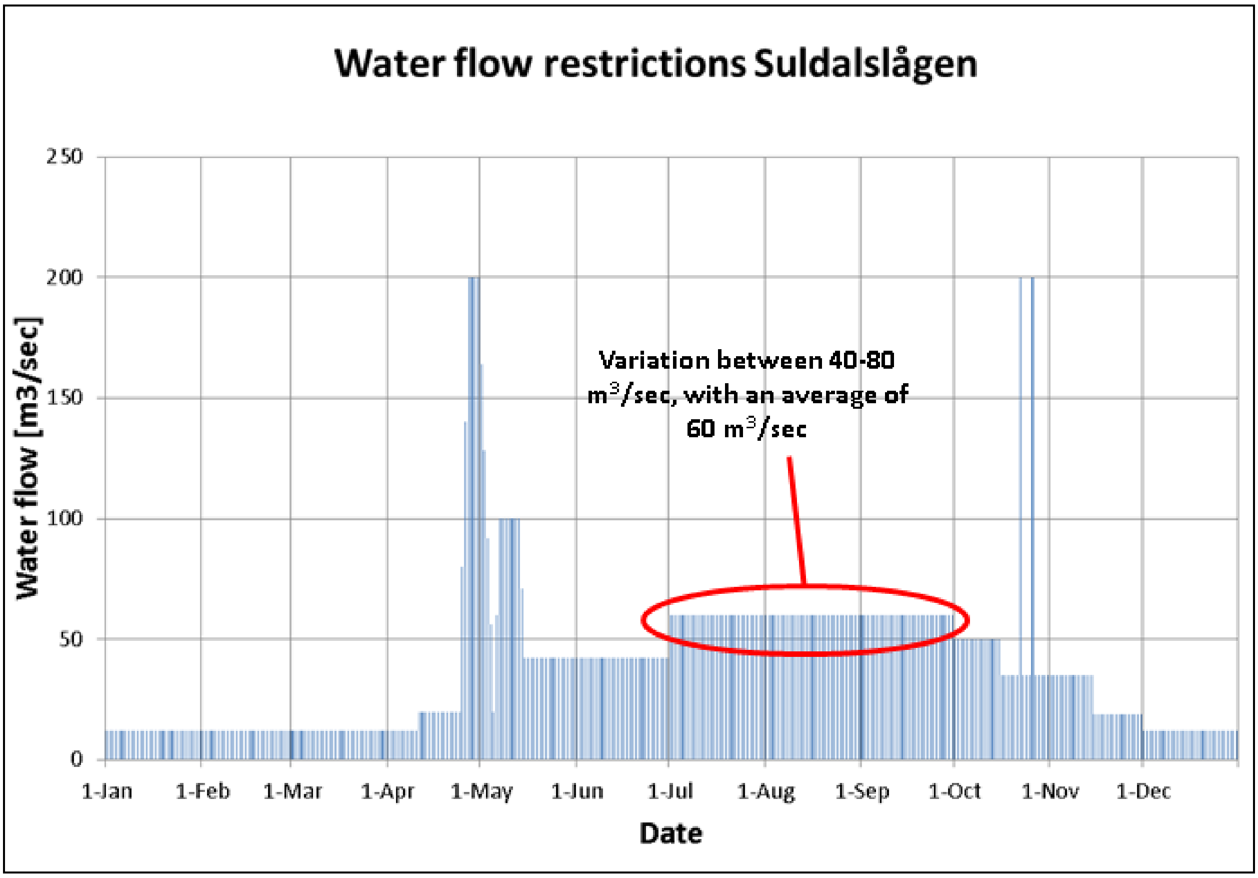


Figure 5-3. Water flow restrictions in Suldalslågen, as approved by the Ministry of Petroleum and Energy in June 2012.

The water flow regime introduces large variations in flow over the year. In addition, small unregulated catchments will in periods contribute with water. The variations from year to year are, however, small, and the regime does not include any specific considerations regarding dry and wet years, respectively, beyond the natural variation from the unregulated part of the catchment. The biological factors that were most focused when the final regime were set were; smolt migration, (timing and size of spring flood), swim-up (water flow early summer) and access to spawning areas as the basis for stabile conditions for egg development and winter survival of egg and juvenile (flow during winter). It is also required flush floods during fall in order to reduce sedimentation of fine sediments and clogging of interstitial spaces and multi-year accumulation of water vegetation (macrophytes). The fishing interests are allowed for by preparing a specific water flow with some variation during the fishing season (July – September).

The timing of important hydrological events are to a certain degree determined by the weather conditions, as the timing of the increase in water flow during spring ('Spring flood') is given by the water flow in an unregulated neighbour catchment. The flush floods in the fall should preferably coincide with natural flood events. The other requirements have a fixed volume and a fixed date for water release.

It is also worthwhile noting that the water flow regime does not allow drops in water level more rapid than 6 cms/hour, measured at a specific location in the river (restriction on the hydropeaking regime).

The water flow regime was approved by the Ministry of Petroleum and Energy by June 22nd, 2012.

5.3 Experiences with the BBM-approach in Mandalselva at Laudal hydropower plant

Laudal hydropower plant is a run-of-the river plant with a small intake reservoir called Mannflåvann, leading to a 6 km bypass section downstream the intake reservoir. The bypass river reach was severely impacted by acidification the first years after regulation, and had a minimum flow of only 250 l/s and basically no juvenile fish. Liming of the river started in 1997 and the salmon stock was recovered. The hydropower company introduced a self-imposed restriction on minimum flow on the stretch at 3,0 og 1,5 m^3/s summer and winter respectively. Despite this large increase in flow, up- and downstream migration still appeared to be difficult for the migratory fish. The spawning and rearing areas were still of poor quality and a large part of the migrating smolt ended up in the turbines, leading to mortality, and did not pass in the 'safe' bypass stretch.

A clause in the licence agreement and restoration of the river as a salmon river (Mandalselva is a national salmon river) lead to a discussion about the operation of Laudal hydropower plant and the minimum flow release. Focus was, in specific, on the possibilities to facilitate a safe migration route downstream the intake to Laudal for smolt and winter survivors, support of upstream migration of adult fish in the minimum flow reach and improvement of spawning and rearing habitats at the same minimum reach for salmon and brown trout. The proposed water flow regime was supposed to focus on salmonid smolt migration and the migration of adult fish and prepare for game fishing in Mandalselva.

Especially smolt mortality has been a large problem in Mandalselva. In the case of a low flow in the bypass section a large portion of the smolt end up in the intake/turbine of Laudal and die. Experiments have shown that leading a larger portion of the water into the bypass section instead of into the plant will reduce the mortality (Fjeldstad et al. 2012). The proposed water flow regime has adopted these findings and set restrictions on the operational regimes under various circumstances. At the same time, a 5-year trial period is suggested to gain new knowledge about the design of the operational regime/water flow release in order to reduce turbine mortality further. The timing of the artificial flood to sustain smolt migration is determined by observing the natural smolt migration and then facilitates this further by water from Mannflåvatn/co-ordinated with the operation of Laudal.

The proposed flow regime at the bypass section will be increased during the summer according to the proposition and the release shall be adjusted according to the natural runoff. This will lead to a larger variation of the flow regime and to improve the conditions for upstream migration of adults. The flow will also be increased during winter compared to the past and present conditions and will be at a level comparable to the common low flow.

According to a press release from the Norwegian Water Resources and Energy Directorate (NVE) [2], NVE proposes to the Ministry of Petroleum and energy that the operational rules of Laudal Hydropower plant is changed to a minimum flow of 15-20 m^3/sec during summer and 6 m^3/sec during winter. The rationale has been to improve the possibilities for migration for smolt and adult fish and the conditions for game fishing. The change in regime will also improve the habitat conditions for juvenile fish at the bypass sreach and form the basis for increased smolt production[3].

[2] http://www.ntbinfo.no/Norges-vassdrags--og-energidirektorat-NVE/Auka-minstevassforing-i-Mandalselva-ved-Laudal-kraftverk.14882/?pressId=14882&type=opensearch&searchKey=16436158-9bc6-11e1-9598-cfae9ee4901f&pageIndex=236&languageId=NO

[3] Further details on the proposed regime are provided at http://skjema.nve.no/NVE-saksdokument/200701661-39-548632.PDF.


Figure 5-4. The photos shows the intake reservoir and the actual inlet to Laudal hydropower plant to the left.

5.4 Experiences with the BBM-approach in Altavassdraget

Altaelva is one of the most important salmon rivers in Northern Norway, where the outlet of Alta hydropower plant is situated at the upper part of the anadromous section of the river, called Sautso. The inlet to the plant is in lake Virdnejavri, a lake/reservoir caused by the hydropower development.

Before the regulation, the upper part of the river was ice covered during winther, but after setting the plant in operation this was changed. In the first years after the regulation, the water was taken only from the deep parts of the reservoir, leading to release of 'warm' water into the downstream river. Together with the higher water flows than prior to the regulation, this led to the consequence that a stable/permanent ice cover was not formed at the upper part of the river.

After monitoring the fish population for some time, a negative trend in the salmon catches at Sautso was detected. Also the densities of juvenile salmon and smolt production reduced at this part of the river. Detailed investigations showed that fish in rivers that normally are ice covered have a very high energy consumption during ice free conditions because light seem to stimulate to increased activity and thereby the metabolism. Increased energy consumption and limited availability of food cased increased mortality of the juveniles downstream the outlet of the plant/upper part of the river. Ice free condition also involved increased predation.

This negative trend was the starting point of acknowledging the need to change the operation regime of the plant with the aim to re-establish the ice cover at the river. The most important action was to ensure that the water released into the river was colder, i.e. establish a new water intake closer to the surface of the reservoir. According to the new operational regime, water is withdrawn at winter time (December to April) at a level 10 meters beneath highest regulated water level, which is 70 meters higher than in the early days of the regulation. This has reduced the water temperatures with 0.2 – 0.4 ^{o}C during winter. At the same time, water shall be release in a way to increase the possibilities of having a stable ice cover.

The new operation regime seem to have work as intended and ice covered is formed downstream the outlet during normal winter conditions. The operational regime is also designed in way that the timing of the winter period (start and stop) is so close to the natural weather conditions as possible. The start of the winter period is determined by the temperature development in the reservoir and the end is determined by the changes in runoff. Details about the operational regime can be found at the web sites of Statkraft[4] and NVE[5].

The new regime was finally approved by the Minister of Petroleum and Energy in February 2010[6].

This case could not be considered as a formalised process of applying the BBM concept, but contains clear important elements of the approach, by stating clear ecological objectives, both with respect to release of certain water flows, but also with respect to water temperatures.

4 http://www.statkraft.no/energikilder/vannkraft/soknad-om-varig-alta-kraftverk.aspx
5 http://www.nve.no/no/allekonsesjoner/?soknad=4479&stadium=&type=11
6 http://www.statkraft.no/pressesenter/nyheter/2010/manovringsreglement-for-alta-kraftverk-fastsatt.aspx

5.5 Inflow-controlled EF-regime based on BBM-approach

The experiences reported in this section are based on a study carried out by NTNU/SINTEF in Norway, and reported in Alfredsen et al. (2009) and Alfredsen et al. (2012). The objective of the study was to develop a flexible environmental flow regime that has three levels (low, medium and high flow scenarios), using an approach similar to the BBM. The three environmental flow scenarios were based on the same three categories of natural inflow with a shift in environmental flow scenario occurring depending on the natural inflow value. In contrast to some designs suggested in the literature (Gravem et al., 2006), the study wanted to avoid an environmental flow regime based on a direct scaling of the natural inflow by a fixed percentage factor, because the resulting flow of such scaling may not have any ecological significance. The approach was tested in two rivers – Daleelva in Høyanger and in Kjelaåi in Telemark. As Kjelaåi ended out not being suitable for applying the approach, this case in not further described in this section, but the rationale for this conclusion discussed in section 4.8 (Potential barriers in the use of the BBM-approach). Besides the hydrological and environmental testing of the applicability of the approach an evaluation if the approach is manageable within the present legislation system that was made.

The BBM-approach requires the definition of 'blocks' and assignment of magnitudes/volumes of water to each of the blocks. In Daleeleva the following life stages were defined; winter discharge, spawning, hatching, swim-up, rearing of juveniles, downstream migration of smolts, upstream adult migration and recreational fishing for the key species Atlantic salmon. For each of these life stages (blocks) certain values were assigned based on ecological criteria. It should be underlined that the assignment of flow values did not involve or require any field studies and are based on the knowledge of the involved scientists and flow values found in the literature. It should be notes that it was defined a low, normal and high flow regime, representing dry, normal and wet years. The selection of the low, normal and high flow regime were determined by the natural flow conditions.

Table 5-1. Key life stages, corresponding periods of the year and rationale for assigning flow values for the key species atlantic salmon.

Life-stage	Time of the year (week no.)	Rationale for setting flow values (key words, see details in Alfredsen et al, 2009 & Alfredsen et al, 2012)
Winter discharge	Winter	Winter discharge was set at a level which maintains a large abundance of the wetted area without unnecessarily high flows. The flow was set to be as stable as possible (constant).
Outmigration of smolts	19-22	Mid-May was assumed to be the time where the bulk of the smolt run occurs. Therefore, a block of water with a high discharge event with variations in magnitude and duration for each of the three flow situations was introduced in mid-May. The quantity of water was based on the knowledge that the water release must be large enough relative to winter flow to trigger the migration. In a normal and wet year, it was suggested that the reduction after the trigger release would follow a 'natural' recession pattern which should facilitate further migration.
Hatching	19-22	This coincides in time with outmigration of smolts. Outmigration asks for high flows while high flows during hatching increases mortality. Based on knowledge about the natural system, it was clear that the smolt migration block takes precedence over discharge controls for hatching.
Swim-up	25-26	The discharge at the time of swim-up should be kept stable (and low), as the high discharge during the first week after swim-up increase mortality, and no hydropeaking should happen during this life-stage. As for the hatching, swim-up is to a large extent determined by water temperature, but as data on water temperature is limited, this factor introduces uncertainty in the proposed time period for this life stage.
Summer discharge / Rearing of juveniles	27-37	Increased discharge in summer compared to winter flows will ensure a larger amount of wetted area available for fish production, to ensure that the competition due to space limitation for the newly hatched young-of-the-year will be minimized. The summer block is proposed dynamic in order to save water for hydropower productions in some periods and justifying some higher summer flood events for migration purposes.
Adult migration	Episodes during the summer period (27-37)	The timing of the 'migration freshets' should coincide with the natural flows, but not too early in order to avoid disturbing the swim-up phase. The magnitude of the attraction floods should be sufficiently high to overcome the effect of production releases from the hydropower plant, in the case of Daleelva asking for co-ordination of the releases of water from the plants K2 and K5.
Spawning	43-47	According to some studies referred to in Alfredsen et al. (2012) spawning is mainly controlled by water

		temperature and to a limited extent water flow. However, high flows in periods of spawning might increase the risk of spawning in areas that are later (during winter low flows) dried out. Based on this, a maximum level is set on this block, determined by analysis of the relation between flow and wetted areas. The timing of the spawning was set based on the (limited) water temperature data.
Recreational salmon fishing	Summer	Fishing opportunities and other possible recreational uses are also improved by higher flows, and a proposition of high flows for the Summer discharge / Rearing of juveniles regime (+ adult migration) will be supported by the fishing interests. The recreational catches of adult salmon are very low during June and the low flow regime proposed during swim-up period is hence considered not being in conflict with the fishing interests.
Channel maintenance		Despite the fact that the river is regulated, it regularly experience large (natural) floods with. Probably due to this the river is dominated by cobble and experience minimal degree of embeddedness, and no specific flow requirements are set for channel maintenance.

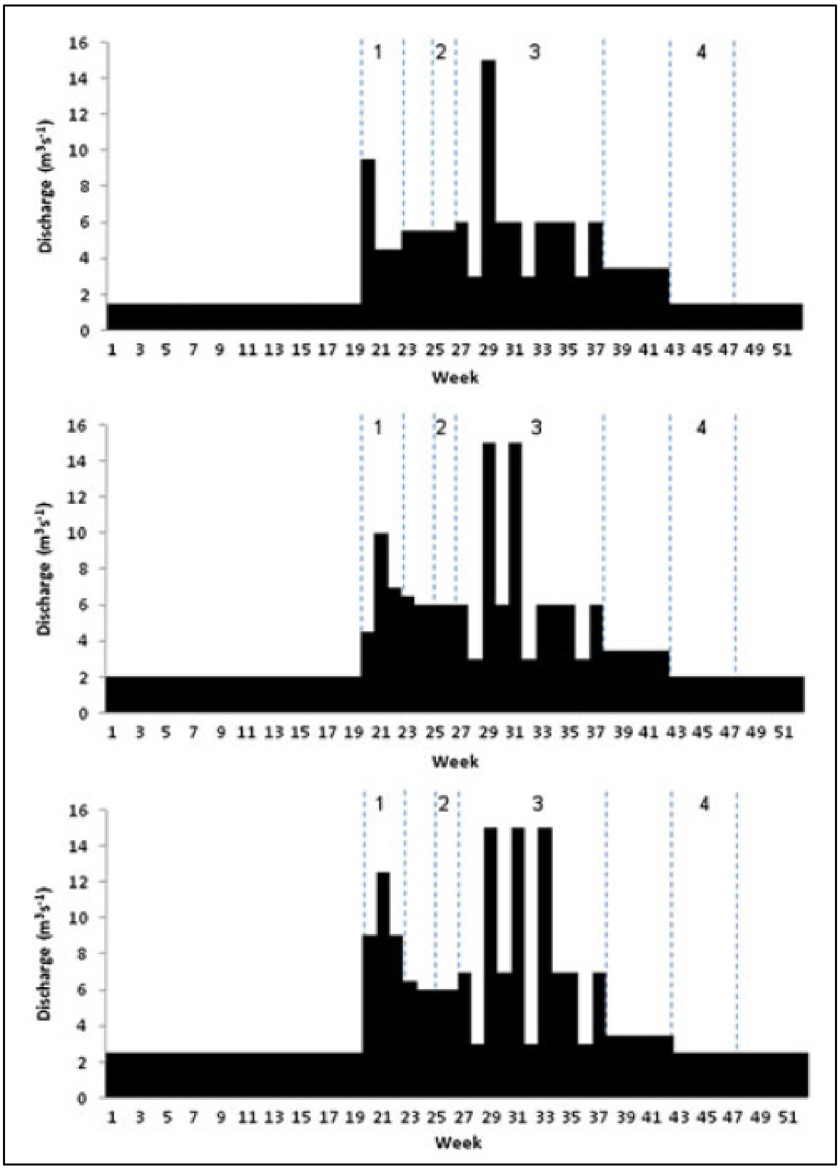


Figure 5-5. The figure presents the proposed flow regimes for Daleelva. Dry year (top), average year and wet year (bottom). The migration peaks and low-flow periods in summer are flexible and can be moved depending on prior conditions in the river and local inflow. Important blocks marked on the figure: 1: smolt migration block defined in weeks 19–22, 2: swim-up cap in weeks 25–26, 3: summer block in weeks 27–37 and 4: spawning cap in weeks 43–47. Source: Alfredsen et al. 2012.

5.6 Use of the BBM-approach in Kvina River – South-Eastern Norway

Very recently the BBM-approach was used in the heavily regulated Kvina River on the south-eastern coast of Norway as one of the instruments for developing a plan to re-establish the salmon population (Forseth et al. 2012) back to a smolt production level comparable to the levels prior to the hydropower development. In order to reach this ambitious goal certain parts of the river should be made accessible for the salmon, habitat restoration/modifications designed, and adaptive release of water for ecological purposes carried out.

Application of the BBM was used for specifying water flow needs for the salmon population by identifying bottle-necks in the production of juvenile salmon and assigning specific water flow values. The scientific basis for setting these values are on previous studies in this river, recent R&D projects carried out within CEDREN (www.cedren.no), long-term accumulated knowledge about salmonids and activities initiated as part of this specific restoration project. The blocks that were identified and the corresponding water values are described in the table below.

Table 5-2. The table describes the identified blocks for restoration of Kvina River and the basis for assigning specific values (magnitude, timing, etc.) of the various blocks.

Life-stage	**Time of the year (week no.)**	**Rationale for setting flow values (key words, see details in Forseth et al, 2012)**
Spawning	November and December	If the flow is too low during spawning some potential spawning areas might experience too low water depths and too low velocities. On the other hand, if the flow is too high the fish might spawn on areas that are dried out during a lower winter flow. Based on mapping of spawning areas, it seemed clear that the river would lose important spawning areas if the flow drops below approx. 6 m^3/sec. Today, the release during this period is 1.3 m^3/sec. The statistical frequency analysis show that the average weekly flow is less than 6 m^3/sec in Kvina in approx. 70 % of the time (see figure 5-5), based on data from the period 1994-2008. Increasing the release during wither from 1.3 m^3/sec to 6 m^3/sec will hence be costly with respect to loss in hydropower production.
Winther survival	October - March	The documentation of the importance of winter flow is fairly good and there is a positive correlation between flow and densities of juvenile fish/smolt production. This is also supported by studies in Kvina, in specific. A higher winter flow is hence considered being one of the most important measures. Within the concept of a certain annual volume of water allocated for release into Kvina ('water bank'), increase of the winter flow would be recommended, see also Table 5-2.
Outmigration of smolts	April and May	The needed flow volumes for smolt migration could vary a lot from year to year depending on the climatic/hydrological situation. A set of criteria were established in order to release a specific volume of water for a specific duration. This means that water will be released in ('dry') years with lower average flows than 20 m3/sec (and limited variations prior to release). The volume of the release is 30 % of the average flow values prior to the release and lasting for 1-2 days. This release will typically be a much lower volume of water to be released than the water allocated to reduce other bottlenecks by release of water. In wet years, no release of water will be needed.
Maintenance of habitat qualities		Reduction in interstitial spaces due to clogging by fine sediments is experienced as a problem In some regulated rivers,

(hydromorphology)		probably due to reduction of the size of the floods. For this reason, flush floods have been discussed as a measure to maintain the original substrate composition. In Kvina, reduced floods and construction of weirs have resulted in deposition of sediments and reduced habitat qualities. As introduction of flush floods might make the situation even worse by reactivating the fine sediments, it is recommended not to introduce these artificial floods until further investigations have been made.
Early survival	Spring and early Summer	The reduction in floods due to regulation has probably reduced the mortality in the early stages, both because of less disturbance and higher temperatures. Based on this, it is proposed no changes in the operational regime affecting the water flow in Kvina River.
Rearing areas / Summer habitat	June - August	Suitable habitat is a pre-requisite for growth and survival. The juvenile salmon can be limited by access to areas with suitable water velocities and/or access to areas with sufficient access to shelter/hiding places, determined by water covered areas and the interstitial spaces within the substrate. The importance of these factors might vary with population, age of the juvenile fish and along the river. It should also be taken into account that the salmon population undergo a density-dependent regulation. It would hence be very important to find water covered areas at various water flows. Sufficient suitable areas during summer are considered being very important (second priority after winter flows, if prioritisation between 'blocks' needed) for the allocation of water from the 'water bank'. It is evaluated setting 4, 5 or 10 m^3/sec as minimum releases in order to meet the requirements for Summer habitat. Setting the requirement to 4 m^3/sec will mean that only very little water would be needed to be released from the upstream dam as this flow is in most days provided by the residual flow. With a flow requirement of 5 m^3/sec, the release will increase and occur every 9-56 days (in contrast to 0-9 days with 4 m^3/sec). Setting the flow requirements to 10 m^3/sec will introduce a high cost in loss of power compared to 4-5 m^3/sec. See figure 5-6 for details.
Migration of adult fish and game fishing	July-August	The water flow can in dry years be very low during the summer and reduce the upstream migration of adult fish and provide poor conditions for game-fishing. As there has been a goal to re-establish good conditions also for recreational interests a proposed release of water from the 'water bank' has been developed. According to local fishermen the conditions for fishing are dramatically reduced when the water flow is below 15 m^3/sec, which also will affect upwards migration negatively. Based on this Forseth et al, 2012 proposes to release water in periods with natural increase in flow to such a level that the flow in Kvina reaches at least 15 m^3/sec and this flow should last for at least 2 days. Such a trigger release should be produced up to 3 times during the specified period. See duration curve for the period June – August in Table 5-2 and calculated additional water release for the water bank in the upstream reservoir in

		figure 5-6.

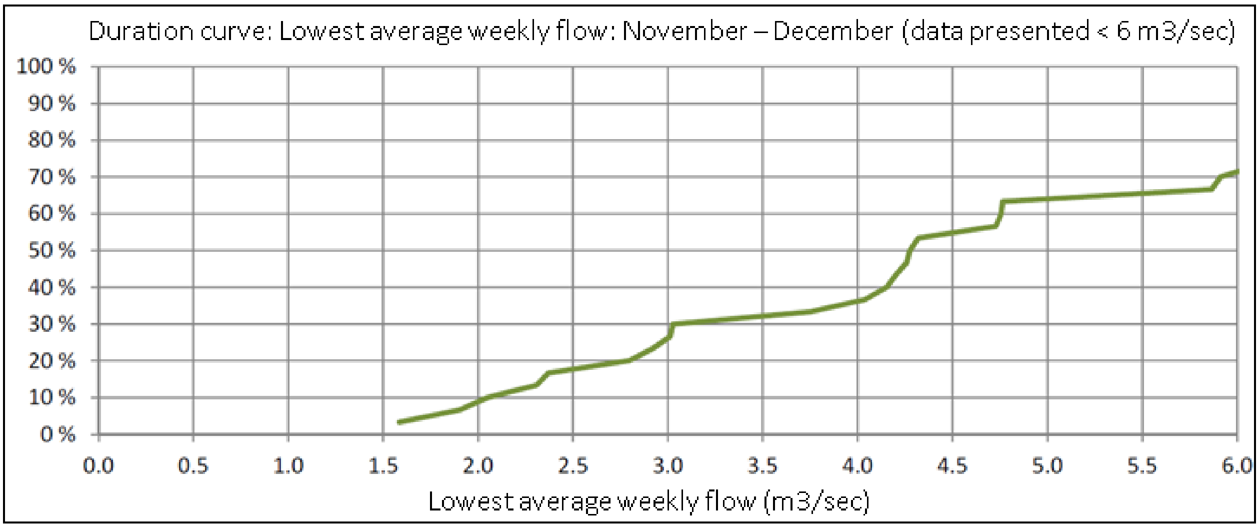


Figure 5-6. The figure shows duration curve for Kvina River for the period November - December, based on flow data from the period 1994 – 2008. The figure presents lowest average weekly flow. This curve is used to assign water to the river in order to meet the needs for spawning. Flow values in the range of today's 1.3 m^3/sec and less than 6 m^3/sec are considered, being in the range of approx. Q95 – Q30 respectively. It should be noted that the data used to derive this duration curve is not data from unregulated conditions, but from the Kvina with the existing regulation scheme before the planned extension. Source: Forseth et al. 2012.

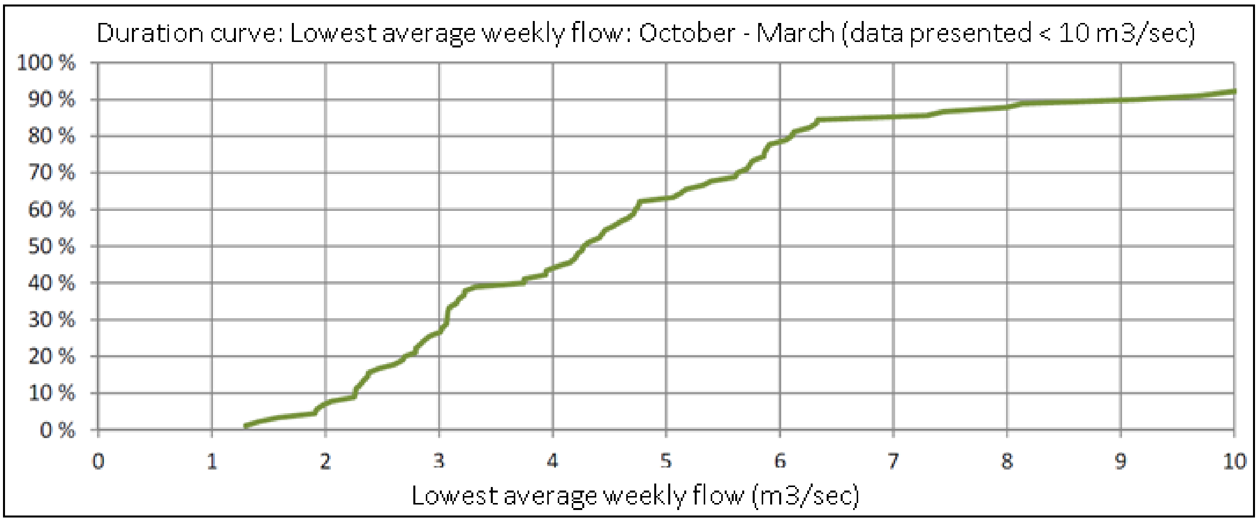


Figure 5-7. The figure shows duration curve for Kvina River for the period October - March, based on flow data from the period 1994 – 2008. The figure presents lowest average weekly flow. This curve is used to assign water to the river in order to meet the needs for Winther survival. Flow values in the range of 3 m^3/sec to 7 m^3/sec are considered, being in the range of approx. Q75 – Q15 respectively. It should be noted that the data used to derive this duration curve is not data from unregulated conditions, but from the Kvina with the existing regulation scheme before the planned extension. Source: Forseth et al. 2012.

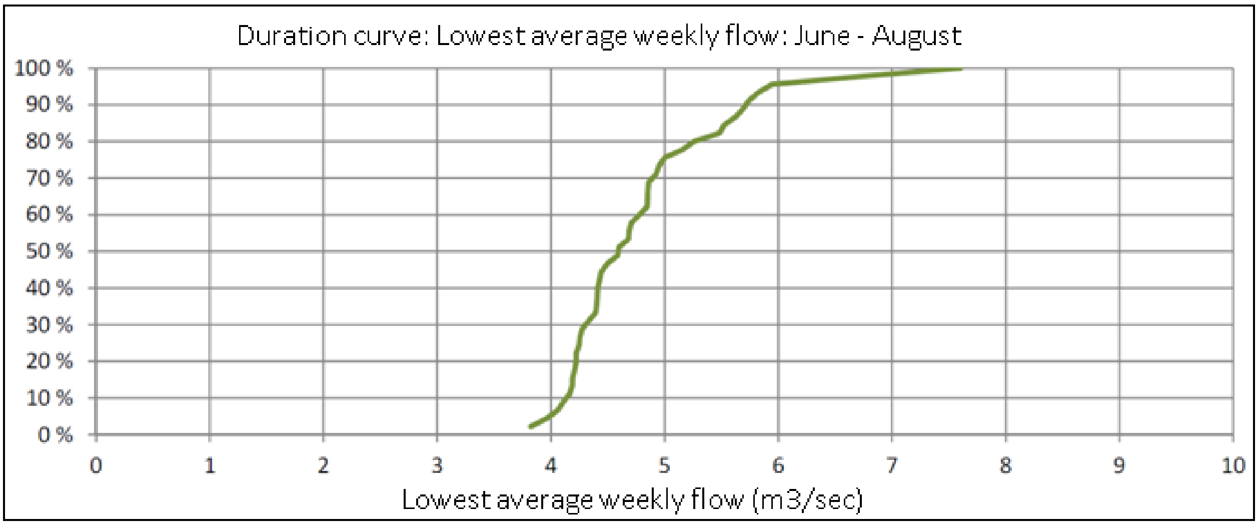


Figure 5-8. The figure shows duration curve for Kvina River for the period June - August, based on flow data from the period 1994 – 2008. The figure presents lowest average weekly flow. This curve is used to assign water to the river in order to meet the needs for rearing areas / Summer habitat. Flow values in the range of 4 m^3/sec to 10 m^3/sec are considered, being in the range of approx. Q25 – Q0 respectively. A water flow of 10 m^3/sec is considered too costly as it would introduce additional and costly releases. It should be noted that the data used to derive this duration curve is not data from unregulated conditions, but from the Kvina with the existing regulation scheme before the planned extension. Source: Forseth et al. 2012.

Forseth et al. (2012) also discusses the concept of assigning a certain volume of water to a water bank, in order to provide water in periods considered being critical bottlenecks in the life-stages of salmon. The dynamic release from the water bank will hence be adapted to the ecological needs and the variation in hydrology.

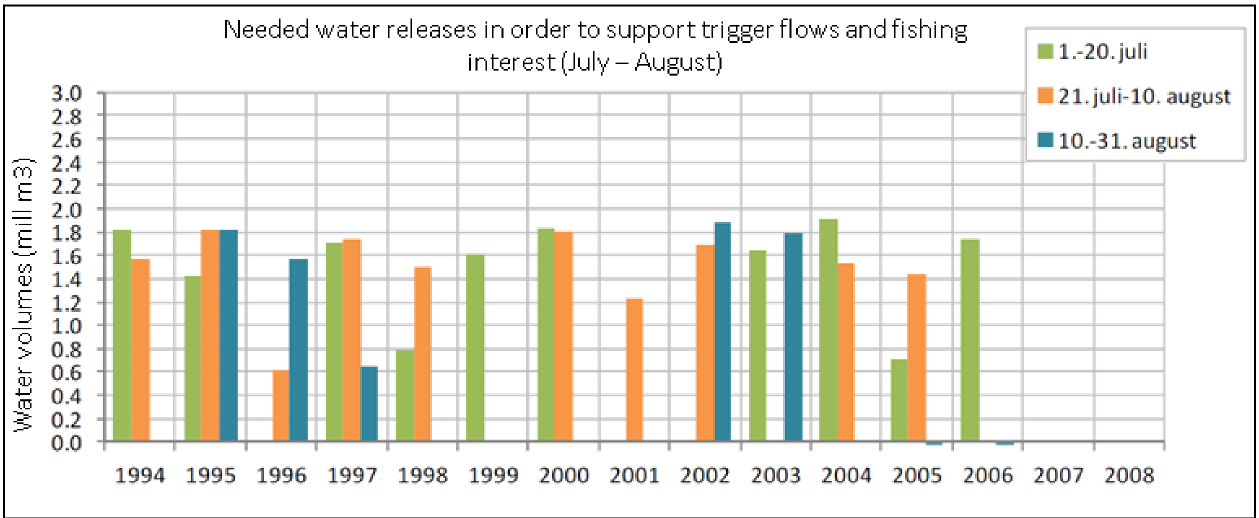


Figure 5-5. The figure shows needed water volumes to be released from the upstream dam in order to meet the requirements of 3 periods with 15 m^3/sec in Kvina River during the period July-August to trigger adult fish to migrate and to provide suitable fishing conditions. Source: Forseth et al. 2012.

Finally, from the report by Forseth et al. 2012 it seems like the process of setting the flow values were to a large extent driven by scientists with limited stakeholder involvement.

5.7 Conceptual application of the BBM-approach – Example from United Kingdom

Acreman et al. (2010) has proposed applying the BBM-concept in order to meet the EU WFD. The example presented is in the given paper discussed on a conceptual level. It is interesting noting by comparing table 5-1/5-2 and figure 5-8 that many of the identified blocks are similar (migration, spawning, etc.), but the magnitude, timing and duration of the blocks will, of course, vary from river to river, and probably also within one and the same river, i.e. headwater parts of the river may have different requirements than the downstream (lowland) parts of the river. The basis for defining the blocks will be knowledge about the hydrology, hydraulics and the ecosystem of the river in question from prior studies of the specific river or similar rivers or new studies.

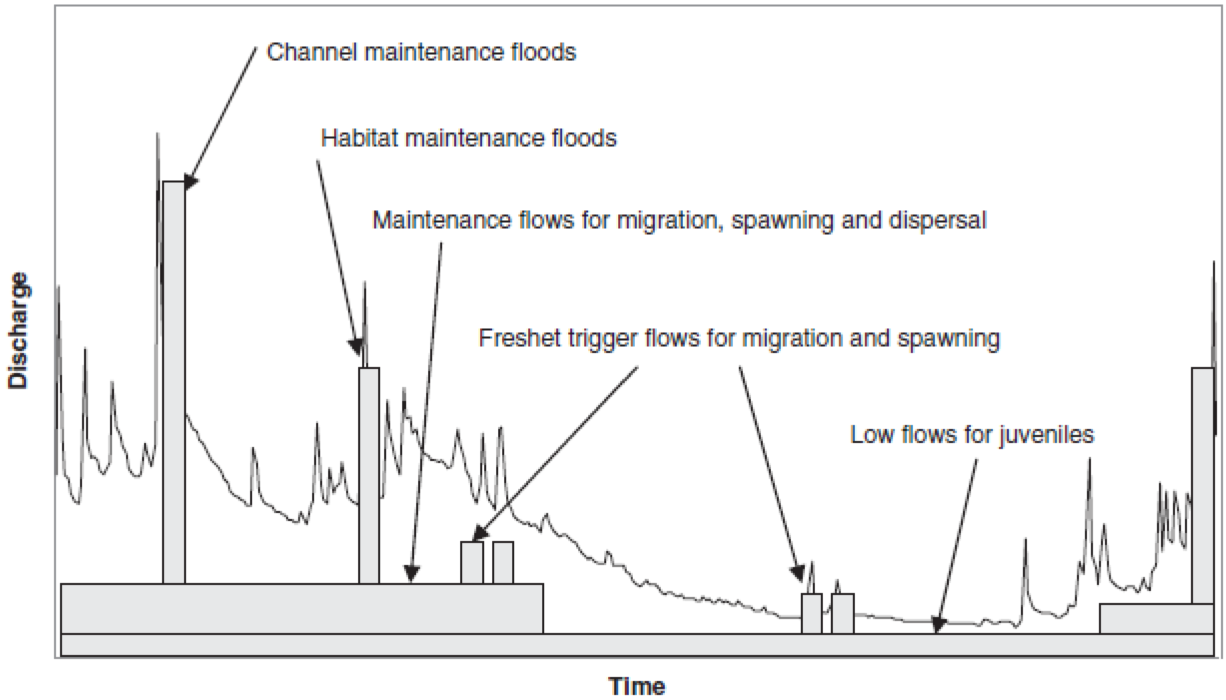


Figure 5-6. A conceptual approach for building an environmental flow release regime. The continuous line represents the natural flow hydrograph for one year; the blocks represent the flow regime required to maintain a healthy ecosystem. Source: Acreman et al. 2010.

5.8 Experiences with the BBM-approach - Setting the water level regulation in Lake Vansjø

It is interesting to draw the attention to Lake Vansjø in South-Eastern Norway where the BBM-approach has been applied with a wider scope than setting environmental flows (Skarbøvik et al., 2011). The lake experience severe, annual eutrophication due to over-load of nutrients and possible recycling of nutrients deposited in the sediments. At the same time the lake is a source of drinking water to many thousands of people in the Moss region and a very popular area for recreation, including swimming, canoeing and fishing. The lake is regulated for hydropower purposes, but environmental concerns have resulted in a suggestion to change the present operation scheme of the dam. A number of user interests will be affected by changes in the water level, and stakeholder groups (including the environment) were therefore invited to discuss the operation scheme by using the BBM. Overall, the process was deemed successful, and the BBM approach was believed to be a major contributor to the positive outcome.

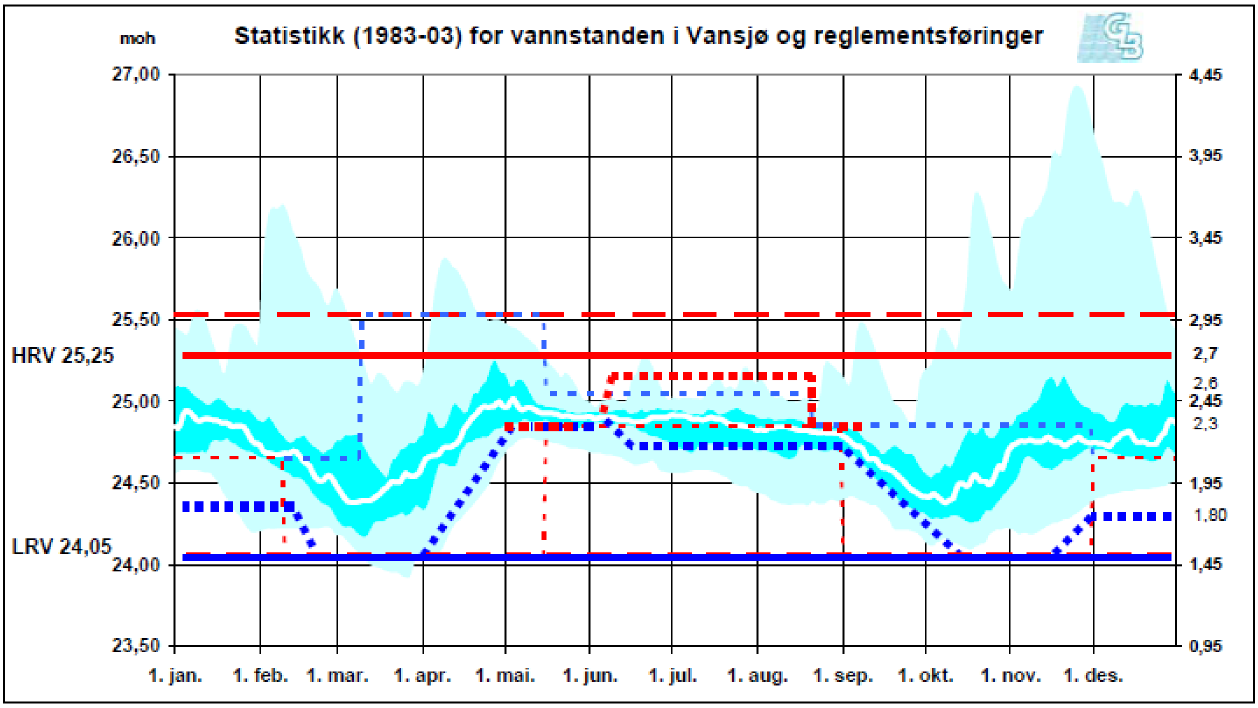


Figure 5-7. Proposed new regime of regulation in Lake Vansjø where the solid blue and red lines are minimum and maximum regulated water level respectively. The bold dotted blue and red lines are the new and proposed regulation scheme, while thin dotted lines are the regulation regime from 1983, from Skarbøvik et al. 2011.

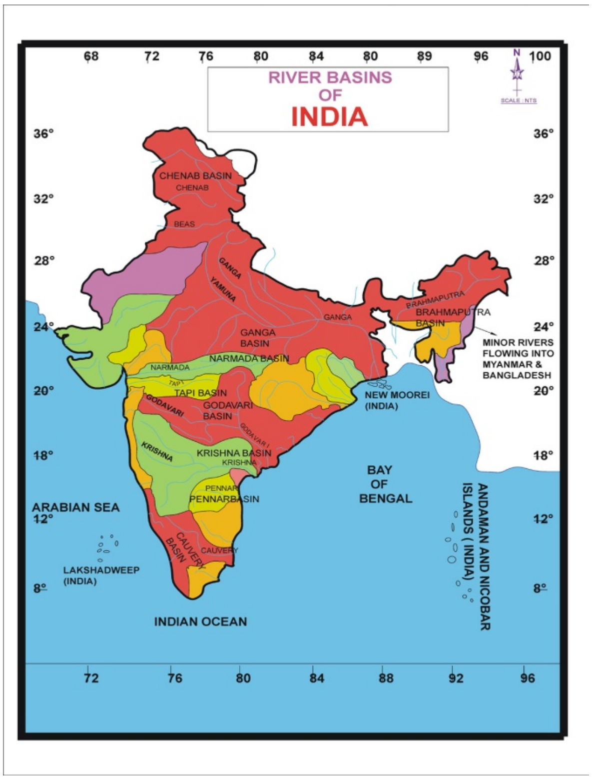
One of the basic pillars of the BBM-approach is that the method should end in consensus. It is clear that such a goal is not always possible to achieve. It is not difficult to foresee scenarios, especially when water allocation in dry years is negotiated, which can hardly end in a situation where all involved parties are satisfied with the outcome. Applying the BBM and discussing alternative water allocation prior to these, more extreme situations might, however, lower the tension in a potential future conflict.

It should be underlined again that it can be argued that the process in Vansjø to a large extent was a negotiation process in order to minimise the user conflicts instead of finding an optimum or balanced water level with respect to ecological requirements, but the principles of identifying and defining all the water (level) needs and in a consensus-based approach defining a water regime that to the extent possible meets all requirements follows the principles of the BBM.

A similar approach was also carried out for Lake Øyeren to set the operational regime (water level), and is reported in Berge et al. (2002).

5.9 Experiences with BBM - Setting water allocation regime in SRSP, India

The BBM-approach was adapted to and tested in the Sri Ram Sagar Project (SRSP), Andrah Pradesh, India by Norwegian and Indian researchers in close collaboration with Indian stakeholders. The information provided in this section is to a large extent based on the comprehensive documentation of the study provided by is study is comprehensively reported by Sauterleute et al. (2012) and Bakken et al. (2012). SRSP is a multipurpose project is located across the Godavari River than 122 TMC (thousand million cubic feet) of water (www.aponline.gov.in) (accessed September 24th, 2012). The reservoir water irrigates 0.39 million ha of land through three canals, and supplies nearby areas with drinking water and water for hydropower generation (installed capacity is 36 MW in four 9 MW units). The water used for hydropower production is later released into on of the irrigation canals. In addition to water from the reservoir, groundwater is an important source for irrigation in this region.



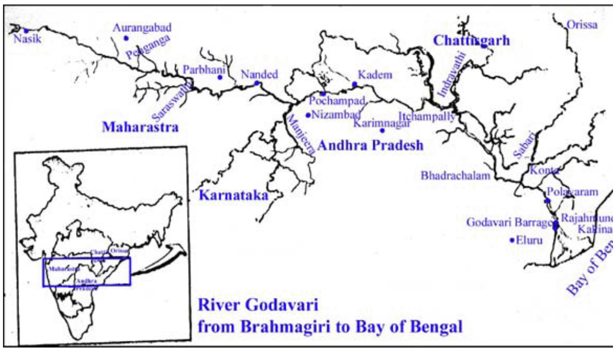


Figure 5-8. The map shows the location of the Godavari River Basin in India (in the centre of the map to the left) and the location of the Sri Ram Sagar Project within the Godavari River Basin to the right (Bakken et al. 2012).

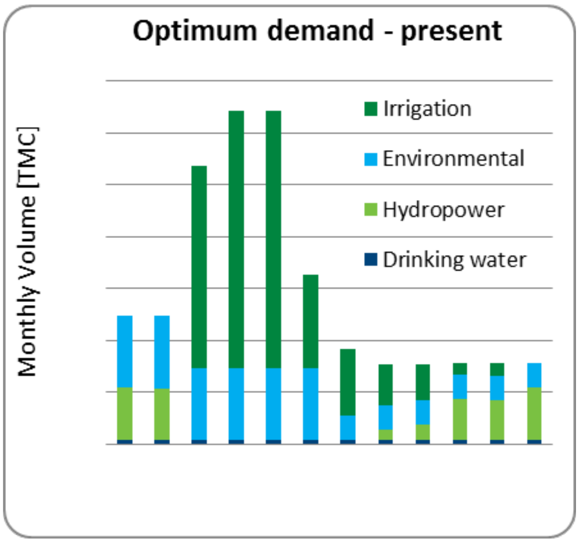
The rationale of using the adapted BBM to this case was to evaluate if this framework could possibly improve the water allocation in specific and more generally management practise in this project and similar cases.

A one day workshop on the use of BBM was organised at the Irrigation & Command Area Development office in Hyderabad on September 7th, 2011. About 20 stakeholders from relevant sectors with stakes in the SRSP, including drinking water, irrigation and hydropower from both state governmental and regional levels, participated in the workshop. The workshop was divided into sessions, and in the first session general information about the purpose of the workshop was given. In addition, the expectations of the workshop participants' were explored, a brief introduction to the BBM was given, and workshop guidelines and rules discussed. When applying the concept in the workshop, a set of rules was clarified for the participants;

- All participants should freely express their genuine water demand;
- All participants should accept that persons from other sectors could express their needs, and the water demands should basically not be disputed;
- All participants should express their demands and desired withdrawal in thousand millions of cubic feet (stored water) per month (TMC/month).

Figure 5-15 shows the optimum water demand for the present and future, taking into consideration climate change. The amount of irrigation water required from the Sri Ram Sagar Reservoir was calculated taking into consideration cultivation of wet and dry crops, respectively, minus the proportion of irrigation water covered by the use of groundwater. The minimum demand was obtained by reducing the optimum demand by 20 % for all months, based on expert judgements from the workshop participants. The future needs were also specified (decline by 5-10 %). The drinking water demand was calculated based on a fixed rate of consumption per capita, and it was differentiated between rural and urban population. It was decided that the demand should be limited to human beings; hence livestock was not accounted for. Since influences like population growth, urbanisation and losses in the pipeline system were considered; it was assumed that drinking water consumption would increase in the coming years. The water demand for hydropower was based on the present maximum and minimum power production, respectively. The demand is unlikely to change because there are no plans for extending the capacity of the operation of the hydropower station. As noted earlier, the demand for hydropower also accounts for irrigation, as the water from the turbines discharges into one of the irrigation canals (Kakatiya). This means that there is no additional hydropower demand, if the demand for irrigation is equal to or greater than the demand for hydropower. In addition, water allocated to environmental flow was introduced by experts in the project team, mainly for illustrative purposes as there presently are no defined requirements for environmental flow in the Godavari River.

According to these calculations and assumptions, the total water demand is expected to decrease by 1 to 10 TMC in the period of August to December within the next 10 years, as a result of reduced demand for irrigation. In the remaining months of the year, the effect of larger demand for drinking water is negligible with an overall increase in water demand of less than 0.1 TMC.



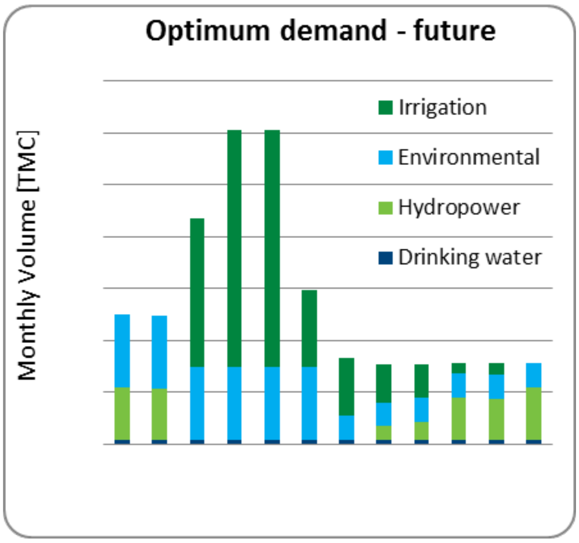


Figure 5-9. Required monthly volumes of water from the Sri Ram Sagar Reservoir. The optimum demands are given sector-wise for the present (left) and as expected in 10 years time (right) (Sauterleute et al. (2012) and Bakken et al. (2012)).

As described in section 4.1 the Building Block Methodology (BBM) was originally developed as a workshop-based method to assess environmental flow. However, the application of a modified version of the BBM to the Sri Ram Sagar Project widens up the scope of this method, as it also includes water requirements from other sectors than environment. The overall conclusions from this pilot-case are encouraging, since the adapted version of the BBM seems to have potentials to become a useful and supplementary tool in integrated water resources management in general and water allocation schemes in particular; especially in areas experiencing water stress with conflicting stakeholder interests. We also believe that this case in India could illustrate the potential of applying in Norway for the purpose of setting new flow regimes in bypass sections, especially if we see the process setting the flows as a process of balancing also social needs and not only ecological.

5.10 Potential barriers in the use of the BBM-approach

In the following, some elements are listed to illustrate the possibility that the identified approaches are difficult to apply on regulated rivers in Norway:

- Lack of knowledge about 'ecosystem bottlenecks' in order to define the critical life-stages/blocks (to assign water flows to). It is a risk vital blocks/flow regimes to sustain vital ecosystem functions are left out without knowing when designing building blocks.
- Lack of knowledge and/or data in order to define the right periodicity and magnitude of the different blocks (relation hydrology – ecosystem response not always known)
- Most of the cases presented in this report take a 'one-species approach', leaving out other biological quality elements to be considered according to EU WFD
- Difficulties in defining the GES/GEP; even if the relations between hydrology and ecosystem response should be known, it is not clear where to draw the border between moderate and good ecological status/potential (which is partly a political decision)
- Difficulties in defining an applicable control regime for dynamic flow values as dynamic flow regimes are more difficult and time-consuming to control.
- If low, normal and high flow regimes are proposed on top of a dynamic regime, the mechanisms to control if the environmental requirements are followed are even more demanding.

6 Conclusions and recommendations

There is a clear need for identifying simple relations between changes in flow and ecosystem response for the improved management rivers and the implementation of the EU WFD. Despite this, it appears very difficult to identify widely applicable relations between hydrological/hydraulic parameters and ecosystem response. Reviews made by e.g. Lloyd (2003) concluded that;

"Despite the unequivocal evidence for ecological responses to flow change, the relationship between these two measures was not simple. Small flow changes could produce large ecological responses and no simple thresholds were detected".

This was also supported by Poff & Zimmerman (2010);

"The quantitative analysis provided some insight into the relative sensitivities of different ecological groups to alteration in flow magnitudes, but robust statistical relationships were not supported. Our analyses do not support the use of the existing global literature to develop general, transferable quantitative relationships between flow alteration and ecological response; however, they do support the inference that flow alteration is associated with ecological change and that the risk of ecological change increases with increasing magnitude of flow alteration".

In the sections (6.1 – 6.3) the following is summed up in more detail:

- The review of used EF-approaches in Europe basically reveals that a number of approaches are used, most of them ending up in minimum flow/environmental flows in the range 5-10 % of mean annual flow. Summary of findings from the review of setting environmental flows in selected European countries, and the compatibility with meeting the EU WFD requirements of GES/GEP. Further details on this are provided in section 6.1.
- We propose to use the building block methodology (BBM) as a conceptual framework for setting flow targets in regulated rivers. This would support the overall idea of the EU WFD of introducing ecosystem-based management to European waters with stakeholder/end-user participation. Section 6.2 describes in further detail how a BBM-approach could be facilitated. Further details on this are provided in section 6.2.
- We propose to develop a methodology of using hydraulic parameters (e.g. wetted areas / width) as proxies for ecological status in rivers and relate these hydraulic parameters to habitat requirements of aquatic species. These hydraulic analyses should preferably primarily be driven by data that are easily accessible, for instance map-based data from public databases, aerial surveys or measurement campaigns covering larger areas, and applicable in a scale (extent) relevant for supporting management of regulated rivers. A systematic approach for generalisation of transect would probably aid the use of this approach in environmental management. Further details on this are provided in section 6.3.

6.1 Setting the Eflows – summed up European experiences

Several different Eflow assessment methodologies are available and in use today. While some Eflow thresholds are based on hydrological parameters only, others also try to incorporate ecological parameters and expert knowledge. Methods vary not only between, but sometimes even within a country. In any case, it is a great challenge to determine an ecologically suitable Eflow which allow both, the sustainment of ecological processes and the abstraction of water (Mielach et al. 2011). The natural differences in flow variability between certain river types make it even harder to derive universal and generally accepted Eflow assessment methods. In addition, the availability of time and data plays an important role, and could be a limitation in many cases. The definition of Eflows is important, but their suitability to fulfil WFD requirements has to be verified after application by means of field measurements, monitoring and habitat modelling.

In Austria, Eflow is defined based on national regulations, which have to be applied for all surface waters with the exception of artificial and heavily-modified water bodies. The regulation defines objectives for the high hydro-morphological status and guiding values for the good hydro-morphological status. The guiding values describe conditions under which the values laid down for the good status of the biological quality elements can be reached with high probability. These values concern not only Eflow, but also other hydro-morphological pressures as impoundments and hydropeaking. These values and criteria are fairly sophisticated defined, including threshold values for minimum depth and minimum flow velocity (see further details provided in section 2.2).

The German Wasserhaushaltsgesetz from 2010 states that the instream flows must be set such that they are in agreement with the requirements of the WFD, but it is up to the states (regional authorities) to implement this. Very few, or none, of the states have yet developed or specified their guidelines for setting flows in regulated rivers to be in line with the EU WFD.

In Finland, habitat modeling is an important methodology in assessing environmental flows in regulated rivers (bypass sections/HMWBs), taking both the site-specific physical conditions and the biological needs (typically of juvenile salmonids) into account. Whether Finland will use this methodology or adopt another strategy in setting environmental flows is under discussion and the environmental authorities recently established a working group to consider which approach to use during the implementation of the EU WFD.

UK is the country that seems to have defined the most specific water flow targets in Europe for reaching the goal of GES, at least for allowable water abstraction. The lookup tables proposed by Acreman et al. (2010) define how large percentage of the natural flow that could be withdrawn without reducing the standard to lower than GES. Maximum allowable withdrawal is typically in the range of 15-25 %, with a maximum of 35 % of the natural flow, depending on river type, season and flow rate. Taking these values into the context of releasing additional water into almost dry bypass sections, these water flow targets do not seem realistic for Norway, given the large losses in electricity production these will introduce.

Based on this review it seems clear that there is no common European standard in setting the environmental flow values, which is also acknowledged and addressed by the EU Blueprint to Safeguard Europe's Water (http://ec.europa.eu/environment/water/blueprint/index_en.htm, accessed, October 8th, 2012). As there are significant differences in terms of water availability, quantity, quality and efficiency, etc. the *Blueprint will not put forward a one size fit all straight jacket*, but rather try to put in place a tool box that Member States can rely upon to improve water management at national, regional and river basin level.

Table 6-1. Summary of historical/current practise of setting environmental flow (minimum flow requirements) and proposed approach for setting EF in line with the EU WFD in bypass sections of regulated rivers.

Country	Historical/current practise of setting EF	Approach for setting EF in line with EU WFD
Norway	Common low flow (Qc) as the starting point. Qc is often in the range of 6 % to 12 % of mean annual flow (Q_{MF}). Qc is approx. 0.956 quantile of the flow duration curve, being close to the widely used Q_{95} low flow index.	Pending
Sweden	Minimum/E flow is typically close to 5 % of mean annual flow, some in the range of 10 % of mean annual flow. A very few in the range 20-30 % of $Q_{MF.}$	Pending
France	Min.flow/EF typically in the range of 5 % to 10 % of mean annual flow, hydropeaking plants typically in the lower end.	Pending
Romania	The minimum release is typically approx. 10 % of mean annual flow or $Q_{95.}$	In the first RBMPs, EF was considered to be the minimum between $Q_{95\%}$ and 10% of the mean annual flow (10 % of Q_{MF}).
Austria	As a rule of thumb, EF represents 20 % of the actual flow. However, EF is not allowed to undercut a permanent minimum flow rate, defined by a set of specific criteria/values (see section 2.2), but basically these are assumed to be met if Eflow ≥ 1/2 $MALQ_{d\ natural}$ (natural mean annual minimum flow).	The EU WFD-requirements are assumed to be met if the approach specified in the cell to the left (section 2.2) is followed.
Slovenia	The minimum/e flow releases are typically in the range from 8 % to 22 % of mean annual flow.	Information not available
United Kingdom	As a general rule the Q_{95} is used, which corresponds with low flow values typically being within the range of 7-25 % of mean annual flow.	UK has defined maximum allowable withdrawal in order to meet GES. The values are typically in the range of 15-25 %, but are dependent on river type, season and flow rate.
Italy	No standardised methodology, to a large extent handed over to regional authorities. Actual practise unknown.	Information not available
Finland	EF is set case by case and the typical method used is expert judgments and/or physical habitat modelling assessing changes from flow regulation to the amount of suitable habitat for juvenile salmonids.	It is not clear if Finland will continue to use current approach or introduce a new methodology in order to comply with EU WFD. An expert group is established in order to evolve this topic.

Germany	This is to a large extent managed by regional authorities. As an example, the guidelines of Baden-Württemberg defines a 2-step approach where the first step calculates minimum flow to be 1/3 MALF (MALF = mean annual low flow). This is in the second step adjusted/adapted to local conditions, based on hydraulic assessment, habitat modelling or filed studies. The local adapted flow can not be less than 1/6 MALF. In Bavaria, a different methodology is defined (see section 2.2).	Pending. The responsibilities are to a large extent handed over to the regional authorities. Guidelines for implementing the EU WFD are missing, and must be defined/developed over the next years.

Most of the countries listed in table 6-1 have not yet proposed a clear approach/methodology of defining water flow targets in bypass section in line with the requirements of EU WFD. There are, however, reasons to believe that these countries will propose an approach that is not very different from the current national management practise of setting minimum/environmental flow. We would underline the need for hydrological data of sufficient quantities ('long dataseries') and qualities in order to perform hydrological analysis as described in table 6-1.

6.2 Use of BBM as a concept of ecosystem based management

The authors of this report believe that application of the Building Block Methodology (BBM) (King et al. 2000) as a framework is the preferred way forward in setting environmental flows is line with the specific requirements of EU WFD, and management of regulated rivers in general. The rationale for this recommendation is:

- BBM introduces an ecosystem-based approach to river management, supporting the overall policy of knowledge-based management.
- BBM is considered being a holistic approach for setting environmental flows, including all species or ecosystem functions presented in the river and riverine environment, and the variation in time (varying requirements with life-stages). The approach could possibly also include user interests (i.e. all ecosystem services, including recreational interests, hydropower production, water supply, flood control, etc.)
- BBM can be tailored as the supporting tool for both comprehensive studies in river basins with conflicting and divergent interests present, and in river basins where less comprehensive studies are requested. The BBM should be able to support process where less resources and/or data for investigations are available.
- BBM seems to be widely accepted within the scientific community and among environmental managers. Pilot studies/applications also report positive feedback from user interest groups involved in these studies.
- BBM can stimulate a wider public/user interest participation in river management, which is clearly in line with the ideas of the EU WFD.

It seems, however, that finding generic blocks are very difficult and building blocks cannot be easily transferred between sites due to differences between rivers (Acreman et al. 2009). Despite this, the same authors (ibid.) recommend the building block approach for setting eflows downstream of large dams in the UK and trials are currently being undertaken.

Table 6-2. The table lists some of the key issues to be addressed/answered prior to or during the processes of applying the BBM. We would also refer to King et al. (2000), for a more detailed description in how to apply the BBM.

	Question	Consideration
Prior to the formal BBM	1. Are sufficient and proper competence, information/data and resources on carrying out a BBM-process on the river available? 2. Are all relevant species/stakeholders present/available in order to convey a participatory BBM-process? 3. Are there other aspects causing environmental degradation than hydromorpological changes present in the river (i.e. other pressures like eutrophication, acidification, invasive species, etc.)?	Determine if critical resources (funding, competence, data, information) are available in order to carry out the process according to the principles of a proper BBM-process. Furthermore, the goals of the BBM process must be clearly stated, i.e. if it aims to facilitate the implementation of the EU WFD, revision of a hydropower licence or other management tasks. In the case of the EU WFD, the biological quality elements for rivers (and possibly lakes) should be focused in the study. In rivers regulated for hydropower production it is very important that the all major stakeholders are involved, including the power producer. It is important that the proposed flow values coming out of the BBM-process are within the range of acceptance for all stakeholders, including the power producer and also the national authorities responsible for security of electricity supply (securing the national supply). If several pressures are present other measures than for instance pollution control can be as important as assigning the right flow values. This must be clarified prior to starting the BBM-process, which focuses on setting flow values.
During the BBM	Which blocks should be included and specified in the study?	Define those processes that are considered critical life-stages for the species to be included, e.g. Winther discharge, outmigration of smolts, hatching, swim-up, summer discharge / rearing of juveniles, adult migration, spawning, channel maintenance, etc. All these life-stages should be assigned a block with specific water flow values.
	What is the magnitude/size of each block and do they represent maximum values (caps) or minimum values?	Define the magnitude, timing and duration of each of the blocks. The basis for setting these values could be expert judgements, literature values for the specific river, prior studies in similar rivers or new instigations. New investigations could range from site visits to more detailed model studies. The available resources will determine how comprehensive the study will be, with certain minimum requirements. The flow requirements are for most life-stages minimum values, but could for be maximum values for some stages, e.g. flow during swim-up.

	What is the periodicity of each of the blocks, i.e. which period of the year do they appear and how long should they last?	The timing/dates of each of the blocks must be specified and will vary from river to river depending on the climate and hydrology (e.g. water temperature). The basis for setting these dates (timing and duration of the blocks) could be expert judgements, literature values for the specific river, prior studies in similar rivers or new instigations. New investigations could range from site visits to more detailed model studies.
	Are there any blocks that occur less frequent than every year, and should the magnitude/periodicity of any of the blocks vary from year to year?	It might be processes that occur less frequent than every year that should be included in the proposed water flow regime. This can typically be more extreme events than naturally occur less frequent than once a year (larger floods), that is important for instance channel maintenance (flushing of fine sediments).
	Is the proposed regime valid (identical) for all parts of the studied river or would the requirements vary in the longitudinal direction?	The release of environmental flow will typically happen from an upstream dam and the same volume of water will be available at all downstream sections, possibly with some additions due to tributaries entering the river and/or groundwater inflow. The proposed water flow regime should hence be the water regime optimised for the whole river.
After the BBM	Does the BBM-process uncover aspects in conflict with the assumptions made prior to starting up the formal BBM-process?	A proper evaluation of the whole process, starting with the initial assumptions made should be carried out.

In addition to carrying out a BBM-process defining water flow regimes on a weekly or monthly basis, we would encourage the management authorities to also include requirements and restrictions on water flow regulations on a shorter time step in order to provide water flow regimes that sustain the ecosystem functions in regulated rivers. Furthermore, it can be relevant to include events (blocks) to happen less frequent then annually, for instance flushing in order to maintain proper substrate qualities.

We would underline the need for hydrological and biological data of sufficient quantities and qualities in order to specify which blocks to include in the analysis and to assign values to each of the blocks that are scientifically solid.

6.3 Developing hydraulic analyses as an approach for setting flow values

Rivers are holistic systems where interacting process scales range from small micro-habitats to entire catchments. The concept of "riverscapes" portrays rivers as broad scale trends in energy, matter, and habitat structure as well as discontinuous zones and patches. Recent technical and methodological developments in river research enable to gain high-resolution data for entire rivers at reasonable costs. Together with an advanced GIS-linked data base ("Fluvial information system", FIS), such data can be used for the extraction of primary fluvial variables (e.g. width) and the derivation of second-order variables (e.g. shear stress) and physical habitat conditions. High-resolution data increases the performance of mesohabitat-models and allows for using 2D and 3D hydrodynamic models at larger scales. The analysis of high-resolution data from a large number of rivers is very promising.

However, the interplay between the different spatial scales is not fully understood yet, and several up- and downscaling approaches are still tested on an academic level. Environmental flow standards for the EU WFD have to be developed both on a regional scale allowing for setting flow targets for many rivers simultaneously with limited resources, and at a local scale for single cases. Therefore we recommend combining some well-established methods for the regional scale such as hydraulic-geometry (HG) relationships with knowledge about the large variations of fluvial variables.

The following tasks are recommended:

1. Establish a Norwegian fluvial information system (FIS) that integrates existing data of flow variables such as bed levels, velocity and substrate and allows for managing and analysing large amounts of new fluvial data including high-resolution data from remote sensing surveys.
2. Establish a Norwegian river classification system working at the river reach scale using available information and additional field investigations.
3. Analyze river data with respect to hydraulic parameters (i.e. wetted width) as function of discharge and other variables. Derive empirical functions that can be used for the estimation of environmental flow standards on a regional scale as function of a given river type.

Existing data should be brought together and analysed using the FIS, and new field data acquisitions and/or modelling studies should be performed for only selected rivers covering different river types. The protocol for these investigations has to be developed in cooperation with researchers from different disciplines (engineers, biologists, ecologists, hydromorphologists, etc.). A Norwegian river classification system tailor-made for the river reach scale would allow for the development of relationships between ecological metrics and flow alteration for an entire type based on data obtained from a limited set of rivers of that type within a region.

7 Acknowledgement

A very important part of this project was the organisation of an international workshop with the many of the most prominent experts within this field of science in Europe. The workshop was a 2-day event arranged in Trondheim, Norway in April 2012, hosted by SINTEF Energy Research. The review of approaches for setting flow requirements in countries similar to Norway, state-of-the art in the applying indices for defining ecological status, etc. are based in the prepared presentations and discussions during this day, hence feeding into this report. The organiser of the workshop and co-ordinator of the project would like to express their gratitude to the participants at the workshop.

Table 7-1. National researchers and managers and international experts participating the Water Flow Target workshop.

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