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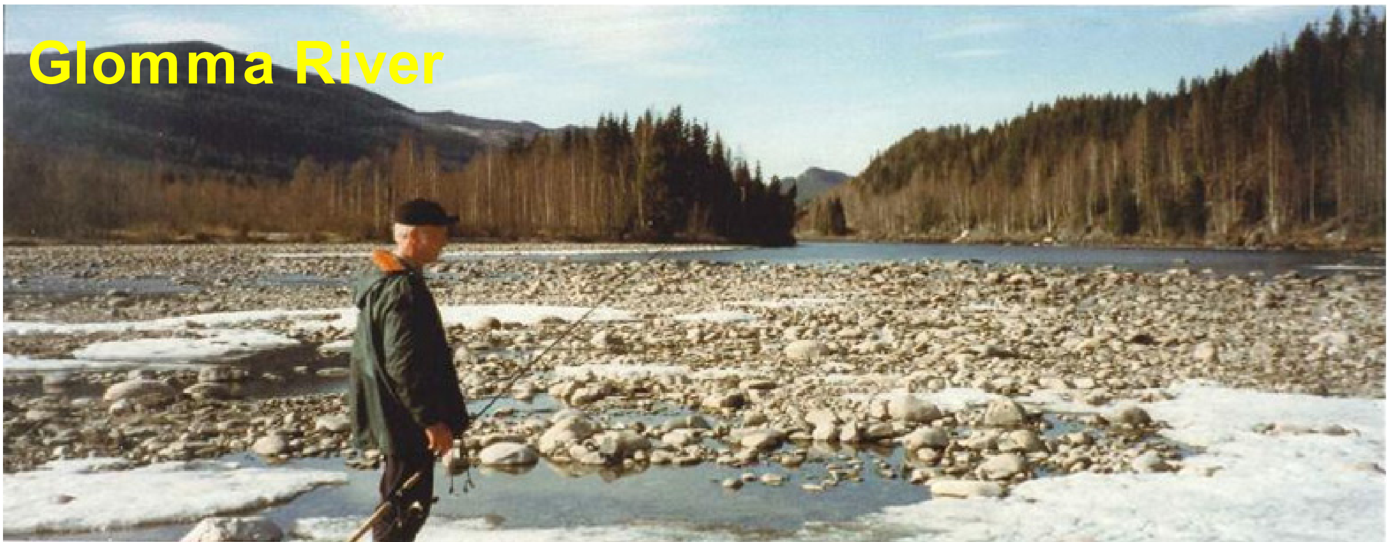
The Use of Environmental Flows in IWRM

with reference to the hydropower regulated Glomma River (Norway) and Sesan River(Vietnam and Cambodia) (STRIVER WP 8)



A TWINNING

PROJECT

Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

The project is Work Package 8 of STRIVER Project and belongs to FP 6 sub programme Twinning Europe – Asia, which aims at studying how different IWRM aspects are dealt with in the two regions and to learn from each other. WP 8 deals with environmental flow (EF) in the heavily hydropower regulated rivers Glomma River in Norway and Sesan River in Vietnam /Cambodia. The report reviews how EF has been dealt with in the nearly 60 hydropower plants in Glomma, reviews international methods, and how it has been dealt with in Sesan River. In nearly all the Glomma regulations there are requirements for minimum flow in downstream river stretches, but there are no such requirements in Sesan River. The regulation of Sesan River in Vietnam has created a lot of problems for the people living in downstream Cambodia where 35000 people are depending on fish as protein source. 70-90 % of the fish is gone and people are suffering. All the dams in Glomma River are equipped with fish bypass systems, whereas in Sesan there is none. Several new dams are under construction and new are planned to be constructed. When all are finished, about 60 % of the main stream Sesan River is converted into a cascade of reservoirs. Environmental flows will then mean to regulate the reservoirs in such a way that they function well as lake ecosystems, and to re-regulate the diurnal water level fluctuation in the river stretches. At the border the Vietnamese are building such a re-regulation reservoir. The project has developed a more structured version of the Expert Panel Method for assessing EF which is called the PIMCEFA method (pressure-impact-multi-criteria-environmental-flow-analysis) and tested it in the two rivers. The report gives also some advices on how to manage the two rivers with the aim of reducing the negative impacts of the hydropower regulations.

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STRIVER

Strategy and methodology for improved IWRM - An integrated interdisciplinary assessment in four twinning river basins

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Preface

This report is the main delivery in Work Package 8, which deals with Environmental Flow (EF) in connection with hydropower development in a context of Integrated Water Resources Management (IWRM). It is a twinning of experiences from Glomma River in Norway and Sesan River in Vietnam/Cambodia. The report reviews the international methods of assessing EF, it addresses the transboundary issues, and it also gives some recommendations on how EF can be assessed, and how it relates to other mitigation measures aimed at reducing the negative impacts of hydropower development.

Ph.D Dang Kim Nhung (geographer) at the Institute of Geography in Hanoi has been the WP leader throughout the project. The other participants of the Vietnamese team are Phi Thi Thu Hoang (IOG hydrologist), Phan Van Mach (freshwater ecologist), Nguyen Kiem Son (Fish biologist) and Vu Thu Lan (hydrologist).

M.Sc. Dag Berge (limnologist) at the Norwegian Institute of Water Research (NIVA) has been the leader of the Norwegian EF team. The other Norwegian team members has been Ph.D. David N. Barton (environmental economist, NIVA), and Ph.D. Ingrid Nesheim (ecologist at the Centre for Development and the Environment, SUM).

The Cambodian team was originally lead by His Excellency Bun Hean at the Ministry of Water Resources and Meteorology (MOWRAM) with M.Sc. Mao Hak (hydrologist at MOWRAM) as operative project leader. However, MOWRAM withdraw from the project medio 2007, and Kuon Komar, former Senior Programme Officer at the Mekong River Commission (MRC) has become the Cambodian in-house consultant.

The original plan was that the work in each country should be carried out by the national teams. After MOWRAMs withdrawal the WP8 work in Cambodia has been taken over by Dag Berge.

We would like to thank EVN (Electricity of Vietnam) and their affiliated PECC1 (Project Engineering and Consulting Company No 1) in Vietnam for making available their data for the project. Also MOWRAM in Cambodia has kindly placed their data at their disposal. Several NGOs has been helpful for the work in Cambodia, e.g. NGO Forum, and 3SPN (Tree S River's Protection Network). Particularly we want to thank Mr Meach Mean from the 3SPN office in Ban Lung for his kind and excellent assistance. In Norway we want to thank the GLB (Glommen and Laagen Water Management Association) and Mjøsforbundet (The Lake Mjøsa Association) for their kind assistance, as well as NVE (Norwegian water and Energy Directorate) and the Environmental Departments of the different County Administrations.

The report is compiled by Dag Berge with input from the other participants.

Oslo, Hanoi October 16, 2008

Dang Kim Nhung	*Dag Berge*
WP8 Leader	*Main Report Author*

Contents

Executive Summary

All river regulations that include water diversion, significant water abstraction, damming, storing of water, create considerable changes in the natural hydro-morphological regime of the river. All these changes will have negative impacts on river ecology and on the traditional use of the river. The magnitude of the impacts are related to the type of regulation, the comprehensiveness of the regulation, the total regulation scheme in the river, as well as to what extent there is taken relevant mitigation measures to reduce the negative impacts.

Environmental Flow (EF) is one out of several mitigation measures
There are many mitigation measures that can be taken to reduce the negative impacts of a regulation – one of them is Environmental Flow. There are described more than 200 methods for assessing environmental flow in the literature. Most of them are aiming at assessing a flow in the original river downstream of dams or diversion points, and has earlier been called minimum flow, or minimum release, or compensation flow. A growing awareness of that a more dynamic minimum release was more beneficial for the water ecosystem has evolved a great research activity on environmental flow and methods to assess it. The methods range from just selecting a minimum release as a percentage of natural flow to complex eco-hydrological model network.

Assessing EF include both mathematical calculations and expert judgements
All methods include both mathematical calculations and subjective expert judgements. No method can be said to be best in all situations. EF needs to be seen in close connection to other abatement measures, and it should be realized that EF is only one out of many such measures. For example what does EF means in a river like Sesan where most of the main river stretch will be converted to a cascade of lakes where the tailrace from one regulation enters into the reservoir of the next regulation? Hundreds of km of river habitat have been lost by inundation (main river + tributaries). The dams create migration barriers, and only part of the former river species can convert to reservoir life (lake habitat). Here it is the water level fluctuations that are the decisive factor for how well the reservoir will function as a lake ecosystem. The Norwegian experience is that a reservoir with only 2-3 m of artificial water level fluctuation, produce approximately 3 times more fish than a reservoir with 8-10 m water level variation. Water levels in reservoirs can be adjusted by tapping from the dams, i.e. by flows. Most water use interests are also depending on water levels. Therefore water level fluctuations in the reservoirs should also be included in the term environmental flow. All stretches of regulated rivers should be evaluated with respect to EF. On the other hand, when the politicians have decided that the river should be regulated for hydropower purpose, the EF has also to be within what is economical feasible for the regulation purpose. Setting EF is a matter of both environmental science and political trade off (i.e. calculations and judgements).

A suitable definition of EF which covers both Glomma River and Sesan River could be:
Adopting water release manoeuvring rules for the different reservoirs to obtain as favourable water levels (and water flows) as possible for the total river ecology and the human water use interests, within the constraints set by the economical feasibility of the regulation. This applies both for the reservoir stretches and river stretches.

The Holistic Methods of EF assessment has the necessary flexibility to cover both Glomma and Sesan River
This type of methods takes care of the flow needs to preserve a healthy aquatic ecosystem and the flow needs of the water use interests. The assessment includes an expert panel consisting of both professional experts and local experienced river users and relevant representatives from the water authorities. The methods are flexible and can be used in most types of regulations and for most types

of impacted river stretches. In Glomma River, where minimum flow is assessed, this is done by different loosely defined versions of the expert panel method. The most advanced of these are the South African Building Block Method (BBM). This is, however, very comprehensive to use, and STRIVER has therefore tried to develop a simpler version of a holistic method that we called the PIMCEFA method (Pressure-impact-multi-criteria-environmental-flow-analysis).

The PIMCEFA Method for assessing EF
It is a further development of a recent methodology used in renewing the concession of the Øyeren Regulation in Glomma River. It consists of the following steps:

- Identify the key river ecological values (fish, bottom animals, periphyton, etc)
- Identify the key water use values (Water supply, fishing, bathing and washing, hydropower, etc.,)
- Appoint an Expert Panel consisting of professional experts and local experienced water users within the fields of river values above, include relevant representatives from water authorities (local, regional and central)
- Draw preliminary optimum water level curves over the annual cycle which you mean serve the river value you are treating
- Identify critical periods, i.e. periods that you are quite sure that the water level needs to be at certain levels (migration periods, spawning periods, boating depths, etc)
- For the critical periods, draw pressure - impact curves (i.e. assess maximum damage and minimum damage and draw the most likely curve between these two points)
- Load the pressure impact curves into a multi criteria analysis tool MCA(we have chosen DEFINITE, but others also exist)
- Use the MCA tool to evaluate the impact curves of the different river values against each other
- After trade offs between the different values are done, construct the resultant optimum water level curve
- Use hydrological models to convert water levels to water flow and to give advice to the hydropower companies how to manoeuvre the dam release

To give secure results, the method requires that baseline studies covering the relevant river values and preferably also EIA studies are performed. It should be known how the power plants are planned to be operated. However, it is also possible to use the method with less data available, but the results will then be more un-secure. The method can also be used without a multi criteria analysis software but it will be more laborious do the trade-offs. The result will then easily be steered by the strongest debater.

Some Main differences between Glomma River and Sesan River
It can be instructive to give some information on differences between the two rivers related to the hydropower regulations, consequences and mitigations:

- In Glomma natural lakes are used as reservoirs, where as in Sesan they don't have lakes, and they need to dam the river both to get head for the turbines and storage capacity for water.
- In Glomma the local population are not subsiding from ecosystem services from the river, while this is very important in Sesan River, particularly in Cambodia. In Glomma fishing is mostly for leisure.
- The local population and sports fishermen's association has a strong stake in decision making in Glomma, where as in Sesan people living along the river are ethnic minority people with weak stake.
- In Glomma dams are equipped with fish bypass system, while in Sesan they are not
- In Glomma most dams has established rules for minimum flow downstream, but in Sesan they have not.
- In Glomma the hydropower owners run fish stocking programmes to compensate for degraded spawning conditions, in Sesan they do not.

- In Glomma the HPPs are not used in peaking el-production, but base load type which gives even flow over the diurnal cycle. In Sesan most HPPs have intermittent operations which give intermittent flow downstream. The Sesan 4A reservoir is built as a re-regulation reservoir and will be used to level out the diurnal water flow variations downstream. This will be an important measure for the Cambodian Sesan River.
- In Glomma it is established a well developed system for economic compensation for affected people including annual tax to the municipalities (benefit sharing), in Sesan this is much weaker developed, particularly in Cambodia.
- In Glomma there has been no resettlement of people due to the regulations, but in Sesan they have resettled a lot of people living in the inundated areas in Vietnam, this will also be the case if the planned HPP developments in Cambodia are carried out.
- The Sesan River is much more species rich than Glomma (higher biodiversity), the ecological niches are narrower, and the impacts on biodiversity will be larger than in Glomma, where there are few species and vacant niches.
- Main stream Glomma is not a transboundary river in terms of Hydropower Regulation impacts, whereas Sesan are, and the regulations in Vietnam have created several transboundary problems. Co-operative actions are initiated between Vietnam and Cambodia, both bilateral and via Mekong River Commission, and hopefully the transboundary problems can be solved.

Some final advices for Glomma River
All river stretches (rivers and reservoirs) should be evaluated with respect to environmental flows as part of the River Basin Management Plan in connection with the Implementation of the EU Water Framework Directive. The evaluations should not only be done regulation by regulation, but it should also be done for the total regulation scheme in the river system. This could reveal information that could be useful in future renewals of concessions. The EF should be seen in close connection to the other types of mitigation measures. Experienced professional experts and experienced local river users, as well as relevant authorities should be involved in the EF assessment.

Some final advices for Sesan River
The regulations in Sesan River are more comprehensive than in Glomma River, whereas the levels of mitigation measures and compensation measures are less developed. Vietnam and Cambodia should develop a joint water management plan for the Sesan River. EF assessment should be part of this. They have developed a joint update of the master plan for hydropower development which could serve as a starting point. All river stretches (rivers and reservoirs) should be evaluated with respect to environmental flows as part of the River Basin Management Plan. The evaluations should not only be done regulation by regulation, but it should also be done for the total regulation scheme in the river system. Experienced professional experts and experienced local river users, as well as relevant authorities from both countries should be involved in the EF assessment. It is important to face the fact that it is the reservoirs that will be the most important water bodies in Sesan River when the total regulations scheme is carried out. If these are manoeuvred with water level fluctuations of less that 3-5 m, they can produce much fish. Stocking programme may be necessary to compensate for lost spawning conditions. It will be great reductions in biodiversity in the main stream river and many important species will disappear. This is in-avoidable with such a comprehensive regulation scheme. To abate some of this loss, fish bypass systems could be installed at the dams, but only few species will be able to use these. The EF in the river stretches should first of all be assessed to secure that the river could function as spawning and nursery area for reservoir fish, in addition to serve local river use. The EF could be released via fish ladders to achieve max benefit.

The EF should be seen in close connection to the other types of mitigation measures, and compensation measures, with the aim of achieving maximum preserve of local livelihood and local environment, within what is feasible for the regulation purpose, and accepted by both countries.

1. Introduction

Hydropower regulations in rivers started approximately 110 years ago. Many of the regulations took place before the extent and importance of the ecological impacts was understood. Since approximately 1970 this has got increased attention world wide, both with respect to understand the impacts as well as introduce abatement measures to reduce the negative impacts. One of the most important abatement is to secure some minimum flow in the regulated stretches of the river. There are of course other important remedial measures as well, but these will not be dealt much with in this report.

The precursor of the Environmental flow (EF) was that the water management authorities required a minimum release, both downstream the dam if the water was diverted, and/or downstream the tailrace entrance from the power station in cases the power station was shut down. The minimum release was most often a fixed low flow released from the dam. It was sometimes called "compensation flow". The minimum release was determined by so-called expert judgement (Halleraker and Harby 2006). In Norway, during the last 25 years, the dominating method for establishment of a minimum release is expert judgement. Their advice is based on baseline studies of ecological conditions prior to the regulation. Often, the authorities have realized that the basis for final decision about the minimum release was not present, and therefore it has become common to give manoeuvring rules for a test period of 5 to 10 years with the proposed minimum release. Thereafter there can be some adjustments (Brittain 2002).

Internationally there has been a rapid development towards the recognition that it is needed a more complex compensation flow than just a minimum release (Tharme 2003). The most frequently used name of the new type of compensation flow was "environmental flows". Note the plural. Even in the name it is indicated that there is a need for variation in the hydrological regime. An increasing focus on the environment has led to that many countries evaluate several methods to assess EF realizing increasing need for sustainable water management and use of the natural resources.

There exist many definitions of EF summarized by Moore (2004). There exist specific scientific journals and series of conferences which deals with environmental flows as e.g. Ecohydraulics in Trondheim , Norway 1994, and in Madrid 2004; Environmental flows 2002 in Cape Town, South Africa; and Regulated Rivers 10th Int. Symp. in Scotland 2006. Halleraker and Harby (2006) in their review of EF methods define EFs as: *A flow that as far as possible takes care of the entirety and integrity of the ecosystem, the different user interests, and the future resource base in the watercourse.* It is not only a term but a water management tool aimed at preserving species, habitats, livelihood, water use, recreation values, etc. in water courses (King et al 1999). It is important that it is not only a single minimum release that is needed, but a dynamic flow regime that secures the hydrological variability needed to take care of the species and their habitats.

The project is a twinning of experiences from how EF is dealt with in the 110 years old hydropower regulation history of Glomma River in Norway, and which of the Norwegian findings could be used in the only 10 years old, fast evolving regulation scheme in Sesan River in Vietnam/Cambodia. It reviews the international methods of assessing EF, and it addresses the transboundary issues. At the end the report also gives some recommendations on how EF can be assessed, and how it relates to other mitigation measures aimed at reducing the negative impacts of hydropower development.

2. Short Review of international methods for assessing environmental flows

Several international reviews of methods for assessing environmental flows have been given over the last 10 years e.g. Jowet 1997, Dunbar et al 1998, King et al 1999, Tharme 2003, Halleraker and Harby 2006). More than 200 methods are described in the literature. The reviews categorize the methods, and describe briefly the most important of them, but have to a minor extent evaluated the usefulness of the results from the different methods in assessing EF in different types of watercourses. Halleraker and Harby (2006) gives advise on which type of method should be used in Norwegian watercourses. Even though Norway is well aware of the existing methods decisions about minimum release is still mainly taken by expert judgements based on baseline studies of rivers (Halleraker and Harby 2006). Countries with water scarcity, like Australia, South Africa, as well as many states in the USA, has requirements of installing EF in regulated rivers, and advice that the assessment should be done using certain types of methods. In this chapter we will give a short review of the EF methods described on the international market.

2.1 Norwegian practise

In the Norwegian Water Resources Law it is stated that for hydropower projects with a production less than 40 GWh/year (Concession free) the minimum flow downstream of the withdrawal point should be at least "normal low flow". Normal low flow is a special Norwegian term which is not used by any other country, and equals around 10 % of average annual flow, or slightly less. It is defined in the following way: If you have 10 years of daily flow measurements, arrange the data for each year with rising flows. Take away the 15 days with lowest flows for each year and arrange then the Q_{16} for each year in a rising manner. Take away the 3 lowest values (30 %) of these, and the value that follows is defined as "the normal low flow". Q_{16} equals 96-percentilen, so the normal low flow is a little less than that. This is required only in the small projects that do not need a concession.

For the bigger HPP projects, which need a concession (above 40 GWh/year), minimum flows should be assessed in each case. It is not given any lower limit for this minimum flow, and there is not given any method for how it should be estimated. Normally, <u>the decision on compensation flow is taken by expert judgements based on baseline studies on environmental conditions in the watercourse</u> (Halleraker and Harby 2006). There is only given technical requirements, e.g. when and how large the minimum release should be. Up to now, there is not given any environmental quality standards that the hydropower company should comply with. It is not given any requirements to the number of experts that should be involved in the assessment, or to their competence. It is very seldom that there is used any clear method that can quantify the relationship between the hydrological changes and the environmental impacts (Halleraker and Harby 2006).

2.2 Internationally described methods

Internationally, more than 200 methods to assess environmental flows in regulated rivers are described (Tharme 2003, Halleraker and Harby 2006). It will be impossible to go through all these one by one, so they have to be treated group-wise in some manner. We chose a grouping applied by several earlier reviewers (Halleraker end Harby 2006, Jowet 1997, Dunbar et al 1998, Tharme 2003, Scruton et al 2005).

1. Hydrological methods
   - Hydrological reference table method
   - Identification of central hydrological events
2. Hydraulic methods
3. Functional connections between physical alterations and river biology
4. Holistic methods
5. Hybrid model framework

Each of the groups will have methods that involve both mathematical model simulations and subjective evaluations based on expert judgements.

2.2.1 Hydrological methods

It is the hydrological change in the regulated river that is the primary driver for the environmental impacts. The principle for most of these methods is to find an acceptable minimum flow given as a percentage of the natural flow, most often as a percentage of mean annual flow. To be able to assess this you need to have daily flow measurements over several years. If such don't exist, it is possible to calculate such via modelling, or by proportional scaling from a near by situated river which have measurements.

In France, for example it is stated in the French Water Law from 1992 that at least 1/40 of the natural flow shall be in the river at all times. After 2002 the required flow has been increased to 1/10 (Sabaton 2002). In England Q_{95} is used, i.e. minimum release should be larger than the flow that is exceeded 95 % of the time. In Norway there is a general requirement of a minimum release of at least "normal low flow" (se chapter 2.1 for explanation). In most countries this minimum release is too small to support a sustainable fish production.

Some of these methods, like the Tenant method (USA) are based on statistical connections between fish stock and minimum flow in a large number of regulated rivers (Tennant 1976). The Tennant Method have recognised that if good fish productivity is the goal, then a minimum release has to be approximately 35 % of average flow. Very seldom a minimum flow is set that high, due to significantly loss of hydropower production. For example the Norwegian "normal low flow" will by the Tennant method give a fish status categorized as between Poor and Severe degradation. A refinement of the Tennant method which gives recommendations for monthly minimum release is known as the Texas method (Halleraker and Harby 2006).

In Northern Spain there is developed a method called the Basque-method which aims at protection of bottom dwelling animals. It is based on empirical connections between the number of benthos species and wet perimeter and flow. They have constructed a reference table over minimum releases which secure at least 15 benthic species will be back (Dunbar et al 1998, Garcia de Jalon 2003).

The hydrological reference table methods are easy to use, and can be used as a first step towards assessment of EF. However, they have to be calibrated to each river as there might be some specific events (like e.g. fish migration) that have to be taken care of (Acreman and Dunbar 2004).

Richter et al (1997) elaborated a method based on a well accepted theory that hydrological variation is an important ecological factor in rivers. The method is called the IHV-method (Indicators of Hydrological Variability). To preserve the local biodiversity in a regulated river, the water flow regime should not deviate much from the natural with respect to flow size, variations, frequency of extremes, timing, and velocity of changes. IHV is a quick, but comprehensive statistical method that gives a detailed description of hydrological variability in several regions in a representative way (Olden & Poff 2003). It does not come out with a certain flow regime, but it visualise the variability in a river and gives indications of special events which should be taken into account when EF is assessed (Aarbakk 2008). For Norwegian rivers, Halleraker and Harby (2006) recommend that at least monthly mean, and 7-day minimum and maximum should be presented together with annual mean flow, as a basis for evaluation of EF in regulated rivers.

2.2.2 Hydraulic methods

This group of methods was popular in the 1970ies. They describe via models how different flows impact the area of water covered river bottom, water velocity, sedimentation and erosion, etc. (Halleraker and Harby 2006). The hydraulic methods give more detailed and local information on how a regulation will impact the physical environment than the hydrological methods can give (King et al 1999). Gippel & Stewardson (1988), however, still find it difficult to propose an EF based only on hydraulic methods, but they address that the connection between water covered bottom area and wetted perimeter should be included in a good EF assessment. It is anticipated that there is a good connection between the hydraulic variability and the biodiversity in the water course (Kyläkorpi et al 2005). However, this connection is not studied in these methods.

2.2.3 Functional connections between physical alterations and river biology

The hydrological and hydraulic methods do not include any functional connection between the physical changes and the preferences by local biology. Such studies include habitat requirements of different species, temperature preferences, water velocity, growth relationships, etc. As the impact on the biology by physical alterations can be studied and quantified, these data can be put into predictive models which can describe how a certain regulation will impact local biology. It can also be simulated how the negative impacts can be reduced by altering the hydrology (Halleraker and Harby 2006). In Norwegian regulations it is likely that fish growth downstream dams could be increased by withdrawing surface water in the summer instead of cold deep water (Tjomsland 2004, Halleraker et al 2006). The American model framework IFIM (see chapter 2.2.3) has several sub-models for estimating temperature as e.g. SNTEMP and QUAL-2E (Bovee et al 1998).

The large fish migrations in Sesan River are often triggered by the increased flow in the start of the rainy season (Baird et al 2000). This is a general anticipation (Halleraker and Harby 2006), and in Norway it has been in many regulated rivers given requirements of so called “luring floods” in the salmon migration period. But as this often is release of deepwater from reservoirs, which is cold and clear, it has often small effect (Thorstad et al 2003). Bergan et al (2003) found that temperature and time of the day, not only water flow, was important to trigger migration. Natural flow increases bring also terrestrial debris and erosion products into the water (turbid and “good” smelling) which is not the case with luring releases from reservoirs, and it seems like the conditions for optimal migration triggering is a complex task (Halleraker and Harby 2006). However, predictive models based on water flow and temperature has given high degree of explanation for the outward migration of young salmon from the regulated River Orkla in Norway (Hvidsten et al 2004). As the fish’s preferences for different physical conditions are better known, these can be built in models to simulate the optimum conditions for migration.

Another problem confined with peaking el-production is the quick water level fluctuations. These cause fish and other organisms to be caught on dry land (stranding) during the water withdrawal phase. In Norwegian rivers it has been shown that if the water level is falling more that 10-15 cm per hour young fish will be lost in considerable amounts (salmonids) and will die due to stranding (Saltveit et al 2001, Halleraker et al 2003). The knowledge about the effects of rapid water level variations can be built in hydraulic models (like e.g. the American model HEC-RAS), which is a useful tool to calculate fish mortality due to stranding at different operation strategies of the power plants.

Habitat modelling is a type of models that combines hydraulic models with the preferences of different biology groups for certain physical parameters, like depth, water velocity, temperature, substrate conditions, refuge, etc. The hydraulic model describes the connection between water flow and these parameters, and it combines with the preference functions (curves) of the different biological groups for the same parameters (Harby et al 2005). Habitat simulation models are most applied where it is focus on a key species of fish, but is also applied for large groups like bottom animals (Harby and Halleraker 2006, Jowett & Richardson 1990, Fjellheim 1994). There are several such models available for conducting habitat modelling. The report COST Action 626 within European Aquatic Modelling Network (Harby et al 2005) gives an overview and a description of the most important of these, with reference to where they are use and from where they can be purchased. The overview in Table 2-1 is taken From Halleraker and Harby (2006).

Table 2-1. Habitat hydraulic models for predictive modelling of quantitative impacts on key species as a result of changed water flow (From Halleraker and Harby 2006)

Navn (Forkortelse)	*Beskrivelse*	*Referanse(r)*
PHABSIM (Physical HABitat SIMulation system)	*The original physical microhabitat simulation model for use within the IFIM framework*	*Bovee (1982)*
RHABSIM (Riverine HABitat SIMulation)	*A commercial software program incorporating the PHABSIM*	*Payne (1994)*
RYHABSIM (River hYdraulic and HABitat SIMulation)	*A microhabitat based model for New Zealand, similar to PHABSIM*	*Jowett (1989)*
EVHA (EValuation de HAbitat)	*A French microhabitat based model, similar to PHABSIM*	*Ginot (1995)*
RSS (River System Simulator)	*A Norwegian microhabitat model (HABITAT) contained within a riverine modeling framework*	*Alfredsen and Killingtveit (1996); Killingtveit and Harby (1994)*
CASIMIR (Computer Aided SIMulation of habitat In Regulated streams)	*A German simulation model based also on shear stress for hydroelectric development impact assessment*	*(Jorde 1996)*
HABIOSIM/HYDREAU FRC (Fish Rule Curve)	*Canadian microhabitat modeling system incorporating PHABSIM and habitat time series analyses*	*Lafleur and LeClerc (1997); Locke (1996)*
RCHARC (Riverine Community Habitat Assessment and Restoration Concept)	*A modeling system comparing the habitat hydraulic conditions between a reference situation and alternatives.*	*Nestler et al. (1996)*
RIV2D	2-D ice-free and ice-covered hydrodynamic modeling of riverine habitat in the Canadian Prairies	http://www.river2d.ualberta.ca/, *Stickler et al. (2003)*

Full scale habitat modelling is very laborious and costly, and the use is therefore relatively restricted. Cemagref (Institute for agricultural and environmental engineering research) in France has therefore developed simplified habitat modelling via statistical methods (Halleraker and Harby 2006). Statistical hydraulic modelling is less work intensive than traditional habitat modelling, e.g. through application of the model Stathab from Lamouroux et al (1998). Stathab generates the distribution of the hydraulic conditions in a set of water flows, and can be combined by traditional preference curves. A further development of Stathab (Estimhab) can also model habitat quality (Lamouroux and Chapra 2002).

2.2.4 Holistic methods

The concept is a structured evaluation of composite expert judgements, where experts from different disciplines work together in interdisciplinary workshops. There exists at least 16 such method (Tharme 2003). So far the methods have got popular only in Australia and South Africa (Halleraker and Harby 2006), but it is recommended to be further developed and adapted to British conditions by Dunbar et al (1998).

The most famous of the holistic methods is the BBM-Method (Building Block Method, King et al 1999) from South Africa. BBM aims at including the flow needs for all components in a river ecosystem. It can also include the flow needs by the water use interests (King et al 1999). The method gives flow recommendations for each month as a result of adding building blocks to take care of the flow needs. An expert panel representing different aspects of the river ecosystem, as well as different user interests, exchange wishes of water flow. Much of the work is performed in workshops. All important components get a water flow wish. It is necessary to have good baseline studies to base the flow wishes on. The method is flexible and can utilise both mathematical simulations and expert judgement. The BBM-method has a detailed manual (King et al 2000). The method is used as a routine in South Africa to secure that water abstractions and regulations are following the South African water Law from 1998 (Acreman and Dunbar 2004).

In Australia several holistic methods are used. These are based on compilation of expert judgements made in working groups, without real quantitative evaluations. The recommendation for environmental flows comes after consensus in the expert group.

In Norway expert judgement is the dominating method to assess environmental flows in regulated rivers. There is, however, not adopted any standardised and structured methodology. Nor, is it any fixed requirement which type of experts should be involved, and the number of experts. In old regulations it was normally only a couple of experts involved, a fish expert and sometimes one from the timber floating activity.

2.2.5 Hybrid model frameworks

This group of methods consist of model frameworks that link the former 4 categories together. The models can be used in estimating environmental impacts of different regulation manoeuvring rules, e.g. the impacts on water quality, the impacts on fish, etc.

The RiverSmart (Egger et al 2005) is such a model framework which aims at finding the relative contribution of improvement by different mitigation measures, as biotope adjustments, habitat improvements, changes in water flow regime, etc. The RiverSmart model framework is suitable for optimising water management plans where also hydropower economy is included (Halleraker and Harby 2006).

The River System Simulator (RSS) is a Norwegian package of model software, based on several numerical simulation models. It was constructed to assess impacts of different water flow scenarios on economical, physical, chemical, biological, and recreational conditions in regulated rivers (Halleraker and Harby 2006). The RSS contains models for hydrology, hydropower production, water chemistry, erosion, sediment transport, water temperature, ice conditions, ground water, fish habitat, fish growth, bathing, paddling and other recreation use. The sub-models describing hydraulic conditions, fish habitat, and fish growth are those who are applied mostly (Harby et al 1994). The full potential of the RSS is not used in any large scale (Halleraker and Harby 2006).

The model concept IFIM (Instream Flow Incremental Methodology) was developed during the 1970-1980ies (Bovee 1986, Stalnaker et al 1995, Bovee et al 1998) in USA. This is a multidisciplinary model framework aimed at decision making in connection with river regulation and water management. It is much used in USA. Many of the sub-models can be downloaded free from the Internet (http://fort.usgs.gov/products/software/ifim/ifim.asp). US Geological Survey offers training courses in the use of IFIM. Those who have developed the IFIM stress that using the model framework is a process, consisting of many phases and sub-models (Stalnaker et al 1995). This is one of the most comprehensive model framework used in assessing Environmental Flows (Halleraker and Harby 2006). It is however, more suitable for protecting a few key species than for preserving biodiversity such as the holistic methods aim at (Bovee et al 1998).

3. Other measures than EF to mitigate negative environmental impacts of hydropower regulation

The Environmental flow is only one out of many measures that can be taken to reduce the negative environmental impacts on a river by hydropower development. These other methods are not part of the STRIVER project, but since they form important part of the integrated water resources management planning (IWRM) in regulated rivers, we find it important to give a short brief of these. This will also facilitate the understanding of the term EF and put it in its' correct perspective. Environmental flow is one of the most important measures and is often established together with other measures. It is normal to divide these measures into two groups:

- Mitigation measures in the construction phase
- Mitigation measures in the operational phase

3.1 Mitigation measures during the construction phase

3.1.1 Measures against erosion

Roads and road sides
Digging out roads in the steep valley sides in soft soils leaves large areas of denuded soils open for rain and water erosion. This problem applies to the inner side of the roads with the drain ditch, as well as the road itself, and the outward facing road fill. Even for temporary roads this will create wounds in the terrain that will slide and erode for tens of years if no stabilisation is done.

Recommended actions
The construction of roads should begin at the onset of the dry season with the excavating and earth moving activities. Before the wet season sets in the road sides should have been sowed by a convenient grass type. In particular erosion prone areas the grass should be sowed in degradable screen/net which is efficient in establishing stabile road sides. The sowing is most easily performed by spraying out glue-treated seeds. Ideally the grass should have sprouted before the wet season sets in.

The road ditch should be lined with stones in erosion prone areas. The water in the road ditch should be released into existing brooks/streams. The road ditch should be released as often as possible, i.e. wherever there is a natural brook/flood brook. Road ditch outlets should not be allowed to be discharged into the valley sides in places where there has been no waterway before. If this is necessary in some places, relevant enforcement should be made to prevent erosion.

The permanent roads should be paved as soon as possible after the construction.

Parking lots, camp areas and construction sites
The same erosion preventing actions as given for roads is recommended for this kind of areas.

3.1.2 Runoff from tunnel blasting and tunnel drilling

The water from the tunnel excavation, either it be by blasting or full profile drilling, should pass a sedimentation pond prior to be discharged into the river. The fine, newly formed particles by drilling, grinding, etc. has sharp edges that can damage the gills of freshwater organisms. If the tunnel is blasted, the use of ammonia-nitrate as blasting material creates large amounts of ammonium in the runoff. If at the same time, the tunnel is sealed and tightened by use of concrete (particularly the spray type of concrete), the runoff can contain high amount of free ammonia, which may lead to fish kill in periods of low flow.

In the low flow period, the sedimentation pond should be monitored with respect to ammonium, free ammonia, and pH. If necessary, pH should be adjusted to neutrality before discharge into the river. In the wet season, the ammonia discharge will not be big enough to harm the river biota.

3.1.3 Soil deposits and spoil rock deposits

In the first period after a major tunnel and hydropower construction work the spoil rock deposit is normally used for construction purposes, filling material for road construction, quarries, etc. After some years they are abandoned, and should be terminated in a proper way.

To prevent impact on water environment, the location is important, the water handling is important, and the final termination is important.

Location and water handling
These deposits should not be placed in too steep terrain. The best would be to locate them to natural depression with infiltration outlet. Such depressions are, however, not always easy to find in the vicinity of the construction area.

The second best would be to place the spoil rock deposit in a flat area with little runoff (i.e. upstream catchment) and good infiltration capacities (sandy soils).

If they are placed in a valley-like depression, incoming water should be drained through by a pipeline of the necessary capacity to safely by-pass storm flows. Downstream of the deposits there should be constructed a sedimentation pond to settle out as much as possible of the eroded particles. The drainage from areas upstream of the deposit should be by-passed the sedimentation basin. If possible the runoff from the spoil rock deposit should be infiltrated in the terrain.

Runoff from blasted tunnel material should be controlled with respect to content of nitrogen and particularly ammonia and pH. Water with high concentration of ammonia and high pH can cause fish kills in periods of low flow. In such cases the pH in the sedimentation pond should be adjusted to neutrality before discharge.

Final termination of the spoil rock deposit
When there is no more interest for using the spoil rock deposit it should be levelled and formed into nature-looking terrain and covered by vegetation. In material from full profile tunnel drilling it can often be sowed and planted directly, while material from blasted tunnels must be covered by fertile top soil first.

It is best first to establish some kind of grass cover, and after a while wild bush and trees will establish by them self.

3.1.4 Sanitary effluents from the construction workers camp

During the construction phase there will be large activity centres at the different construction sites. These will partly be residential camps for construction workers, and partly administration, workshops, machine parks etc. From these sites there has to be built sanitary systems with no direct discharge to the river. Preferentially, the camps should be placed in areas where there is good infiltration capacity in the ground. In such areas standard pit latrines may serve the intention of preventing hygienic pollution of entering the river.

If suitable infiltration soils cannot be found, toilet water (black water) and wash water (grey water) should be separated. Toilet water should be collected in watertight tanks and infiltrated at a safe place.

The grey water can be infiltrated in the terrain.

An alternative is to have mobile latrines of the type that are used in the military service, and at large sports arrangements. These can be emptied every day/every second day at the sewage system of the nearest town, or at a safe infiltration site.

3.1.5 Oil and chemical spill

The construction work will need a large park of machinery like, trucks, tractors, excavators, bulldozers, drilling machines, cars, etc. These will need diesel and gasoline, motor oil, hydraulic oil, cooling liquid, battery acids, etc. There has to be established storage places of such chemicals, filling places, workshops, etc.

It is important to secure that such compounds are not allowed to enter the river.

The storage and fuel filling should take place on paved area, which is water-tightly drained to a collecting tank in case of accident spills. The workshop floor should be drained to a collecting tank from where the content can be removed and given the correct treatment.

The machinery parking area should consist of loose material with infiltration capacity, which can absorb small spills. This means that the area should not only consist of stones and gravel, but also contain sand and silt.

3.1.6 Measures against accidental water releases and dry-ups

A temporary dam (cofferdam) combined with a bypass tunnel is normally constructed to provide dry river construction area for the main dam. The coffer dam should be built so strong that it will withstand all floods, and the by-pass tunnel should have capacity to take all flood sizes known to can occur in the river. This to prevent coffer dam breaks.

The initial filling of the reservoir should be done only in the wet season with bypass of an amount of water at least corresponding to 10-15 % of average annual flow at the dam site. In the dry season, the normal low flow should be allowed to pass the dam. It is important that the river is not allowed dry up at any time.

The functioning of the spillway gates should be tested out properly with respect to both opening and closing before filling the reservoir.

3.2 Mitigation measures during the operation phase

The operation phase is the period after the construction is completed, the initial filling of the reservoirs is finished, everything is tested properly, and the power plant is put into normal operation. The operation phase has a lifespan of 50 – more than 100 years in most hydropower plants.

The change in hydrology is often the main reason for the environmental damage that follows a hydropower development scheme. The aquatic life has over thousands of years adapted to a certain hydrological regime which is relatively predictable from year to year. In the summer the monsoon rain is causing the Sesan Rivers to swell, which again triggers the spawning migration of hundreds of fish species. The floodplains are flooded and the farmers are planting their rice in the paddy fields. In November-December the water levels goes down in the onset of the dry season. Fish migrate back to the larger rivers, the farmers harvest the rice, etc. Every year, approximately the same cycle is repeated, with a few deviating years now and then. These deviating years are also important to prevent certain organism to develop too strong and dominating populations.

The hydropower schemes interrupt this normal hydrological cycle that both the aquatic life and the human use have adapted according to. The dams, and any dry stretches, break the ecological continuum of the river, and prevent fish of reaching their spawning grounds, feeding grounds, nursery areas, etc. The changes in hydrology often bring increased erosion activity, which gives water quality problems, siltation problems, and sedimentation problems.

3.2.1 Using the Sesan 4a as a deregulating reservoir for levelling out diurnal flow variations.

Several hydropower plants are planned in Sesan River with the aim of supplying the society with electricity. Realizing that one cannot store electricity, the production of power has to follow the need in the society. This implies that the flow will vary over the diurnal cycle, with high flow during daytime and low flow during night time. This variation creates a lot of erosion based problems.

The most efficient way of reducing these impacts is to use the Sesan 4a reservoir to level out the diurnal variations. The flow out of Sesan 4a should be tried to be kept as equal to natural flow as possible.

3.2.2 Prolong the wet season filling of the reservoirs

This will be particularly important for the large reservoirs. The timing of the onset of the high flow season is important both for fish migration and for the filling of the rice paddies, and fish spawning wetlands along the Cambodian Sesan River. To allow the initial flows and water level rise in a normal manner will increase the time used to fill the reservoirs, but not to a large extent. To have the flooding as early as possible, is also important to allow for necessary time for fish egg and larvae development as well as ripening of the rice crop.

3.2.3 Reduce the nutrient inputs to the reservoirs

Reservoirs that receive runoff from cities and agricultural areas are prone to be eutrophic lakes, which can give rise to blue green algal problems, both in the reservoir and downstream. Such problems can be mitigated by collecting the sewage water and build treatment plants with phosphorus removal before the effluent water is discharged the rivers. Agricultural runoff should also be controlled, particularly if there are some large scale animal husbandries like piggeries etc. In the Glomma catchment all reservoirs have reduced the nutrient input to below the stage of blue-green algae formation by building effluent treatment plants from sanitary and industrial effluents. In Sesan River there have been suspicions that toxic algae were produced in Yali reservoir the first years after the regulation which followed the water to downstream areas (Fisheries Office 2000). The SWECO (2007) study found *Microcystis spp* in Yali reservoir and small amounts of the algal toxin microcystin, but not in high enough concentrations to give problems for drinking. In a master thesis student work under the STRIVER project it was also found *Microcystis spp* and the algal toxin microcystin in small concentrations in the Cambodian Sesan River in March 2008 (Tiodolf in prep). *Microcystis spp* is not a river species and it is believed to come from the reservoirs. Nutrient controlling measures at Kon Tum Town and Pleiku Town will reduce the algal growth in the reservoirs.

3.2.4 Minimum releases in low flow stretches

Covered by the EF term, and not described further here.

3.2.5 Water level fluctuations in the reservoirs

Not covered by the term EF in international assessment methods or definitions, but proposed included in the STRIVER approach to EF, and will be treated later. Not described further here.

3.2.6 Fish bypass systems

Most dams in the Glomma Rivers are equipped with fish bypass canals, see Figure 14-1. This prevents the dams from being fish migration barriers. Even though the migration is less efficient as before, it has shown to be an important measure to protect the biodiversity in the river.

Such systems are of three types:

- Canals
- Ladders
- Lifts

Which systems will be best fitted in Vietnam/Cambodia, needs to be considered very carefully with expertise on the fish species present.

3.2.7 Fish stocking programmes

If the regulation after some years prove to have reduced the biomass of particularly important fish species, for example by destroying their reproduction success, it should be considered if it could be possible to replace the loss by fish stocking programmes. This is being done many places in the Glomma River with respect to the most important species, the trout *(Salmo trutta)*, see Figure 3-1. One and two year old fishes are used. Other fish species, however, have got little attention in this respect.

3.2.8 Development programme for aquaculture

The regulation scheme in Vietnam has resulted in considerable loss of fish in the Cambodian part of Sesan River (SWECO 2007, Fishery Office 2000, Baird and Mean, 2005). This is a problem for the protein supply for the local residents along the river. This loss can be compensated by development of aquaculture along the rivers. As there is very little tradition for aquaculture in this region of Cambodia, one need to go through a development program aimed at low cost production in simple pond system, or floating cage systems. Only local species should be utilized in principle. Experience shows that it is necessary to establish a stable delivery of young stocking fish from regional hatcheries.

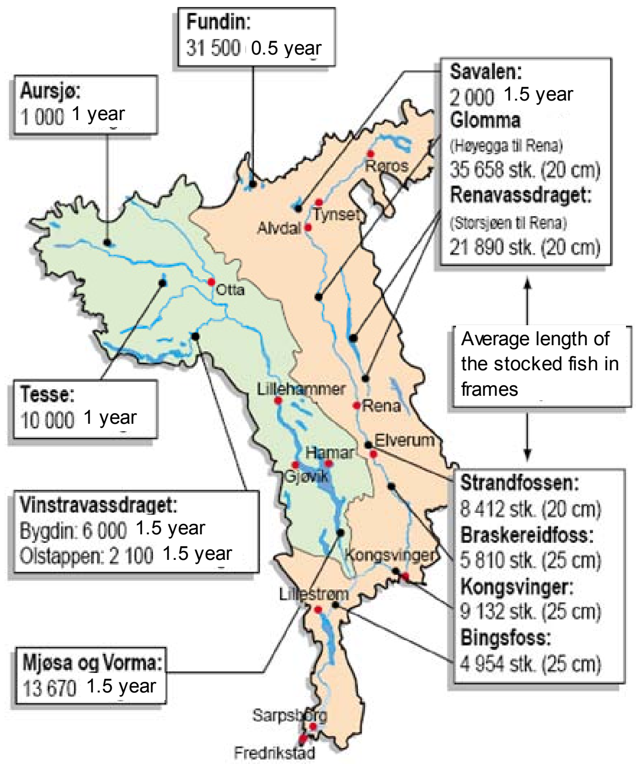


Figure 3-1 Fish stocking programme in River Glomma is compensating for lost spawning conditions due to the hydropower regulations. Numbers are annual stockings of 1-3 years old fish (www.GLB.no).

3.3 Socio-economic measures

In addition to the measures aiming at mitigate ecological conditions in the river, there are several socio economic measures that can be taken. The most important of these are the

Resettlement and compensation programme.
Health measures
School and training programmes
Safe drinking water supply
Etc....

As WP8 focus on Environmental flows, we will not go into detail about pure socio economical mitigation measures here. However, many of the people living along rivers in developing countries are subsiding from ecosystem services, as e.g. a viable fish population, and the measures aimed at mitigating environmental impacts will also help preserving livelihood.

4. The different types of regulations and different river stretches

There are many types of hydropower regulations in a water course which impact the environment in different ways and with different severity. Likewise, different river stretches are impacted in different ways. In Figure 4-1 some of the most common situations are illustrated. In the following they will be given short comments about impacts. Impacts can be reduced by abatement measures, but that is not included in the comments. I.e. the impacts are described as no mitigation measures are taken.

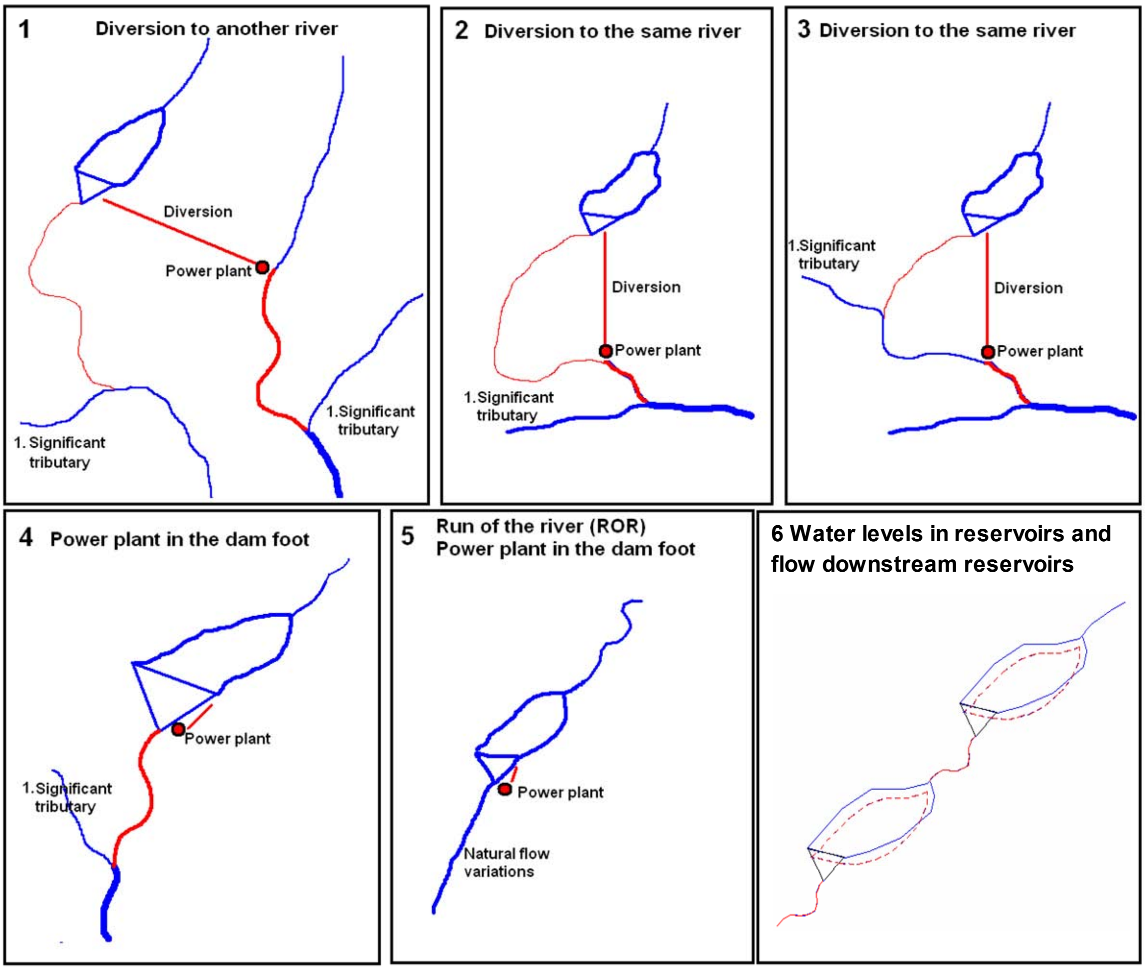


Figure 4-1 Different types of regulations and different river stretches impacted by a hydropower regulation.

Most projects that include a dam, result in migration barriers for fish and other migratory organisms. However, if the dam is built on top of a fall which was a migration barrier also before the regulation, the project does not impose a new migration barrier. The Yali Regulation in Vietnam did not introduce a migration barrier. The regulations in Sarpsfossen in lower Glomma has not introduced migration barriers, as that falls were barrier in its unregulated form. Glomma has never been a salmon river. For some fish species it is possible to construct bypass canals, or ladders, if the dam height is moderate.

Panel 1 in Figure 4-1 shows a river that is dammed and diverted to another river. This is a big encroachment for both the diverted river and the recipient river, and can potentially give large environmental problems in both rivers. The river stretch from the dam down to the first significant tributary will be completely dry. Introduction of some minimum release, or better an environmentally motivated EF, will be the most efficient abatement measure for this stretch. Downstream of the entrance of the first significant tributary the damage is less.

If the receiving river is small, the outlet from the power plant (often called the tailrace) will create large erosion problems, particularly if the power plant is run in an intermittent manner (often called peaking production). In Norway, several power plants discharge the tailrace water directly into a lake or a fjord. This gives less downstream impacts than when discharging to a river.

This type of transfer of water to another river can also result in spreading of unwanted organisms to the recipient river.

Panel 2 shows a river that is dammed, it is built a large reservoir with storage capacity, and the water is diverted to a power plant situated at a lower elevated site further down in the same river. As in the former, the stretch from the dam and down to the first significant tributary, the aquatic ecosystem will be destroyed if no water is released from the dam. However, here the recipient river is the same, and sized for the flow, and there will be no problems with transfer of unwanted organisms. The problems with intermittent flow will, however, still exist.

Panel 3 is of the same type as 2, with the difference that significant tributaries enter just downstream the dam. The dry stretch will thus be shorter and the impacts less.

Panel 4. The river is dammed to create head as well as storage reservoir. The power plant, however, is situated in the dam foot, and there will be no dry stretch during normal operation. However, during intermittent operation, the river will dry up between stop and start of the turbines.

Panel 5 shows a run of the river (ROR) project. Here there is only built a small intake dam to get a steady head as well as prevent the formation of air pockets in the pressure shafts disturbing the turbines. There is no storage capacity. The ROR projects do not alter the river flow, and is the most environmentally friendly regulation type. The only impact being the migration barrier.

Panel 7 illustrates water level fluctuations in the reservoir. The flows can also be used to optimise these variations environmentally. A reservoir with moderate water level fluctuations (5 m or less) can have higher fish productivity than the former river stretch, but a reservoir with water level variations more than 10 m can seldom have good fish productivity in the long run.

5. River stretches where Environmental Flow should be included

So far, minimum release, EF is used for river stretches downstream the dam, or diversion point, where the river otherwise would have been dry, see the red stretches downstream the dams in Figure 4-1. But, it is the changed hydrology that are the primary cause of the environmental impacts in all other reaches of a regulated rivers as well. The following river stretches should have been evaluated with respect to EF.

- A river stretch where water is diverted to a power plant in another river – gives a long low flow stretch.
- A river stretch where the water is diverted to a power plant situated further down in the same river – gives most often a short low flow stretch.
- The river stretches downstream the dam in periods of filling the dam, or periods when the power plant is turned off.
- The first stretch downstream of the tailrace entrance in case of peaking power production , particularly if the receiving river is small
- Water levels in reservoirs should also be included in the environmental flow term

6. Stakeholder involvement in the assessment of Environmental Flow

The environmental flow shall take care of the 3 main items:

1. The ecological values in the river (achieve good ecological potential)
2. The water use interest (try to fulfil the needs for water level and water flows for a wide spectre of water use)
3. Not create un-proportional large disadvantages for the regulation purpose

The stakeholders involved should be a combination of local river users and professional experts, as well as regional and local water authorities. Depending on the size of the project the following type of persons should be consulted in the process of assessing EF. It should be noted that EF is only part of the EIA tasks in a hydropower development, as e.g. transmission lines, switchyards, dams, power plant, access roads, etc. The list of stakeholders is therefore often longer in a full EIA.

<u>Professional experts</u>
- Fish biologist
- Freshwater ecologist with skills both in primary producers and secondary producers
- Ecologist with knowledge about the riparian ecology
- Health and sanitary expert
- Hydrologist
- Environmental economist

- Socio economist
- Hydropower experts

Water users

- Local fishermen
- Boaters
- Farmers (irrigation, watering of animals, flood control)
- Water based tourism
- Water supply
- Recipient use

Water authorities

- Environmental authorities (local and regional, in large projects also central)
- Water use authorities (e.g. sanitary engineer, and health personnel from the local municipalities)
- Energy authorities (regional and central)

The process of assessing the EF should be transparent, quantifiable and replicable. Important background for their work is the baseline studies from the river as well as the environmental impact assessment, see next chapter.

7. Baseline studies and EIAs

It is important to have good background data as a basis for the Environmental Flow evaluations. There are two types of studies that should be available before the environmental flow work should be performed, namely:

1. Baseline studies (the conditions prior to the regulation)
2. EIA – Environmental Impact Assessment

Both the baseline studies and the EIA should cover the following items

Hydrology[2]
Water quality and erosion
Aquatic ecology including fish and fishery
Riparian ecology
Water use and socioeconomic aspects

The baseline study should cover the annual cycle so all sides of the biological function of the river system should be understood, e.g. spawning areas should be detected and described, migration periods, nursery areas, primary production, benthic animals, importance of flooded forest, etc. One of the problems with respect to hydropower development in developing countries is that there exist no baseline studies (or very restricted) fro the situation prior to the regulation, so this is included in the EIA. Normally, this allows only for a very restricted sampling and gathering of baseline information.

The EIA will use the baseline studies and the plans for the hydropower development as a basis for estimating the impacts of the encroachments, on the aquatic and riparian ecology, on river use, on livelihood for the local residents, etc. Most of the impacts will be negative, but a few will be positive. The changes in hydrology are the main factor for the impacts, so it is very important that this is clearly described, both with respect to damming, water level fluctuations, the operation mode of the power plants, diversions, etc.

In addition to describe the impacts, the EIA shall describe abatement measures that can be taken to reduce the negative impacts. One of these measures is the Environmental Flow, but there are many other measures. To estimate how much the different abatement measures reduce the negative impacts is important. Where to implement EF and how big, should be evaluated together with the other abatement measures.

The two most typical problems in a hydropower EIA is that there are not done baseline studies, and that the hydropower company have not taken the final decisions concerning the operation mode of the power plant. This mode is important for the downstream water flow, and the water level fluctuation in the reservoir.

[2] The hydrology is often studied as part of the hydropower planning, and much of the need for hydrological data can be obtained from that work.

8. Description of the Twinning river basins Glomma and Sesan

Before we start treating the application and methods for introducing Environmental flow in the hydropower impacted stretches of the two rivers, it will be instructive to have a short description of the two river basins.

8.1 Glomma River – physical characteristics

The Glomma River is Norway's largest river. It is located in South Eastern Norway where it covers 41200 km^2. This equals 13 % of Norway's total area. The river basin is shown in Figure 8-1.

Figure 8-1. Glomma River Basin in SE-Norway (From GLB Annual Report; www.glb.no)

The river basin is 600 km long from north to south. The north-western parts consist of high mountain areas (Jotunheimen area with Norway's highest peak: Gallhøpiggen (2468 m.a.s.l.), Rondane and Dovre). 30 % of the catchment is located at elevation above 1000 m.a.s.l, and 40 % between 500 m and 1000 m. The eastern part is covered by forest areas, whereas the central and southern parts comprise large agricultural areas. In total the agricultural areas cover 2400 km^2 and constitute 5.8 % of the total catchment, see Figure 8-2.

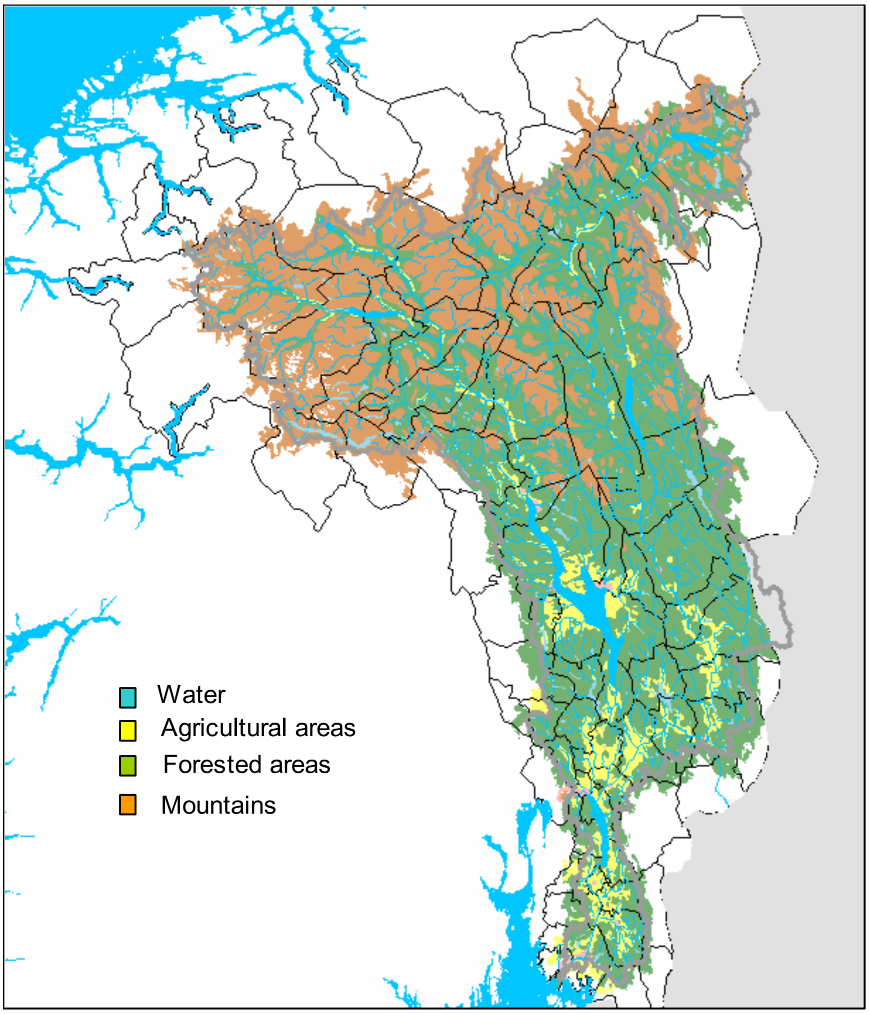


Figure 8-2 Land types in the Glomma River catchment

A large side-branch is entering into River Glomma between Lake Mjøsa and Lake Øyeren, see Figure 8-1. This branch is often referred to as the Laagen Watercourse. It contains Norway's largest lake, Lake Mjøsa, which has a surface area of 350 km^2, and a maximum depth of 450 m.

The total discharge from River Glomma is 22x10^9 m^3/y, and the mean annual flow is 700 m^3/s at Solbergfoss (outlet of Lake Øyeren, the lowermost reservoir, see Figure 8-1). The flow varies over the year from 150 to 3500 m^3/s.

Observed annual precipitation ranges from the driest areas in Norway (North Gudbrand Valley) with 260 mm/y to mountain areas with 1050 mm/y.

At the entrance of Lake Øyeren, River Glomma forms Northern Europe's larges inland river delta, The Northern Øyeren Nature Reserve (Figure 8-3), which is regarded as an extremely important wetland for migratory water fowl (Ramsar Site).

Figure 8-3. The delta in the inlet in Lake Øyeren, The Northern Øyeren Nature Reserve

8.2 Description of socio-economic and political issues

The river Glomma catchment comprises approximately 675000 inhabitants. There are 8 cities, in which half of the population lives. The others live along the rivers in rural areas and in villages. The mountains and remote forested areas are virtually uninhabited.

Hydropower production is an important water use. In the Glomma catchment there are 56 hydropower stations and 26 hydropower reservoirs, see Figure 10-1. The coordination of the manoeuvring of the regulations is taken care by an association (GLB) among the owners of the different hydropower stations. The GLB has for the time being 18 power companies as members. The GLB performs several water management responsibilities in the catchment, among others to secure that the concession conditions with respect to minimum flow in rivers and water levels in reservoirs are not violated. The GLB association was established in 1918. The GLB is also running the hydrological gauging stations in the catchment (water flows and water levels).

Over the last 30 years, particularly in the uppermost part of the catchment, an increasingly larger part of the revenues are created by tourism related activities. This comprises both winter sports like alpine and cross country skiing, as summer activities like hiking, hunting and sports fishing. New Hotels, ski resorts, and farm-tourist centres are popping up. This applies both for cities and country side. These activities need clean and undisturbed nature to be attractive, which causes a great challenge for the hydropower sector, for the municipal waste treatment, as well as industrial discharge management.

On the country side, agriculture activities are still important. The Norwegian farms are small and the agriculture is heavily subsidised. This makes it possible to maintain a relatively large population in rural areas with service centres (villages) serving the farmland populations.

The local population has at all times used the rich fisheries in many of the lakes and rivers for recreational fishing as well as for food. The regulation and the pollution discharges have created problems for these activities. Large amounts of money have been invested in abating the eutrophication of the Lake Mjøsa and Lake Øyeren. This abatement has been successful, but a new pollution problem have arisen, that from environmental toxins entering the food chain, making it risky to consume fish. For example in Lake Mjøsa, resent studies has revealed that the meat of the popular brown trout exceeds the consume standards for brominated flame retardants, a group of compounds used in textile industry. The former important fisheries have stopped due to this, first of all the commercial fisheries, but also sport fishing has declined due to this.

The many regulations has also affected the fisheries negatively many places. The 150 km long river stretch from Høyegga to Rena, where 80% of the water is diverted to Rendalen HPP in the Rendalen Valley, the fish yields are considerably lower than before, see Figure 8-4.

In some of the high mountain lakes the fish productivity is reduced by high water level fluctuations. In the lower parts of the Rena River, which receives the water from the diversion, the increased and more stable flow has caused a great change in the fish diversity. In several stretches the fish and fisheries are good, due to moderate regulation encroachment and efficient abatement measures.

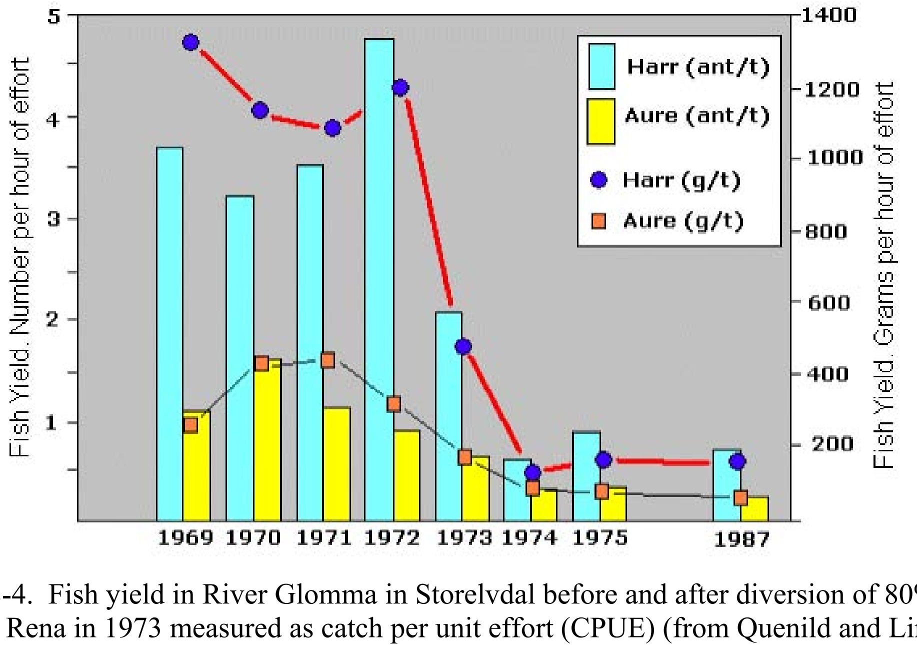


Figure 8-4. Fish yield in River Glomma in Storelvdal before and after diversion of 80% of the water to River Rena in 1973 measured as catch per unit effort (CPUE) (from Quenild and Linløkken 1989).

Several places in the catchment, there have been mining industry, which however, closed down in the 1980-1990ies. The old mines still cause water pollution problems, locally. The problem of ownership of abandoned mines has been, and still are a challenge when it comes to responsibility for abatement actions.

The Glomma River is used as a recipient for municipal and industrial wastewater. Most of these (except from scattered rural population) are now treated in purifications plants before discharges. The pollution situation in the river has improved considerably over the last 25 years. However, there are still many small settlements which don't have efficient effluent treatments. These are polluting the river and are conflicting with the use of the river as drinking water supply. There are several large water works that supply several hundred thousand people with drinking water from River Glomma.

Glomma receives pollution from agriculture, both from diffuse runoff and point sources. All along the river, the agriculture takes irrigation water from the river. However, this use is not so large that it affects the water flow notably.

Boat traffic is important along most part of river Glomma. This is both for fishing (commercial fisheries and for leisure fishing). In some of the high mountain lakes and in Lake Mjøsa, and Lake Øyeren, there is commercial boat transport of tourists in the summer season, see Figure 8-5.

Figure 8-5. The Paddle steamer "Skibladner" is transporting thousands of tourists on Lake Mjøsa every summer. Right panel shows tourist boating in the Northern Øyeren Delta.

Politically the catchment consists of a large number of municipalities, and five counties. Only a few fringes (grey fields to the right in Figure 10-1) belong to Sweden, but these fields are very small and contain no rivers, so with respect to hydropower River Glomma is a one nation river. The municipalities are to a large extent self-ruled when it comes to establish water impacting activities, but they have to comply with certain national standards. The municipal administration executes the decisions of the Municipal Council (elected politicians).

On the county level, there are two types of water related authorities, one (the Fylkeskommunen – the County Commune) is in a way a co-operative organ for the municipalities constituting the county. Each municipality has representatives in the County Council. The administration of the County Council is called the County Commune and is executing the decisions of the County council. They are taking care of the part of the school system, the road and communication, and parts of the health care systems, e.g. the hospitals. They have also some planning responsibilities when it comes to inter municipal and inter-county plans. The County Commune seems to be the coordinating authority with respect to implement the EU-Water Framework Directive.

The other authority on the county level is called Fylkesmannen – or the County Governor. This is the "Extended Arm of the State" and has a controlling function. They control that the national guidelines are followed by the local and regional authorities. Their responsibility comprises pollution and many other water impacts.

Hydropower policy and impacts, is however, not comprised by the control responsibility of the County Governor. These are controlled by a separate directorate (NVE – Norwegian Water and Energy Directorate) under the Ministry of Oil and Energy. The practical management of the many hydropower regulations in the Glomma catchment is performed by the association among the hydropower companies (the GLB), which are responsible for keeping the water flow and water level regulations set by NVE. The GLB has also responsibility for conducting compensation work, like fish stocking programmes, flood protection works, etc.

There has been a privatization wave rolling over the Norwegian Hydropower system the last decade. Particularly the municipalities have sold their power plants to private companies. In earlier days Norway filled up the reservoirs during summer, to prepare for the cold winter. But now the hydropower companies have the goal of earning as much money as possible, independent of the season. As Norway is part of the European electricity grid, and there has been an increasing demand for energy in Europe in the summer for air conditioning, Norway is now exporting electricity to Europe during summer time at good price. Before, summer electricity was very cheep. However, this happens to cause energy shortage in Norway during some winters.

This change has created a need for changing the manoeuvring rules of many regulations. In the new Water Resources Law, there has been set rules for minimum flows for all new regulations. Downstream all dams there shall be a minimum release that equals an old, Norwegian measure called "The Normal Low Flow". This lies in the range of 10% of average annual flow in most rivers. In the old regulations there are no requirements for minimum flow in the concession.

Norway has now decided to implement the EU Water Framework Directive (WFD) as a steering framework for their water management. The goal for the water management in this directive is that all the water bodies shall have good ecological status by 2015. Rivers that are regulated (physically altered) to provide important society goods, e.g. electricity, they can be classified as "Heavily modified water bodies" and thereby get exception from the requirement of good ecological status. The environmental goal for the management of these rivers is called "Good ecological potential". This is not clearly defined yet, but its meaning is something like: With respect to water environment you should make the best out of it within the constraints created by the regulated flow and water level regime. It also seem like the WFD requires a minimum release downstream dams, even though also this is not clearly defined (called the ecological continuum).

8.3 Transboundary issues

Only a few fringes of the Glomma River catchment (grey fields to the right in Figure 10-1) belongs to Sweden, and these fields are very small and contain no rivers, so with respect to environmental flow and Hydropower development River Glomma is a one nation river. However, with respect to pollution transport to the marine areas there has been a conflict with Sweden for many years, see Figure 8-6.

This conflict is for a large part solved after the installing of effluent treatment of the cities of Sarpsborg and Fredrikstad, as well as for the pulp and paper industry of the region. However, still there are some complaints from the recreational areas of coloured and turbid water coming from the north. The remaining pollution is erosion material as well as natural humic material. Most of this brown humic water is coming from the bordering water course, and not from Glomma River. The bordering water course is called the Halden Water Course and contains both a Norwegian branch (Tista River) and a Swedish branch (Eningdalselva River). Both these are heavily brownish stained by natural humic material from forested areas. The pollution issues belong to WP7, and are left out for further treatment in this report.

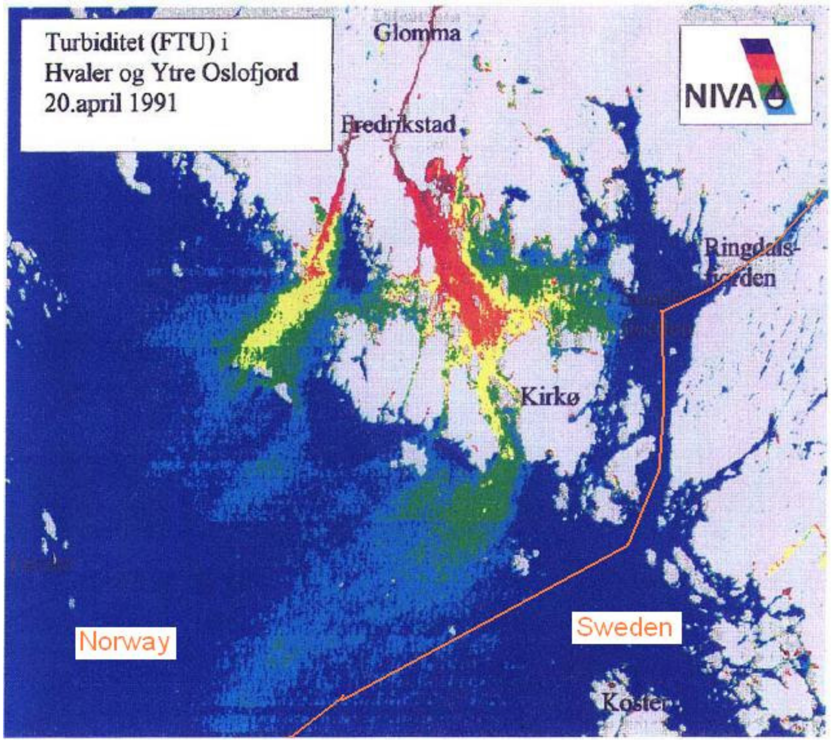


Figure 8-6 The pollution plume from Glomma River is periodically sweeping down to the Swedish coast and caused conflicts to the popular recreational areas of the North Western Swedish coast (Magnusson and Sørensen 1993).

9. Description of Sesan River basin

9.1 Sesan River - physical conditions

Sesan River is one of the largest tributaries of the Mekong River. With its origin in the Central Highlands of Vietnam and the southernmost part of Laos the mighty river flows through mountainous areas in Vietnam's Dak Lak, Gia Lai and Kon Tum Provinces before entering North East Cambodia, where it moves into relatively lowland areas. At the Sesan 3 damsite (se Figure 11-1) the average flow is approximately 330 m^3/sec.(NHP 2005). In Cambodia it winds from east to west through Ratanakiri Province and into Stung Treng Province, where it merges with the Srepok River, another large tributary of Mekong River. The resulting large river flows east where it flows into Se Kong River just before this river enters the Mekong River close to the Stung Treng Town. The Sesan River has a catchment area of 17000 km^2, including 11000 in Vietnam and 6100 in Cambodia. The length of river is about 462 km, of which 210 km in Vietnam. The Sesan and Srepok Rivers contribute 10.4 percent of the flow of the Mekong River at Stung Treng town. See Figure 9-1 for location.

Figure 9-1. Sesan River between Vietnam and Cambodia

The rainy season lasts from August throughout November, with peaking flow normally in Sept-Oct. A pronounced dry season lasts from January to April with the average accumulated flow being less than 15% of the total annual flow. The precipitation varies from approximately 1000 mm in the lowlands in Cambodia to 2200 mm/y in the highlands of Vietnam.

The sediment transport shows clear seasonal variations and almost 88% of the annual sediment transport take place during the flood season. September, which is the month with highest sediment transport, accounts for 36% of the annual total. The sediment transport in the dry months is very low. Between January and April, the sediment transport is only about 1% of the total annual sediment transport. The measured maximum turbidity is 1,220 g/m^3 and the minimum is close to zero.

9.2 Socio-economic and political issues

9.2.1 Vietnamese part

The catchment is situated in Kon Tum Province and in Gia Lai Province. The population density in these two provinces is 32 and 71 pe/km^2, respectively (Statistical yearbook of Vietnam 1999). Of the total population in the Vietnamese part of the river basin, estimated to 710,000 persons. Kinh accounted for 53.2 %; 15,7 % belonged to the Ba Na, 16,7 % belonged to Gia Rai and the Xe Dang were 9.9 %, the Gie accounted for 2.7 %, while the remaining belonged to other ethnic minority groups, such as the Tay and the Brau. The population is predominantly rural, 68 % in Kon Tum and 75 % in Gia Lai provinces.

The economy of the basin is mainly based on agriculture, and the industry's share of the economy is still small. Agriculture represents more than half of total income. In general, agricultural extension services remain poor, and only a small part of the households have access to advanced techniques, and the majority still use old and inefficient production systems. Poverty and famine is still part of the realities of life for up to 15 % of the population, and even higher in smaller villages and in the mountain areas.

Infrastructure is generally poorly developed and constitutes a considerable obstacle to socio-economic development. Low level of education is typical, particular among ethnic minority groups. The standard of living is low, many household face hunger and poverty. Education and health care facilities are under-staffed while being critically important to an improvement of living standards.

The area is rich in water, but drought usually occurs in the dry season and irrigation is needed in the agriculture. The total water demand for irrigation is of 198.5 millions m^3. There are 300 small and medium irrigations works in the basin, including dams (73.3 %), reservoirs (23.3 %) and 10 pumping stations. The irrigation network can supply to 46.8 % of rice total area and 79.3 % of industrial crops only.

The total water demand for household and industry is of 10 millions m^3. There are two waterworks in Pleiku and Kon Tum towns. In the rural areas the people use water from small streams or wells without treatment.

Hydropower production is an important water use. There are 6 hydropower projects in the river basin, and several under construction, and new are planned, see Figure 11-1 and Table 11-1. Yali was the first regulation which was finalized in 2000, filling the reservoir in 1998, Figure 9-2. As hydropower development in Vietnam is relatively new compared to Norway, the environmental impacts need to be better understood, in order to be able to implement efficient mitigation measures. Hydropower will be treated more in chapter 11.

People living along the river are ethnic minority groups with very low level of education. The utilization of the river for hydropower purposes has created problems and conflicts between upstream and downstream areas. This has also created transboundary conflicts between Vietnam and Cambodia as they disagree on the right to use the water.

The information about the water resources in Sesan River is poor, and it is scattered among several authority units. It is much work to get hold of the information that exists. This is a constraint to efficient water management. Between Vietnam and Cambodia there has up to now been very little transfer of information. During the civil war in Cambodia, the Cambodian Sesan area was regarded as a wilderness and dangerous territory to move into, and the EIA study for Yali Hydropower development (carried out by ElectroWatt of Switzerland) did not evaluate impacts in Cambodia at all.

In the first part of the 1990ies when Yali HPP was planned, hydropower was a new business in Vietnam, and environmental impacts were very little known.

Figure 9-2. Satellite image of the Yali Reservoir in Sesan River (Google Earth). This regulation has created large problems downstream in Cambodia.

9.2.2 Cambodian part

In Cambodia the river runs through Ratanakiri and Stung Treng Provinces, which has an average density of 9 and 7 persons per km^2 (National and Provincial Databank of Cambodia, Ministry of Commerce, www.moc.gov.kh/national_data_resource). If we assume a population density of 8 pe/km^2 as an average in the 6100 km^2 of the catchment which lie in Cambodia, the population here are approximately 49000 people. According to the letter sent by Sesan Protection Network (Ratanakiri and Stung Treng 2005) to the Cambodian Priminister (SPN 2005.05.05) there are 55000 ethnic minority people living along Sesan River in Ratanakiri and Stung Treng provinces. The SWECO EIA study from 2007 found that 35000 people are living in villages along the river.

The area of agricultural fields in the Cambodian part of the catchment, is not quantified. However, most of the 55000 ethnic minority people living there are subsisting from a combination of small scale farming and fishing. In the wet season they grow rice on the floodplain, and in the dry season river bank gardening of corn and vegetables are important. They also have a few livestock animals per family, like buffaloes, pigs, cows, and chicken. Wild plants both from the river and the forest are also important in their diet.

These minority people do not speak Khmer, but a local language more related to Lao-Thai. They have very little education, if any.

9.3 Transboundary issues

After the building of Yali Hydropower Dam in 1996-98 (see Figure 9-2), the livelihood of the ethnic minority people along the downstream sections of Sesan River has been markedly reduced (NTFP, Fisheries Office 2000, Sesan Protection Network 2005, Wyatt and Baird 2007, SWECO 2007). According to the above cited letter to the priminister, they have faced the following problems:

- Several times unexpected flooding has occurred
- The river dried up during reservoir filling
- There have been irregular water fluctuations
- The water quality has changed.
- There has been a loss of fish species and fish habitats, and sand has filled in the deep pools where the fish were hiding in the dry season
- It has impacted the people's cultural and traditional system
- Social infra structure has been destroyed
- There has been a loss of river biodiversity in the basin
- A number of people have abandoned their villages because they can no longer rely on the river
- Agricultural production has become difficult because of water fluctuation
- During the dam construction, rice fields and farm fields were flooded
- There has been a loss of fishing, gold panning and vegetation activities along the river
- During the dam construction, human and animal lives were lost
- There has been a gradual loss of wild vegetables growing along the river
- Property, equipment, materials, houses, livestock, etc. were lost
- There has been a loss of animal species that rely on the river

However, there is not only in Cambodia that the local people are affected by the hydropower utilization of the river. In Vietnam the downstream people have faced the same type of problems (CRES 2001). In addition they have a complicated resettlement programme for people who originally lived in the reservoir areas.

There are plans of more hydropower plants on both side of the border, see Figure 11-1, and the local population along the river are very worried. 3SPN and GAPE has recently conducted a fishery study along the villages of Sesan River which has revealed the fish catch is down 74 % compared to pre-Yali levels (Baird and Mean 2005). Electricity of Vietnam has hired Sweco-Grøner AS from Norway to undertake an independent EIA of the consequences of Yali Dam, but also EIA of different scenarios of operating the hydropower plants. This study was finalized in July 2007 (SWECO Grøner 2007) and revealed that fishery was down to from 70-90% of pre Yali levels.

In both Vietnam and Cambodia they have authorities at the national level, at province level, at district level, and at commune level, based upon the social republic administration system. Traditionally people have lived with the water, and subsisted on its resources for thousands of years. They have over the years developed sustainable exploiting techniques with respect to irrigation, fisheries, boating (Figure 9-3), vegetable harvest, etc. However, these techniques are all only suited for small scale utilization. The increase in population, the need for modernizing the societies, has created a demand for more intensive utilization of the water resources, like for example with respect to hydropower production and large scale irrigation, water supply, and discharge off effluents. It is the central authorities that go in front and promotes this large scale water resources utilization projects. Very often they have created unforeseen negative impacts for the local inhabitants that live according to the old utilization forms, which can not be combined with the new forms of water resources utilization. The livelihood of the local population living along a regulated river, are in most cases severely reduced. Both Vietnam and Cambodia have to implement modern principles of water management to cope with the development of more intensive, and large scale water resources exploitation.

There has been established a co-operative Sesan Committee with representatives from both Vietnam and Cambodia, which are working on how to solve the problems with the conflicting river use. Both countries are also member of the Mekong River Commission which is a co-operative forum for both utilization and protection of the Mekong River system, with tributaries. In both countries this new water management organization has started, but there is still a long way to go to be able to secure the "rights" of all water use interests as well as to preserve a healthy aquatic environment. The "Striver" project will be a small, but positive contribution to the transfer of international water management knowledge and experience to these two "emerging" SE-Asian countries.

The ferry at Veun Sai is among the biggest boats that are used in the Cambodian Sesan River

Narrow boats with long tail engine is commonly used in lower Cambodian Sesan

In Pum Phi at the border to Vietnam most boats were carved out of one single tree trunk and operated by paddles.

Figure 9-3. Sesan River is also important for boat transport, but so far no tourist boats as in Glomma.

10. Hydropower regulations in Glomma River

The hydropower installations in the Glomma watercourse produce annually approximately 10 TWh which amount to 9 % of Norway's total electricity production.

River Glomma has a long history of hydropower regulation starting in 1890'ies. The oldest hydro-power plant that is still in operation is Hafslund HPP (HPP=hydropower plant) which has been in continuous operation since 1899. However, the first regulations were done in Lake Øyeren in 1863 with the purpose of improving the conditions for boat transport and timber transport. Figure 10-1 shows all the HPPs larger that 1 MW which amount to 58 HPPs. In addition there are several smaller HPPs in tributaries which are not shown. The newest HPPs are Framruste and Øyberget both finalized in 2005. They belong to the Øvre Otta water course and this regulation was very controversial and caused a lot of protests actions. This case is given a separate treatment in the STRIVER project (Nesheim et al.2008, in prep).

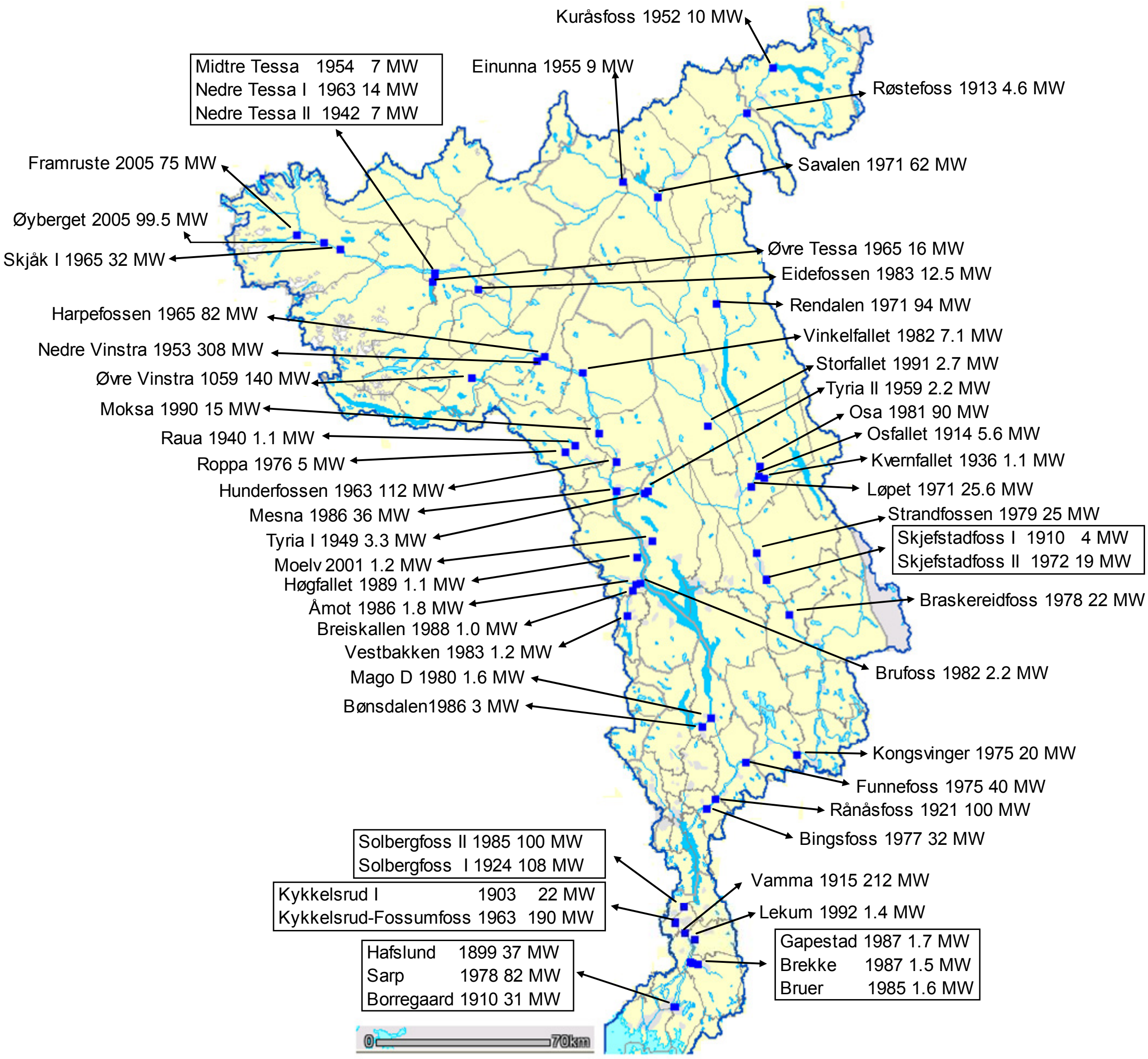


Figure 10-1. Hydropower stations in River Glomma with maximum capacity above 1 MW (from NVE Atlas)

There are 26 hydropower reservoirs, which are in most cases originally natural lakes that are dammed in the outlet. The larger lakes down in the valleys which are bordered by agricultural fields and settlements, are regulated only a few meters (4-6 m), e.g. Lake Mjøsa. The higher situated reservoirs, which lie in uninhabited areas are often regulated more. The highest water level fluctuation has Lake Raudalsvatn (in the Øvre Otta Regulation) with 30 m between MSL (maximum supply level) and MOL (minimum operation level).

Many of the hydropower plants in the main stream Glomma are so called ROR-regulations, or run of the river regulations. In this type of regulations there is no storage capacity, and they produce power with the water flow that is available. They have however, a small intake dam just to secure a steady head and prevent getting air in the turbines. They do not influence on the water flow in the river. Therefore EF is irrelevant in these regulations.

The storage capacity in River Glomma is, however, quite low, only about 15 % of annual runoff. This means that the regulations have only limited ability to prevent large floods. However, the water level in both Lake Øyeren and Lake Mjøsa are lowered during the winter, and this reduces the snow melt flood in most years.

There are no concrete plans for any new hydropower development in the catchment other than some mini power plants in small tributaries, and some upgrading of existing regulations. The power company Eidsiva, are planning to take more water over to Rendalen HPP during the summer season at the Høyegga diversion. They will, however, still comply with the existing requirements for minimum flow in River Glomma downstream of the diversion point. They want to take more of the “surplus” summer water.

11. Hydropower regulations in Sesan

The hydropower potential in the Se San River Basin is primarily concentrated to the main Se San River and it main sources, Krong Poko and Dak Bla Rivers. However, also the potential for high head developments in smaller tributaries has been investigated over the years.

A Master Plan (General Report) on the Se San River Basin was presented by PIDCI (now PICC1) in 1992 and reviewed by SWECO of Sweden in association with Statkraft Engineering of Norway in 1997. Further studies of the hydropower resources of the basin were presented in 1999 in the Se Kong – Se San and Nam Theun River Basins Hydropower Study by Halcrow/EPDC/MK Centennial. Several of the hydropower projects are no constructed and several is under construction, see Table 11-1.

Table 11-1. Main parameters of the Vietnamese hydropower projects on Se San River (PECC1 presentation at Sesan Stakeholder Meeting in Phnom Penh July 2007).

THE MAIN PARAMETERS OF HYDROPOWER PROJECTS ON SE SAN RIVER

No	Item	Unit	Plei krong	Upper Kon Tum	Yaly	Se San 3	Se San 3A	Se San 4	Se San 4A
1	FSL(m)	m	570	1170	514.7	304.5	239	215	155.2
2	MOL	m	537	1147	489.7	304.5	239	210	150
3	Max flood level	m	573.4	1176	517.2	306.5	241.89	216	
4	Gross Storage Capacity	10^6m3	1048.7	173.7	1037	86.7	80.6	893.3	13.1
5	Active Storage Capacity	10^6m3	948	117.3	778.3	0	0	264.2	7.5
6	Qmax pass turbine	m^3/s	367	30.9	420.0	490	564	719	
7	Number units		2	3	4	2	2	4	
8	Qfirm, p=90 %	m^3/s	70.7	11.1	158.9	165.3	168.4	195.1	195.1
9	Spillway Design Capacity	m^3/s	6535		1455 2	17058	14676	15 000	
10	Inflow flood Design, P=0.1%	m^3/s	10000	3500	1740 0	14900	15000	16600	
11	Install capacity	MW	100	220	720	270	100	330	
12	Time of construction start	Year	2003		1993	2001	2002	2004	2004 3
13	The first unit generates	Year	2006		2000	2005	2006	2008	

In 2006 PECC1 updated the Master Plan for the Se San River to also include the Cambodian Part of the river. A workshop on the Master Plan of Hydropower in Cambodia was held on the 2nd – 3rd of February 2007. After PECC1 received the comments from the workshop, the final report was submitted to Ministry of Industry, Mines and Energy (MIME) of the Kingdom of Cambodia.

On the 15th of June 2007, Mr Khlaut Randy (Secretary of State for Ministry of Industry, Mines and Energy) and Dr Lam Du Son (Vice President for EVN signed a MOU between MIME of Kingdom of Cambodia and EVN of the Socialist republic of Vietnam, for EVN to carry out a feasibility study of Se San 1 (also called Lower Se San 3) and Lower Se San 2 hydropower projects. The projects included in the updated Master Plan are shown in Figure 11-1.

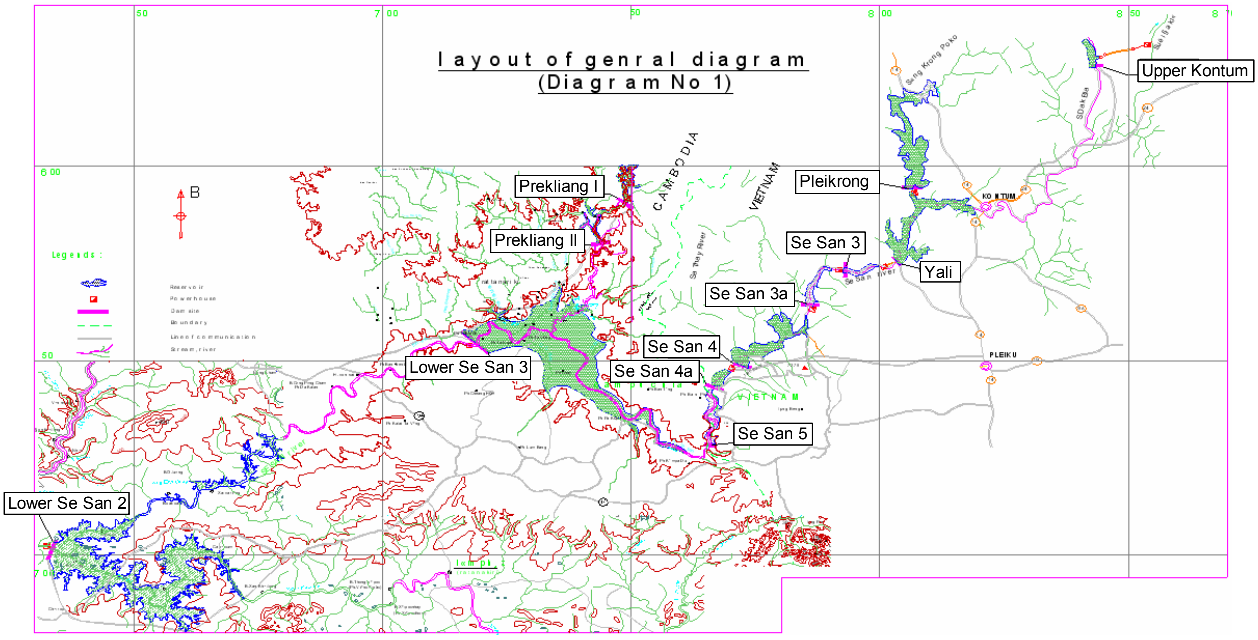


Figure 11-1.The new Joint Master Plan (June 2007) for hydropower development in Se San River in Vietnam and Cambodia (PECC1 presentation at the Sesan Stakeholder Workshop, Phnom Penh, July 2007)

From Figure 11-1 it can be seen that most of the river stretches in Se San River will be changed into a cascade of reservoirs. The river ecosystems will be replaced by lake ecosystems. The dams will create migration barriers for fish, and the fish biodiversity and production will decrease. The livelihood for the local people living along the river will decline. They have lost much already (See SWECO 2007). The large inundations in the two lowermost reservoirs will require resettlement of thousands of people.

12. The application of EF in Glomma in existing regulations and the methods used to assess these

First in year 2000, when the new Norwegian Water Resources Law was adopted, a general requirement for minimum flow in rivers in connection with regulation encroachments has been established. "In connection with withdrawal of water, diversion of water, damming of water, from rivers with permanent flow, and which causes changes in the water flow in rivers and streams, at least the "normal low flow" should be back in the original river". The normal low flow is a specific term adopted to Norway, and not used by other countries. However, it is not very different from 10 % of average flow. However, it is possible to get exception from this general rule in larger regulations where the law requires concession treatment. Most of the regulations in River Glomma are much older than from 2000. The oldest ones are from the 1890ies, whereas the majority is from 1950-1980. In Figure 10-1 we saw that it was about 60 hydropower stations in the Glomma River Basin, and it will be a to big task to go through all the manoeuvring rules and decisions on minimum release in all these. We will, however, give some examples on how it is done in some regulations.

12.1 The Vinstra regulation

In some of the oldest regulations there are no minimum release, and the river are completely dry downstream of the reservoir. The River Vinstra regulation from 1953-59, is such an example (se Figure 12-1), where there is no minimum release from the reservoir Olstappen to the former river. The renewal of the concession will take place in near future (application is lying in the Ministry for Oil and Energy waiting for treatment), and there is connected with attention weather or not the authorities will require a minimum release from the dam to the Vinstra River.

Most likely there will not be any sophisticated Environmental Flow. Norway has not had any tradition for that yet, but a minimum release is normally required.

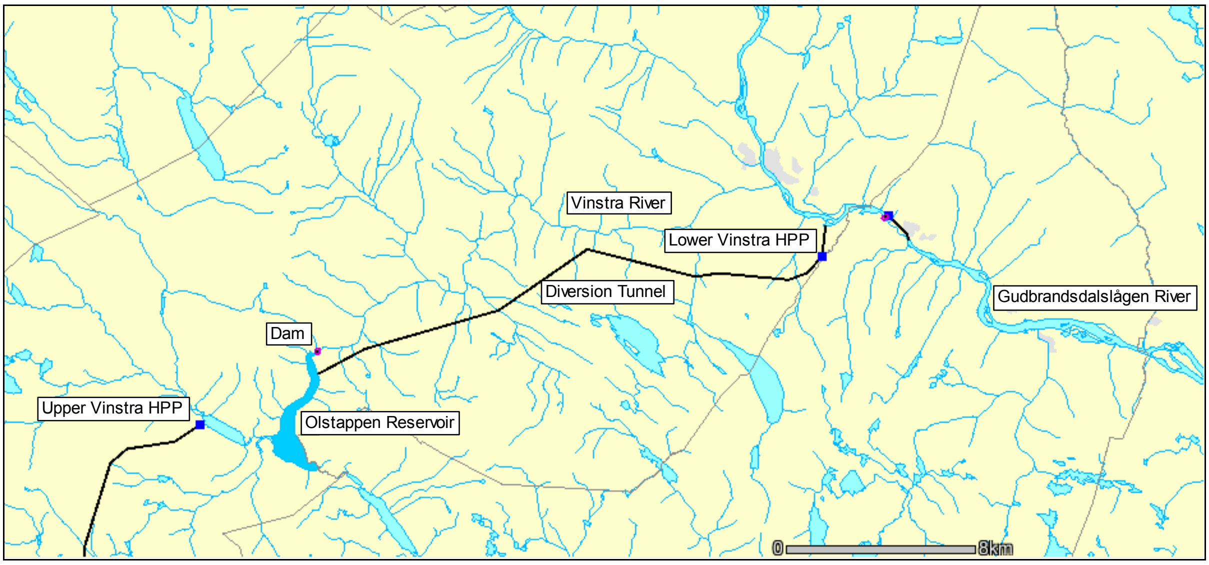


Figure 12-1. In the old River Vinstra regulations (1953-59) there was no minimum release from the reservoir Olstappen to the former Vinstra River. May be it will be required in the renewal of the concession which will take place in near future (Map: NVE Atlas)

Norway is well aware of the international work on the item and is familiar with the methods which are in use. We have our self, contributed with considerable research on the item, and have constructed software for the purpose like the River System Simulator (Harby et al 1997), and have had several research programmes on the item Environmental Flows. We have however, not agreed upon specific methodologies that should be applied. We use still expert judgements (Halleraker and Harby 2006).

However, in all regulations in the Glomma river basin, the water authority (NVE) has given manoeuvring rules for the power plant. These include rules for water level fluctuations in reservoirs (FSL and MOL), fill up rules and draw down rules (time of the year), and often some requirements for minimum water flow in the river downstream of the dam, and downstream of the power plant. These rules are set up partly based on the wishes from the power company, and partly from environmentally needs, and partly from the wishes from the other water use interests. In this way it can be said that the manoeuvring rules include some kind of EF. But there is not used any specific methodology to assess the minimum flow, or compensation flow as it also often called. Often the compensation flow consists of one low winter flow and one higher summer flow.

12.2 The Høyegga diversion to Rendalen HPP

For example where Glomma is diverted over to Rendalen HPP in the Rena River Basin, see Figure 12-2, the requirement in the regulation concession says: *” From the end of the winter low flow period (in April) to the first of September a sufficient amount of water should be released from the Høyegga Dam to provide a water flow at Stai Water Mark of 40 m^3/s. In the remaining part of the year 10 m^3/s should be released from the dam.”*

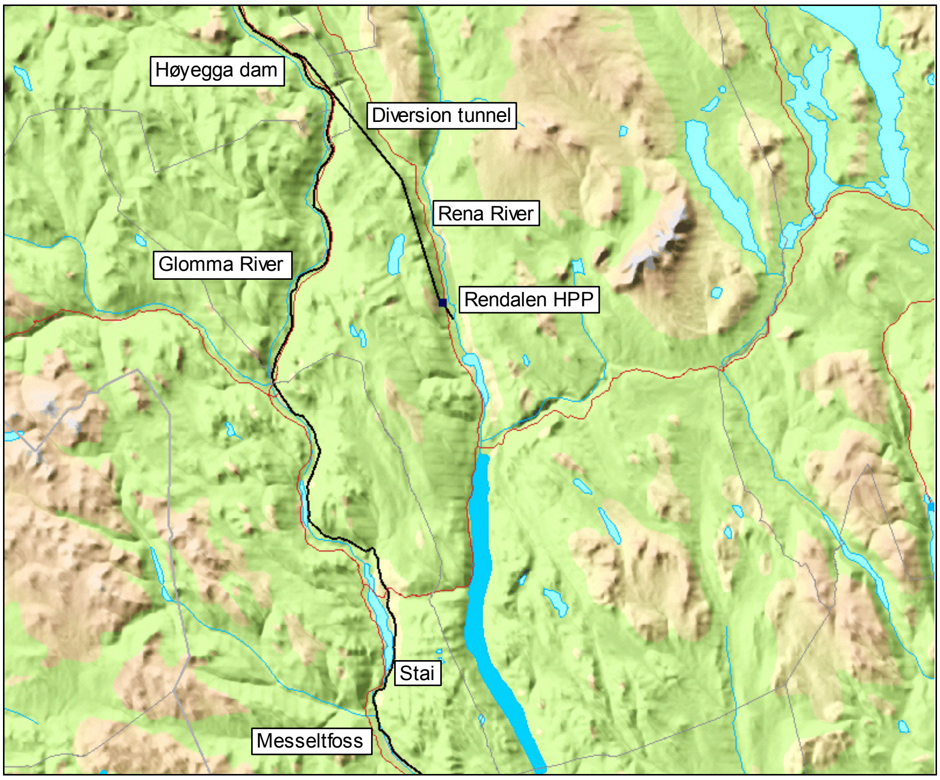


Figure 12-2. The Rendalen diversion. 80% of the water in Glomma River is diverted to the lower elevated Rena River in the neighbouring valley, Rendalen Valley. Stai and Messeltfoss are the gauging stations where the minimum release to the remaining Glomma River is controlled.

The way it is done can be roughly described as Expert Judgement based on Baseline Studies of Ecological Items and Water Use Items.

12.3 The Hunderfossen HPP

At the Hunderfossen HPP in River Gudbrandsdalslågen, just upstream the inlet to Lake Mjøsa, the minimum release is set a little more sophisticated, see Figure 12-3. Here water is diverted out of the river for a distance of about 5 km. This stretch is very important spawning ground for the large trout (*Salmo trutta)* in Lake Mjøsa, as well as for nursery area of the young trout. The swallowing capacity of the power plant is 300 m^3/s. When the water flow in the river is above this figure, the river will have the surplus of water. When the water flow is below this figure, the power plant has to release some compensation flow to the river. The rules are given in Table 12-1. The rules are here set with the aim to secure spawning migration for the famous Hunder Trout in Lake Mjøsa, which can be up to 20 kg in size.

Table 12-1 Compensation flow rules from the Hunderfossen Hydropower Dam in Gudbrandsdalslågen River (inlet to Lake Mjøsa) in the Glomma catchment

Period	Water should be released in sufficient amount to secure that the remaining river at least have a flow
01 July-15 July	15
16 July-01 Sept	20
02 Sept-10 Sept	15
11 Sept-20 Sept	10
21 Sept-30 Sept	5
01 Oct-30 June	Keep the fish bypass ladder full

The hydropower reservoirs with storage capacity in the Glomma catctment are all former lakes. The regulation capacity is normally increased by a dam in the outlet river mouth, and in addition some reservoirs by a submersed withdrawal tunnel. This last means that water level can be lower than the original lake water surface. Many of the lakes in the populated areas of the catchment are bordered by settlements and agricultural land. In addition there are many water use interests confined with the lakes, drinking water, recipient for effluents, industrial water intakes, irrigation water, boat transport, fishing, bathing and swimming, in addition to a long list of ecological values. For these reasons there are often developed strict water level manoeuvring rules for the reservoirs in some of the Hydropower concessions in Glomma River. As the only way of regulating the water level in a reservoir is via release of water (i.e. by varying flows), from the reservoir it self or from the upstream reservoir, the water level regulation must be regarded as Environmental Flows. For the reservoirs Lake Mjøsa and Lake Øyeren, the water level regulation follows very strict rules.

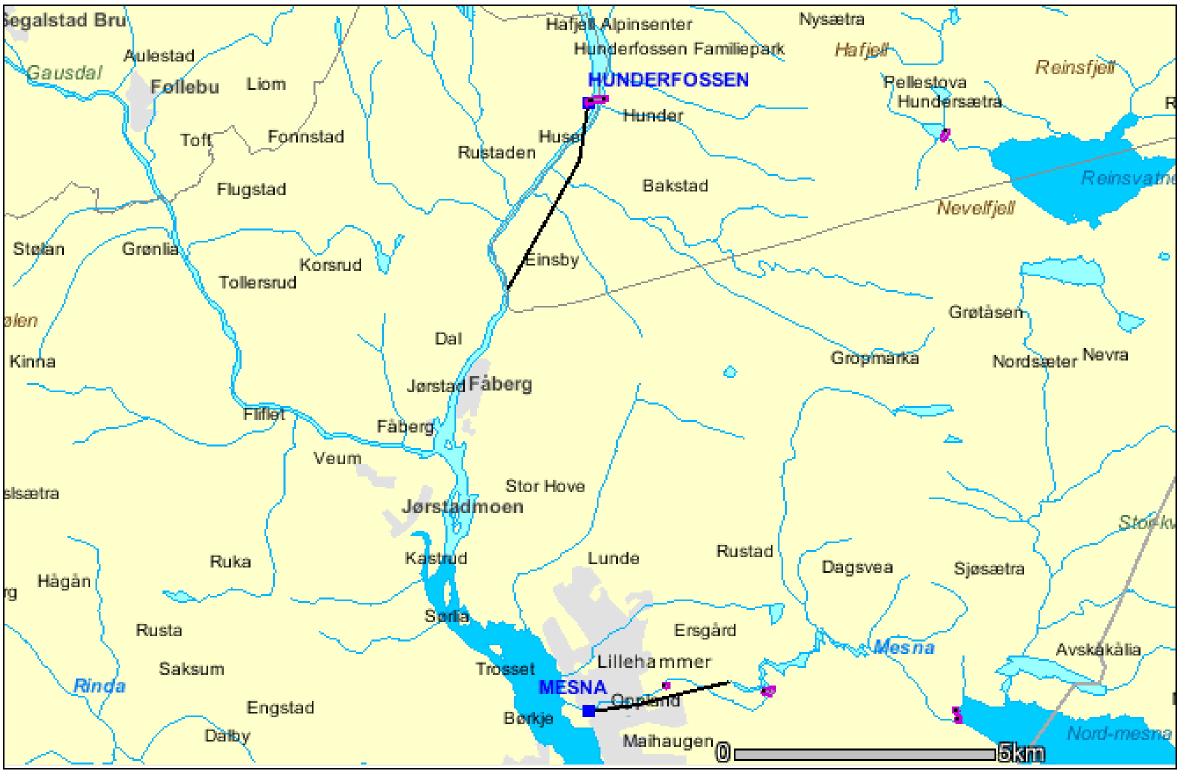


Figure 12-3 In the Hunderfoss Regulation in Gudbrandsdalslågen River, just upstream the inlet to Lake Mjøsa, the water is diverted out of the river Gudbrandsdalslågen for about 5 km.

12.4 The Lake Øyeren regulation

In connection with the application for renewal of the concession for the hydropower regulation (the private hydropower companies) of Lake Øyeren, GLB used a very interesting methodology for assessing an optimum water level regulation where they tried to take care of all the ecological values and user values in the best balanced way. As mentioned in Chapter 8, Lake Øyeren is extremely valuable in ecological terms, particularly the delta where Glomma River enters the lake, see Figure 8-3. It is the most species rich lake in Norway with respect to fish, contains a lot of red list species of aquatic macrophytes, as well as water fowl. It is extremely important as a resting place for migratory water fowl, etc. It is important for a lot of user interests, as boat transport, boat sports, bathing, swimming and recreation, fishing, irrigation and flood control. In addition it is important as a hydropower reservoir.

From 1994-2000 GLB and the Environmental authorities launched a multi disciplinary environmental study with the aim of finding a water level regulation scheme that served the environmental values in a best balanced way. The study comprised several part studies:

- Erosion and sedimentation
- Water quality including phytoplankton
- Aquatic macrophytes
- Bottom animals
- Fish
- Water fowl

Every study should aim at finding the optimum water level regime for the ecological item they were studying. The variations should be within the framework of the existing concession; as the FSL and MOL, and include the necessity of lowering the water level during the winter as a measure for flood control in the spring snow melt (May-June). The study group should discuss how serious it would be (negative impacts) for their ecological item if their optimum water level regime was not followed. It ended up with water levels as given in Figure 12-4.

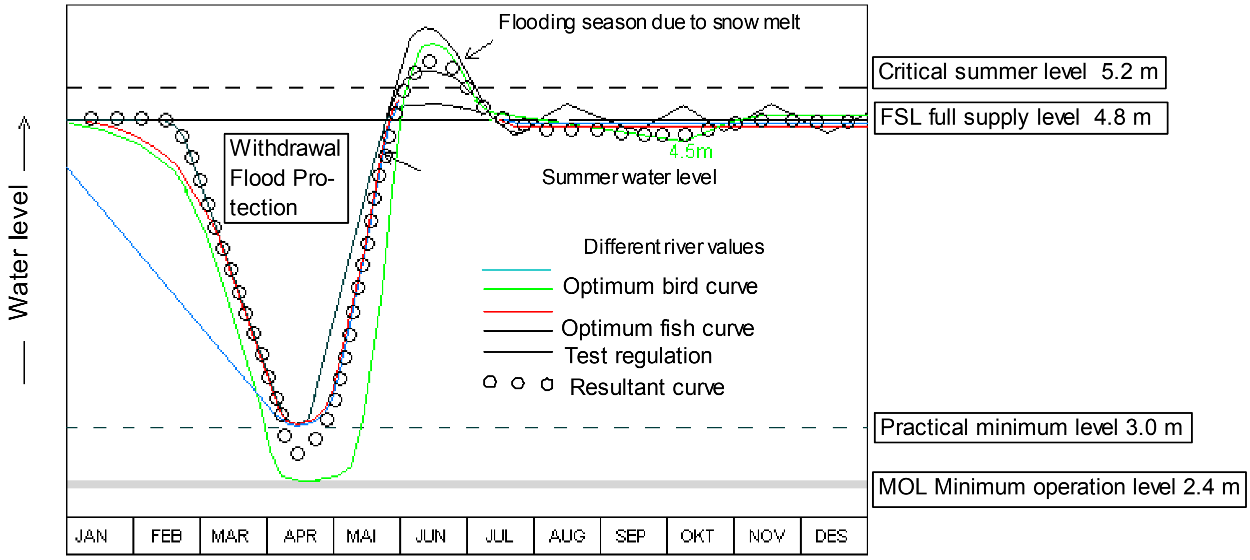


Figure 12-4. From the discussions on Optimum water levels in Lake Øyeren hydropower reservoir (Berge et al 2000)

It was a big conflict between the fish group (black line) and the water fowl group (green line) during the spring. The migratory birds needed as large as possible bare mud banks to feed on, whereas the fish needed to fill up the lake so the fish could have access to the vegetation as early as possible. This was important both for spawning as well as for refuge for young of the year fry. The bird experts were quite sure that to follow the optimum fish level, would be a complete disaster for the birds. They would disappear with few years. The GLB had to find a compromise, the circle line. The birds needed also a smaller decline in the water level in the early autumn for their southward migration. However, here it was not in any big conflict with other ecological values or user values.

The process in Lake Øyeren showed that it is water levels that water users and ecological experts have experience in evaluating. The water levels can be converted to water release manoeuvring rules at the dams, and in this way be converted into environmental flows. The process in Lake Øyeren has inspired us to develop this method further in an attempt to find the best balanced environmental flow in regulated river.

12.5 Conclusion on the use of Environmental Flows in Glomma River

Most hydropower regulations in Glomma River Basin,(if we omit the pure Run of the River Regulations and the oldest regulations), have some kind of minimum release, compensation flows, or environmentally motivated rules for water level variations in reservoirs. The way it is done can be roughly described as Expert Judgement based on Baseline Studies of Ecological Items and Water Use Items. In the old regulations there was often only one expert that took care of environmental aspects, and this was often the regional Fish Inspector belonging to the Directorate for Nature Management. In more recent regulations there are several experts involved in assessing the water flows and the water levels. This expert group is often called an Expert Panel. The panel is not composed in same manner from case to case, and they do not use any clear methodology in their judgements. Afterwards, for example when concession should be renewed, it is not easy to see how they have proposed a certain compensation flow. Their methods are neither transparent, nor replicable.

With reference to international terminology it can be said that it is the Expert Panel Method that is used in Glomma to assess Minimum Flows, or Compensation Flows, or Water Levels in connection with hydropower regulations. There is a need for doing this in a more structured way, both with respect to which type of experts should be involved, which ecological values, and which river use values should be included. In addition a more structured, quantifiable, replicable, and transparent methodology should be applied to arrive at a certain water flow and water level manoeuvring rules.

13. The application of EF in Sesan in existing regulations

Table 11-1 and Figure 11-1 show the status of the hydropower plants in Se San River. The information is based on the updated Masterplan from 2007, which also comprise the Cambodian part of Se San River. All the plants are run in an intermittent manner (peaking). They are in operation from 5-6 in the morning to 22-23 in the evening, and most of them are shut down during night time, or only a few turbines are in operation. During night time water is being stored in the reservoirs to be used for el-production during day time. This gives large diurnal variations in the flow in the river downstream.

None of these HPPs have requirements for any minimum release or EF. However, the lowermost reservoir, Se san 4A is built, primarily to take out the diurnal flow variations before the river runs into Cambodia. In this way the diurnal water level fluctuations in the Cambodian part of the river will be reduced. The construction of Se San 4 A started in 2004 and should be finalized in 2007 according to PECC1 (SWECO Grøner 2007). According to simulations done by PECC1 the reservoir should have the capacity of taking out all the diurnal water level fluctuations caused by the intermittent mode of the power production at the Vietnamese power stations, even in the low flow season, see Figure 13-4 and Figure 13-5.

However, during the STRIVER visit to Sesan River in Ratanakirri in March 2008, the diurnal water level fluctuation was between 1 – 1.5 m at Veun Sai (own observations) at the Veun Sai water mark. Local people said that they were told that the re-regulation reservoir should have been set in operation, but they still observed large water level fluctuations. According to our Vietnamese team members the Se San 4a has not started its operations yet.

The diurnal variation of water flow and water level will cause erosion in a long stretch of the downstream river. The impact will be most significant during the dry season. In Figure 13-1 taken from the report on hydrological simulation study of Sesan River (DHI 2005), the water level variations is shown at Adoung Meas in Cambodia, some 30 km from the border to Vietnam in Nov/Dec 2003 when only Yali Power station was in operation.

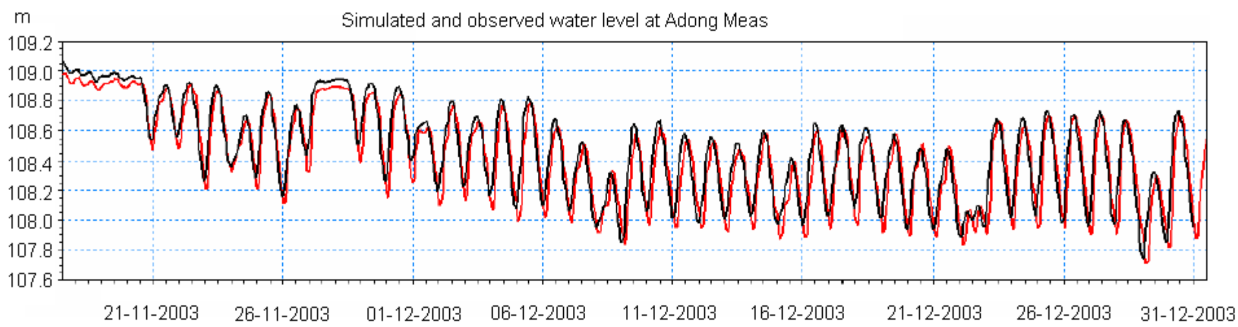


Figure 13-1. Diurnal variations in water level due to intermittent operation of the Yali hydropower plant. Observed (black) and simulated (red) water levels in Sesan River in Cambodia at Adong Meas. (after DHI 2005).

In Figure 13-2 the diurnal water level variations at Adoung Meas is shown for different modes of operation of the Yali Power Plant. The operation mode in the simulation is full turbine capacity and 1 h on and off, 3 h on and off, and 6 h on and off, respectively. It can be read from the y-axis that the 6 h on and off gives a water level fluctuation of 0.6 m at the Adong Meas.

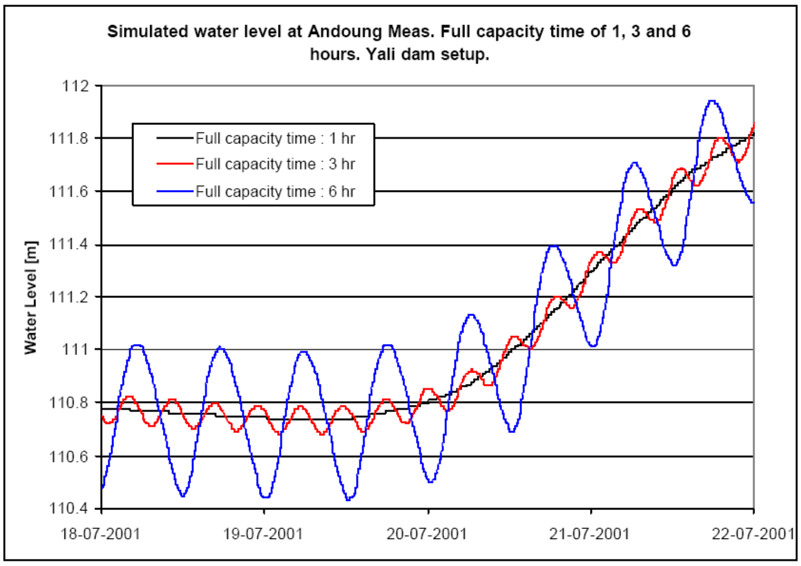


Figure 13-2. Simulated diurnal water level variations during high flow in Sesan at Adong Meas at different running periods of the Yali Power Plant (after DHI 2005)

In Figure 13-3 the water level variations are shown when all the power plants is run in an intermittent manner, Yali, Sesan 3, Sesan 3a, and Sesan 4. The diurnal water level variations will be larger when all the power plants are operating, than when only Yali is operating. (0.6 m and 1.1 m respectively). The water level fluctuations will be much less as you go downstream the river. In Ta Veng the fluctuation will be approximately 20-30 cm, and only 5 cm in Veun Sai according to the DHI (2005).

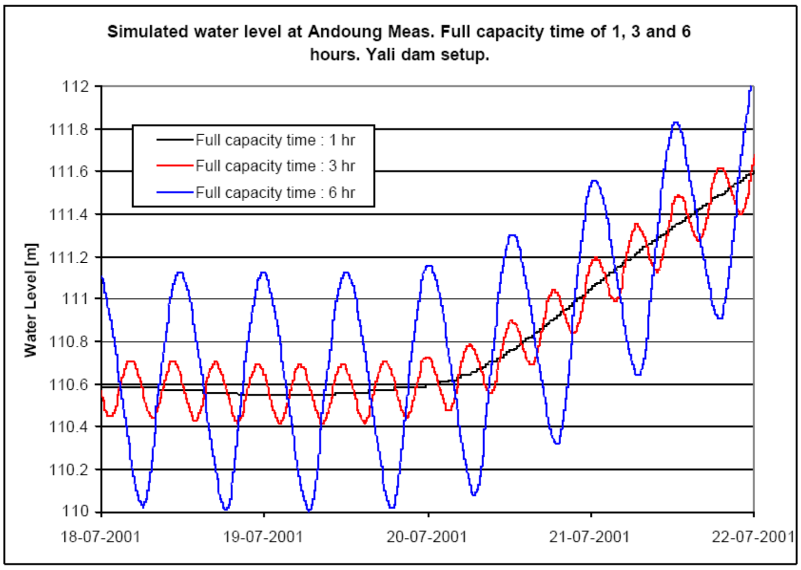


Figure 13-3. Simulated diurnal water level variations during high flow in Sesan at Adong Meas at different intermittent running periods of the Yali Power Plant, Sesan 3, Sesan 3a, and Sesan 4 (after DHI 2005)

A more realistic operation mode (fitted to the society need of power) will possibly be full production during 18 hrs and closed down during 6 hours during night time. The amplitude height of the water level fluctuations will most likely be in the same range as the 6 h on and 6 off simulation alternative. This means that the variations will create considerably river bank erosion at the border area, and at Adong Meas, moderate erosion at Ta Veng and minor (almost negligible) erosion in the Voun Say area.

It should be noted that the DHI simulation figures are representing the high flow situation when the power plants are run at full capacity. The water level fluctuations will be greater during the low flow situation if the power stations are run at full capacity. In March 2008 (STRIVER visit during low flow situation) the daily water level fluctuation at Veun Sai was between 1 and 1.5 m (own empirical observations).

The mechanism behind this type of erosion can be described as follows: The dry season up-and-down movement of the water surface, combined with differences in flow speeds, will create erosion in the lower part of the river bank, making this steeper, and causing slides, etc. When the water level is high for 18 hrs the river bank will be soaked with water until it is achieved equilibrium between the water pressure inside the bank and the external pressure exerted by the river water. When the power plant is switched off, the water level will drop. The external water pressure will disappear where as the internal pressure is still present. This will cause rapid outward directed water movements in the bank, loosing up the soil structure in the bank surface. When the flow is increasing again when the power plants are switched on, the scouring forces of the current will easily dig out some cm of this loose bank zone. This will in the long run dig out the lower part of the river bank causing slides, tree-fall, bamboo-fall, and important riverbank stabilizing roots will eventually disappear. The river bank will be more vertical, and will be prone to large scale erosion during flood periods. The increased steepness, and inorganic character of the changed river bank, will make less suitable for river bank gardening than it was before.

It should be noted that even though the water level fluctuations in the central and lower part of the Cambodian Sesan River will be low, the erosion material from the erosion further up will be transported downstream, and will settle in the deep pools in the dry season. Slowly, these deep pools will become more shallow, and their important ability to serve as dry season fish refuges will be reduced.

Therefore, it will be important to minimise these diurnal water level fluctuation as much as possible, particularly in the dry season.

None of these HPPs have requirements for any minimum release or EF. However, the lowermost reservoir, Se san 4A is built, primarily to take out the diurnal flow variations before the river run into Cambodia. The construction of Se San 4 A started in 2004 and should be finalized in 2007 according to PECC1 (SWECO Grøner 2007). According to simulations done by PECC1 the reservoir should have the capacity of taking out all the diurnal water level fluctuations caused by the intermittent mode of the power production at the Vietnamese power stations, even in the low flow season, see Figure 13-4 and Figure 13-5.

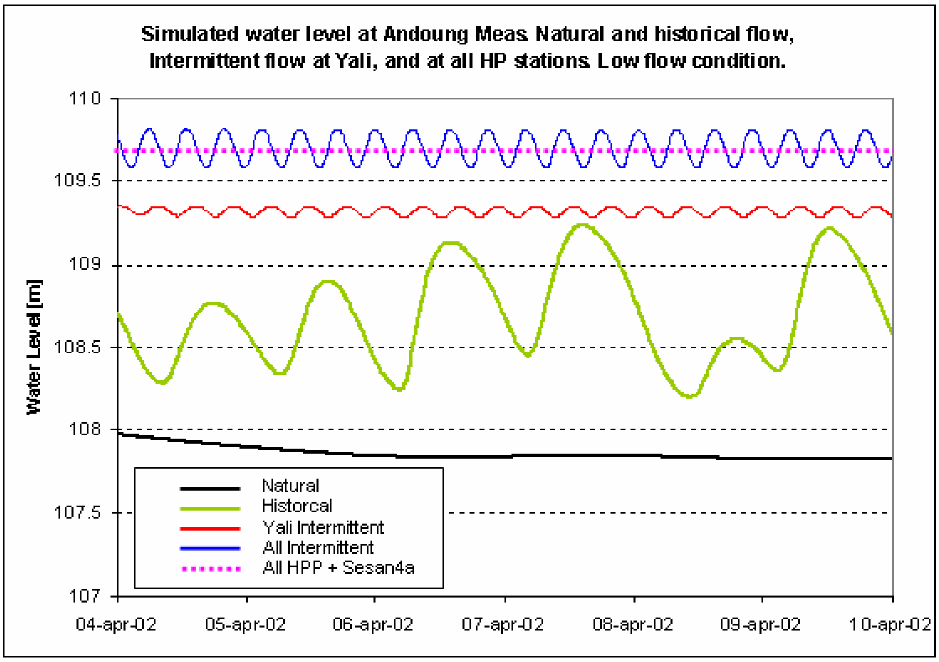


Figure 13-4. Simulated water level variations during the dry season in Andoung Meas. Simulation by PECC1 presented at the Sesan Stakeholder meeting in Phnom Penh. July 2007.

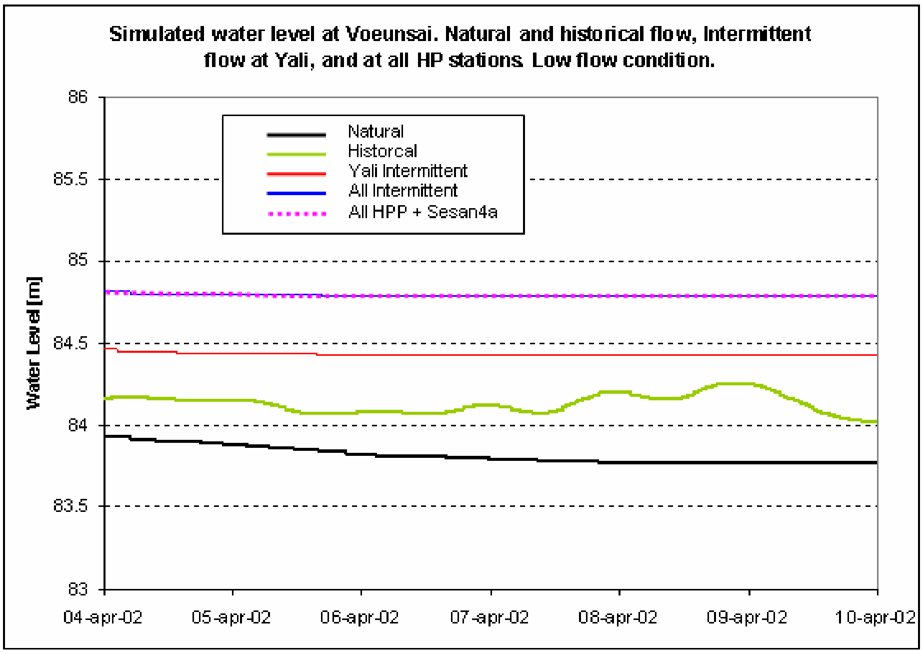


Figure 13-5. Simulated water level variations during the dry season in Veun Sai. Simulation by PECC1 presented at the Stakeholder meeting in Phnom Penh. July 2007.

However, during the Striver visit in March 2008, the Diurnal water level fluctuation was between 1 – 1.5 m at Veun Sai (own observation) at the Veun Sai water mark. Local people said that they were told that the re-regulation reservoir should have been set in operation, but they still observed large water level fluctuations.

In February 2008, from the 16th-19th the river was complete dry, and people crossed the river by motor bikes, and lots of fish was trapped on the dry banks and died. In the small pools left behind, the local people could easily catch most of the fish. After three days the water came back as sudden as it disappeared. Such dry up incidents have happened several times after the Vietnamese had started the construction of hydropower dams. It is quite clear that such dry-ups are detrimental for the fish stocks. The large fishes are old, 10-20 years and even older, and it takes a very long time rebuilt a lost fish stock. The damage by drying up the river is clearly stated in the EIA by SWECO Grøner 2007 (Client EVN) and it stresses the necessity of omitting such incidents.

Figure 13-6 and Figure 13-7 shows simulated water flow in Se San River after all regulations (except Se San 4A) are constructed and started to operate, as compared to natural flows. The first figure is simulation by DHI (2005) while the second figure shows simulations performed by PECC1 (EVN 2007). Generally, the flow will increase in the dry season and be reduced in the wet season. Particularly the first part of the rainy season will be used to fill the reservoirs, where as first part of the dry season will draw on water collected in the reservoirs. At the end of the wet season and end of the dry season the flow will be close to natural.

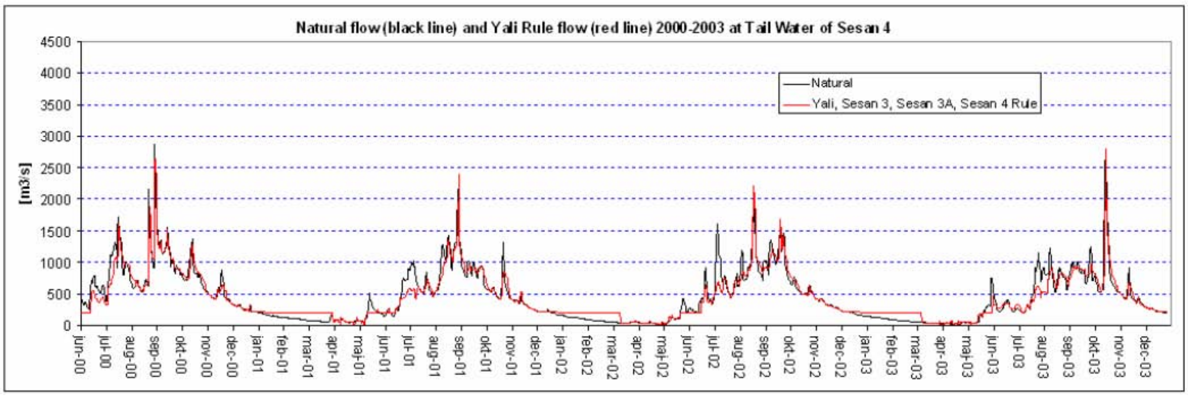


Figure 13-6 Simulated water flows (daily average) in Se San River at the outlet of Sesan 4 just upstream the border to Cambodia. Black natural flows, whereas red is the flow pattern after all the regulations are operating except for se san 4 A. (DHI 2005).

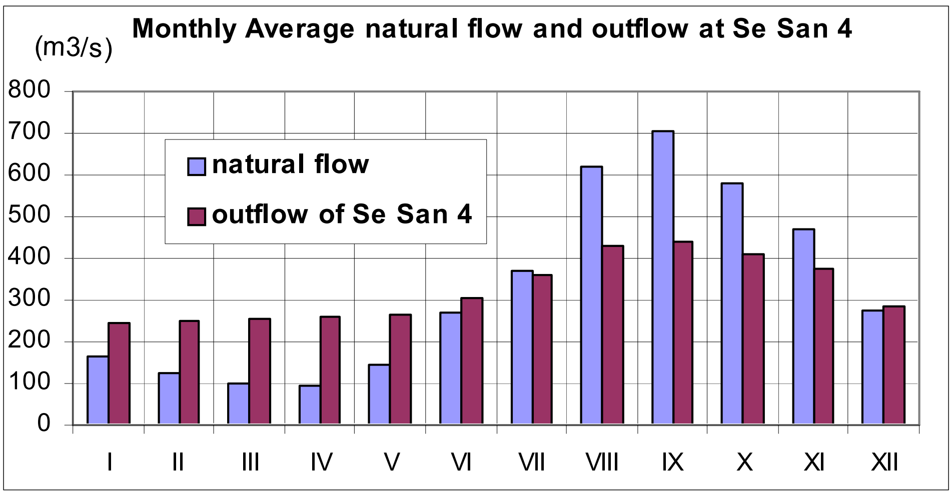


Figure 13-7. Simulated water flows (monthly average) in Se San River at the outlet of Sesan 4 just upstream the border to Cambodia. Blue colour illustrates natural flows, whereas red illustrate the flow pattern after all the regulations are operating except for se san 4 A. (After PECC1 2007).

Figure 13-8 From the construction of the Se San 4A Re-regulation reservoir. Photo EVN 2006.

14. Recommendations for EF Methodology in the two rivers

14.1 Some important differences between Glomma and Sesan River

Despite Glomma is a northern temperate river, and Sesan is a tropical/subtropical river the main principles on how hydropower regulations impact the rivers are the same. However, there are some important differences, both natural and socio economic, that should be taken into account in connection with the establishment of Environmental Flow.

In the Glomma catchment existing lakes are used as reservoirs. They are dammed only a few meters above the natural water level. From the lakes lying on the mountain plateau along side the Glomma valley, the water is taken down to power stations in the valley and the tailrace water is let out in the main stream Glomma River.

In most of the main stream Glomma River the river stretches and the lake stretches are almost as they were in the natural state. The lakes (reservoirs) lying in the main valley are only regulated 4-5 m at maximum. All these dams are equipped with fish bypass systems, which functionality, however, varies a lot. Figure 14-1 shows the fish ladder at Høyegga Dam and Løpet Dam, with a close up of how the water flows in the ladder. It is not problematic for the fish to lift it self 10-20 m in such a ladder. The main problem in many cases is for the fish to find the entrance of the ladder. In the Glomma fish ladders it is first of all the trout (*salmo trutta*), the greyling (*Thymallus thymallus*) and the whitefish (*Coregonus lavaretus*) that successfully passes the dams in the fish ladders.

Figure 14-1. Left panel: Høyegga Dam with fish ladder, Centre: The fish ladder at Løpet Dam (both Glomma River). Right: Close-up of the fish ladder canal. Photo: Left and centre: GLB, right: Tore Qvenild 2008.

In Sesan River, the valley is dammed to create both the reservoir and to create the head for the turbines. Before the construction of Yali started in 1996 (first filling of the reservoir in 1998) the Sesan River was a continuous river, see Figure 14-2, where fish could migrate all the way from Mekong River and far up in Vietnam to the Yali Falls. These falls have always been a natural fish migration barrier.

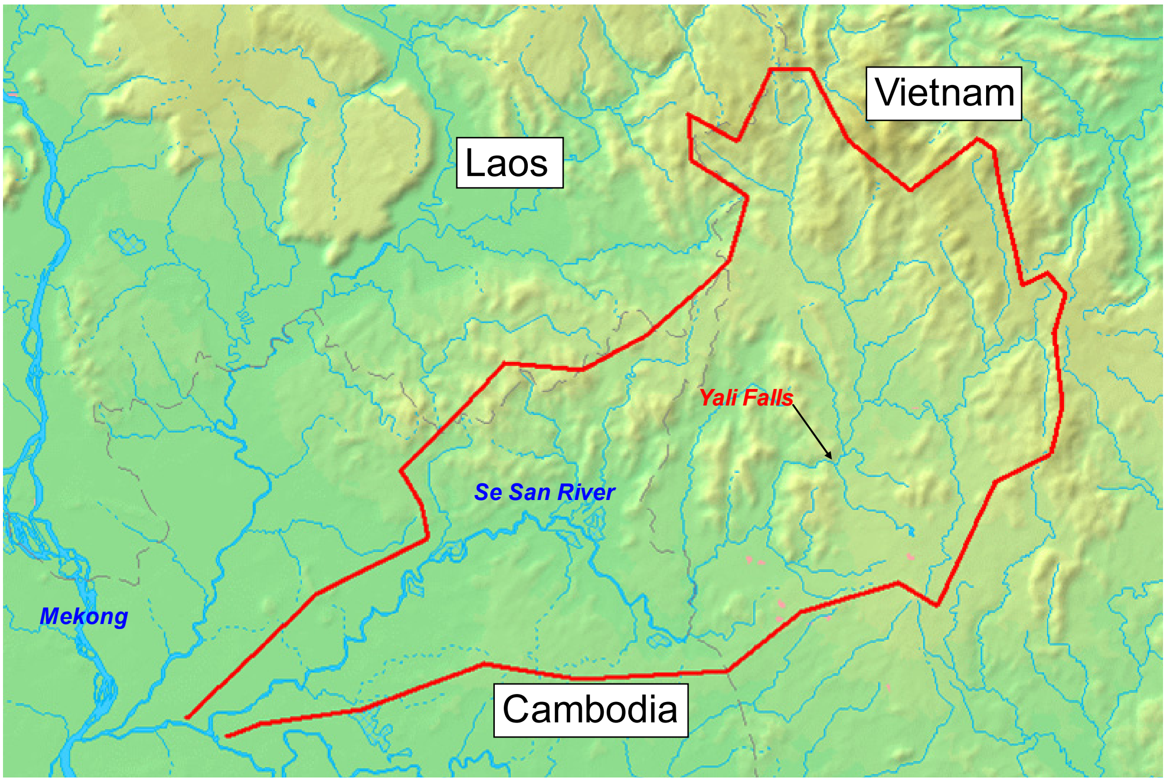


Figure 14-2. Sesan River with catchment. Before the hydropower regulations started in 1998 (first filling of Yali Reservoir) Sesan River was a continuous river where fish could migrate all the way from Mekong River and far up into Vietnam (to the Yali Falls).

Comparing with Figure 11-1, which shows the constructed dams and reservoirs in Vietnam and the planned dams and reservoirs in Cambodia, it appears that more than 60 % of the main stream Sesan River from Kon Tum to Stung Treng is converted from river stretches into lakes. Experience from other HP-regulations in Vietnam is that only 30-40 % of the river fish species can shift into a lake life and lake habitat. I addition the migration from Mekong River is blocked by all the dams, of which none is equipped with fish bypass systems. Even though some of the lost species can survive in the tributaries, it is no doubt that the species diversity will be reduced in Sesan River. Many of the large and popular food fishes are long distance migrants, and these will disappear. In addition the incidents of dry-ups of the river when filling reservoirs, which has happened several times, are detrimental for the aquatic life. For example the Giant Mekong catfish (*Pangasianodon gigas*), see Figure 14-3, and several other species are no longer in Sesan River (SWECO Grøner 2007). However, reservoirs with moderate water level fluctuation (5 m or less) can have good fish productivity (see Figure 14-5), and can replace the lost livelihood to some extent. A stocking programme is often necessary as spawning conditions may be reduced by the regulation. This means that it is often possible to preserve much of the fish based livelihood along a regulated river.

Figure 14-3. The Giant Mekong catfish (*Pangasianodon gigas*) and several other species are no longer in Sesan River (Photo: Fisheries Research Institute, Phnom Penh)

In Glomma River, most hydropower plants are involved in base load el-power production, whereas in Vietnam the base load is produced by thermal power and the hydropower is used to take the peaking in the day time el-consumption. This will create large diurnal flow variations in Sesan River, whereas in Glomma River the regulated flow is constant for long periods of several months duration.

Another important difference with respect to the two rivers is related to the use of the river by the local residents. In Sesan River local people (as e.g. 35000 in Cambodia) are depending on the river fish as the main protein source. In Glomma River fishing is only for leisure. No body is living from the fish catch in this river. In many river stretches in Glomma, as e.g. downstream of the Høyegga diversion a stretch of about 120 km the fish catch has declined by 70-80 % (Qvenild and Linløkken 1989), see Figure 8-4. This makes the loss of fish production less serious in Glomma River than in Sesan River.

Having in mind all the different river stretches that are actual for EF assessment, see chapter 5, and the different flow needs for the ecology in the two rivers (e.g. Sesan with possibly 350 fish species, and Glomma with from 3-25 species), we find it difficult to recommend one single special method for assessing the EF in both rivers. For example in habitat modelling it will be very complicated to assess preference curves for so many fish species.

Figure 14-4. Glomma River downstream of the Høyegga diversion. Large areas of river bottoms dries up during winter time, and the fish stock has declined dramatically (see also Figure 8-4). Photo: Per Rønningen.

14.2 The Expert Panel Method has the necessary flexibility

We find that the holistic methods including expert panels, as e.g. the South African Building Block (BBM) type of methodology has the flexibility to tackle all the different regulation types, the different impacted stretches, and the high diversity in tropical rivers. It is also versions of the Expert Panel Method, which has been used earlier in Glomma River in the cases where compensation flow is assessed, though a much more simplified version than the BBM. It is, however, necessary to have available good baseline studies, and good EIAs conducted in advance, and it is important to appoint a well skilled and balanced expert panel. In some cases the expert panel will need data from eco-hydrological modelling to assist in their judgements. The EF proposed by the expert panel should be applied for a trial period of 5 years, and re-evaluated.

To meet the modern requirements of transparency, replicate able and verification, the Expert Panel Method need to be more structured than it has been used in Glomma River hitherto.

In the Striver project we have further developed a method, which were partly used in Glomma River in renewal of the regulation concession in Lake Øyeren (Berge et al 2002). Here the different experts managed, based on good baseline studies, to identify the periods where certain water levels were required (critical periods), as well as to quantify the damage that were done to the river value they were responsible for, if the water level were deviated at different degrees. The method will be shown more in detail in the following chapter.

14.3 The STRIVER Approach in setting Environmental Flow in Hydropower Regulated Rivers – The PIMCEFA Method

To determine environmental flows in a heavily regulated river is a complicated matter. Already when the decision is taken to regulate the river for hydropower purposes, the possibility to obtain an environmentally healthy flow is restricted to "<u>within the constraints set by the economical feasibility of the regulation</u>" often settled in the concession. It is by then already politically decided which "<u>the most important water use interest</u>" is, namely hydropower production. The experience is that when a river first is opened up for hydropower development, new regulations are coming very fast. In River Glomma there are 45 hydropower regulations and approximately 60 hydropower plants, see Figure 10-1. In Sesan River it will soon be 6 large regulations in the main stream in Vietnam (and most likely 2 in Cambodia), and several small in the tributaries, see Figure 11-1. From Kon Tum Town and down to the Cambodian border it will be a cascade of large lakes almost without any river stretch in between. Only in the low flow season a river stretch (more or less dry) may be seen between the dam and the upper end of the next reservoir. Environmental flows in such a "cascade-river" have a different meaning than in Glomma River. In Sesan River the reservoirs has become the main water bodies, and EF should be used to have the lake ecosystems in the reservoirs to function as good as possible, i.e. water levels and water level fluctuation, secure fish spawning and nursery conditions in the between reservoir river stretches, etc. EF is thus a flexible term that should have been assessed in all stretches of a regulated water course, also in the reservoirs.

In the STRIVER project we have come to that a modern definition of EF in hydropower regulated rivers could be:

Adopting water release manoeuvring rules for the different reservoirs to obtain as favourable water levels (and water flows) as possible for the total river ecology and the human water use interests, within the constraints set by the economical feasibility of the regulation. This applies both for the reservoir stretches and river stretches.

This definition is also in line with the environmental goal of *good ecological potential* used for heavily modified water bodies in the EU Water Framework Directive. In practical assessment terms it is the water levels that are most applicable, both in the reservoir stretches and in the river stretches, but it is only via different releases from reservoirs (flows) that water levels can be adjusted. A fisherman in Stung Treng (lower Sesan River) can tell you how high the water level must be before the fish from Mekong can start it's up migration into Sesan River. If you ask him about m^3/s, he will look like a question mark. A farmer in Ratanakirri can tell you the water level needed to fill up his paddy rice fields, as well as the time of the year this water level is needed. Water flow is an un-known quantity to the local river users. The local experienced river users can give very important information in setting EF.

There is a clear connection between how much electricity you take out of a river and how much well functioning environment there is left, see Figure 14-5. This gives often clear limitations for the ability of local people to reside from ecological services like fish production after the regulation. But it does not have to be like this. A reservoir with a water level fluctuation of only 5 m or less, can produce more fish than the inundated river stretch did before, but a reservoir with water level fluctuation greater than 10 m can not have good fish productivity in the long run (Figure 14-5). It is via the release from reservoirs we can adjust the water levels, either via the turbines, the bottom valves, or the spill ways. When a favourable water level regime is found, the use of hydrological models can convert the findings into flows, and corrected for natural runoff from the local catchment, the necessity for a certain release pattern from the reservoir can be calculated. Things like this should have been taken into consideration when regulation concession is given, but in fact they are most often not considered properly. This is partly due to lack of knowledge and/or lack of practically applicable methodology. Particularly in new regulations too little data are available to run the many sophisticated models produced for the purpose.

The STRIVER project has contributed to improve the methodology for assessing environmental flow in regulated river by making the most frequently used holistic method known as *Expert Panel Method* more transparent, quantifiable, and replicable. The method can be used to design an environmental flow, as well as to assess the degree of damage done to the different river values in different levels of regulation.

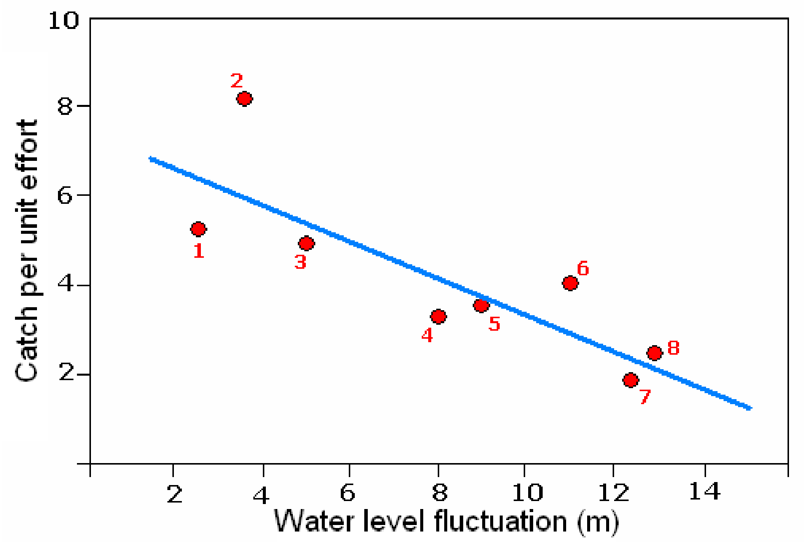


Figure 14-5. Fish yield (catch per unit effort) in some Norwegian hydropower reservoirs with different water level fluctuations (after Garnås and Gunnerød 1981).

An expert panel consisting of local experts (fisher men, farmers, boater, etc) and professional educated experts, both on key ecological elements (ecological values), and key water use elements (water use values) should be appointed for each of the different river sections that are going to be evaluated. The tools that are being used are two types of semi quantifiable models, 1) *Optimum Water Level Curves*, a method that was developed, and successfully applied, in the last renewal of the Lake Øyeren regulation concession (River Glomma), and 2) *Pressure – Impact – Curves* (inspired by the EC Water Framework Directive). As a last step 3) we use the pressure impact curves in a multi criteria decision making tool to find the best co-evaluation of the different river values, and thus propose a best balanced resultant curve. In principle the method can also be used with little baseline information available, but the results will then be less precise. The best is to have good baseline studies and EIA study for all the river values that are treated by the expert panel. In some instances the panel will need some eco-hydrological model results as well.

The members of the expert panel try as good as they can, based on local knowledge and baseline studies combined with the professional expert judgement to construct the optimum water level curve for the different water values (ecological values like water quality, water vegetation, bottom animals, fish, etc., and user values like drinking water, transportation, irrigation, fishery, etc.). They start by identifying the critical periods for the river value they represent, i.e. periods where certain water levels has to be kept. From the different optimum curves a preliminary resultant curve can be elaborated. The curves in Figure 14-6 is from the work with the renewal of the Øyeren Regulation Concession in River Glomma (Berge et al 2002).

When the critical periods for the water value (ecological value or user value) are identified, the next step is to evaluate how seriously the different river values are impacted by the regulation, a semi quantifiable model, called pressure-impact curve, should be created. As an example let us consider the river value "fish production" in a regulation which includes river diversion: If all the water is taken and the river ends up dry, the fish production is damaged by 100%. I no water is taken (no regulation) the damage is 0 (zero). The simplest model between these to points is the straight line, see Figure 14-7. However, this model can be improved considerably by expert judgement (also in cases where little data exist). We know that the fish are adapted to a 30 % year to year variation in flow, so to divert up to 30 % of the water, is not very serious for the fish stock. In the other end of the scale, when most of the water is diverted and most fish are lost, it will be only small pools of water between the stones on the bottom, and it will be like this even if all water is taken. Most ecosystem damage follows such a sigmoid curve, while user interests often follow a curve like the green curve in the Figure 14-7.

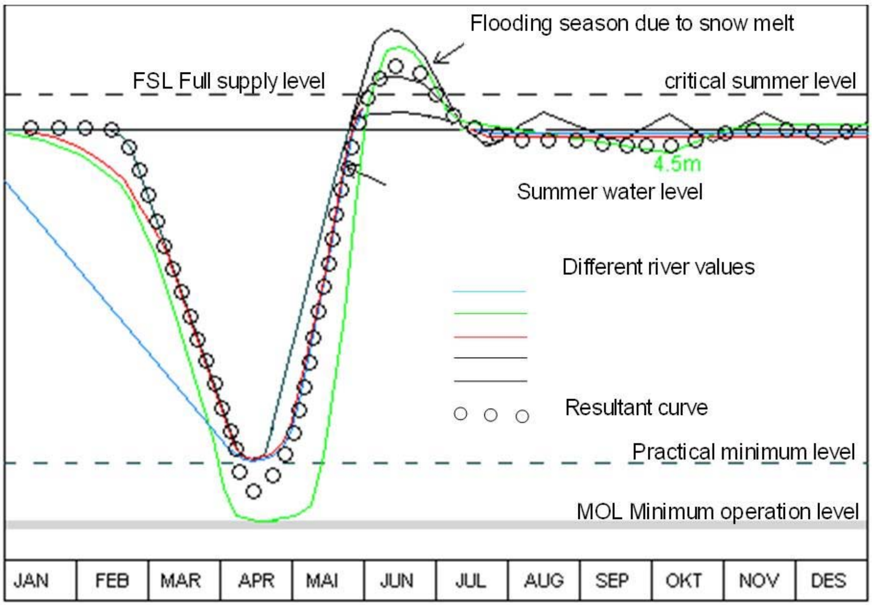


Figure 14-6 Optimum water level curves for the different river values in the Glomma River delta "Northern Øyeren Nature Reserve". From the renewal of the regulation concession (Berge et al 2002).

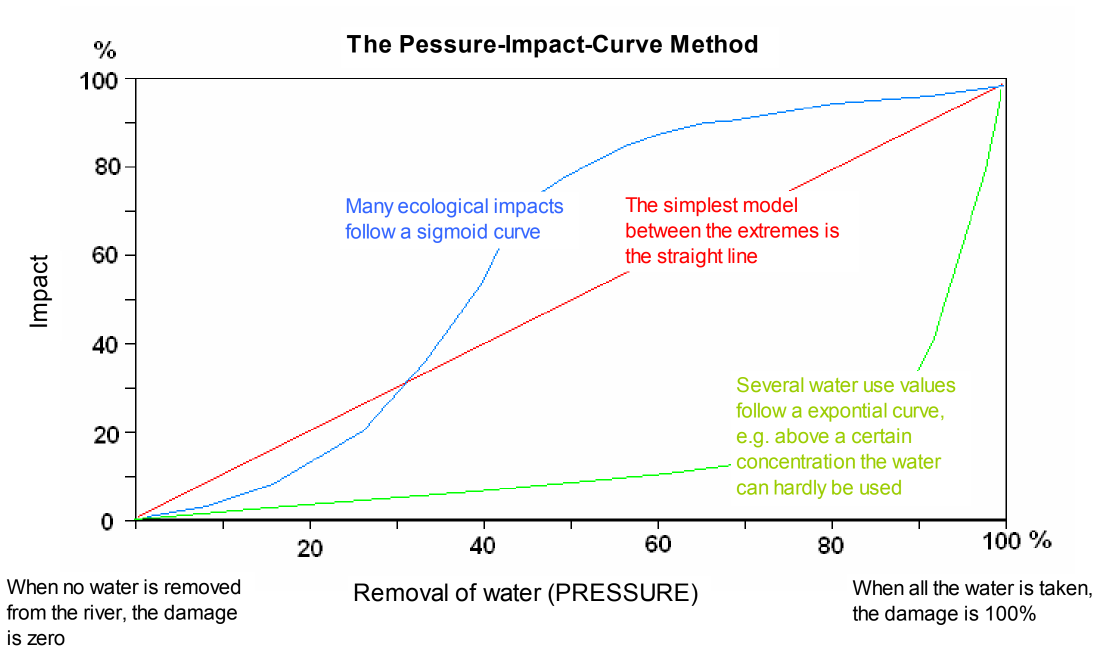


Figure 14-7 The Pressure-impact curve, see text for explanation.

To help in evaluating the different impacts against each other a multi criteria analytical tool (DEFINITE Software) is used. This can also be used in weighting of the different river values including sensitivity analysis of different individual weights. The result can be used to construct the best possible water level resultant curve, which secures that the damage to the ecosystem values and user interest values are within acceptable magnitude. The analysis of the pressure impact curves can be used to adjust the optimum water level curve, which again will give information on how to adjust the water release pattern from the reservoirs.

The method has been tested as an exercise in different parts of River Glomma, as well as in different part of Sesan River, both in Vietnam and Cambodia. The work with this method is presented in Technical Brief from The Striver Project (Barton and Berge 2008, and Nhung et al 2008). We will not go in detail of the technicalities of the method here, only give a brief resume of the test exercises. Interested persons should study the Technical Briefs cited above.

The method is called the Pressure Impact Multi Criteria Environmental Flow Analysis method, or shortened the PIMCEFA method.

14.4 Testing the PIMCEFA-method in Glomma River

The PIMCEFA method for assessing Environmental flows has been tested in The Høyegga area (diversion) and in the Øyeren area (water level manoeuvring), see Figure 14-8.

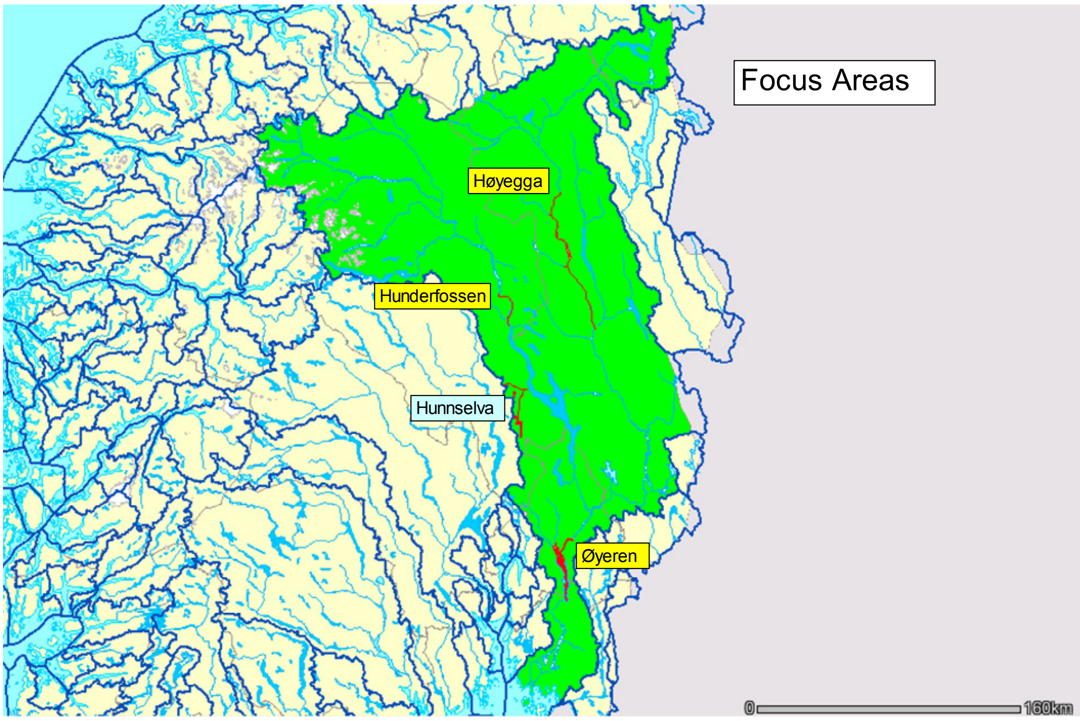


Figure 14-8. Focus areas for testing the PIMCEFA method in Glomma River is marked with red.

The cases had some more actuality than just being an exercise in STRIVER in that in the Øyeren Regulation there is recently applied for renewed concession (being treated by the authorities at the moment), and in the Høyegga Regulation the hydropower company (Eidsiva) wants to take more of the surplus summer water over to Rendalen Hydropower Plant.

One problem that should be mentioned is that it was difficult to bring the different experts together for just a test exercise. Not all the wanted experts had possibility to leave their busy jobs for a whole day event or more, included hours of travelling just for participating in an exercise project. If it had been a real case, it would have been much easier, they said.

14.4.1 Test-case 1: The Øyeren Regulation

We started with Lake Øyeren regulation where the main task has been to find the best possible water level variation pattern. It was appointed an expert panel consisting of the persons given in Table 14-1.

Table 14-1. Expert Panel for test-case 1: The Øyeren Regulation

Name	Expertise	Represents
Dag Berge	Limnology	STRIVER/NIVA
Markus Lindholm	Limnology	STRIVER/NIVA
Marit Mjelde	Aquatic botany	NIVA
David Barton	Env. Economist	STRIVER/NIVA
Gunnar Halvorsen	Aquatic zoologist	Norwegian Inst. Nature Research (NINA)
Svein Dale	Water fowl expert	UMB
Aage Brabrand	Fish expert	Univ Oslo (LFI)
Ingrid Nesheim	Riparian ecology	STRIVER/SUM
....		
Leif Nilsen	Fish biologist,	County Governor of Akershus
Jon Arne Eie	Freshwater biology	NVE, Norwegian Water Resources and Energy Directorate (Authorities National level)
Jens Kristian Tingvold	Hydro power/hydrology	GLB
Gunnar Andersen	Experienced local fisherman	Local fishermen Association
Yngve Kvebæk	Ornithologist	Northern Øyeren Bird station
....		

One Expert Panel Meeting was held the 12th of December 2007 with the aim:
Construction of preliminary optimum water level curves based on baseline studies, identification of critical periods, and construction of first version of pressure impact curves.

The second Expert Panel Meeting was held the January 2008 with the aim:
Confirming, and adjusting the pressure impact curves and introduction to the multi criteria analysis for weighting and evaluating the different impacts against each other.

The river values that were treated in the Øyeren Expert Panel Meetings were Fish life, Water Fowl , and Aquatic Macrophytes (Ecological values) and water use interests were Ornithology (Bird observation), Fishing and Boating.

In this case the optimum water level curves had been created before, see Figure 14-6, so the different groups went directly to the construction of the pressure impact curves. Figure 14-9 shows an example on how the “raw” versions of these were created by the participants, where as Figure 14-10 shows how the curves look like when they are taken into the DEFINITE multi criteria software. All the raw versions of the pressure impact curves (disagreements between experts) can be taken into the software and analysed as a measure of un-certainty.

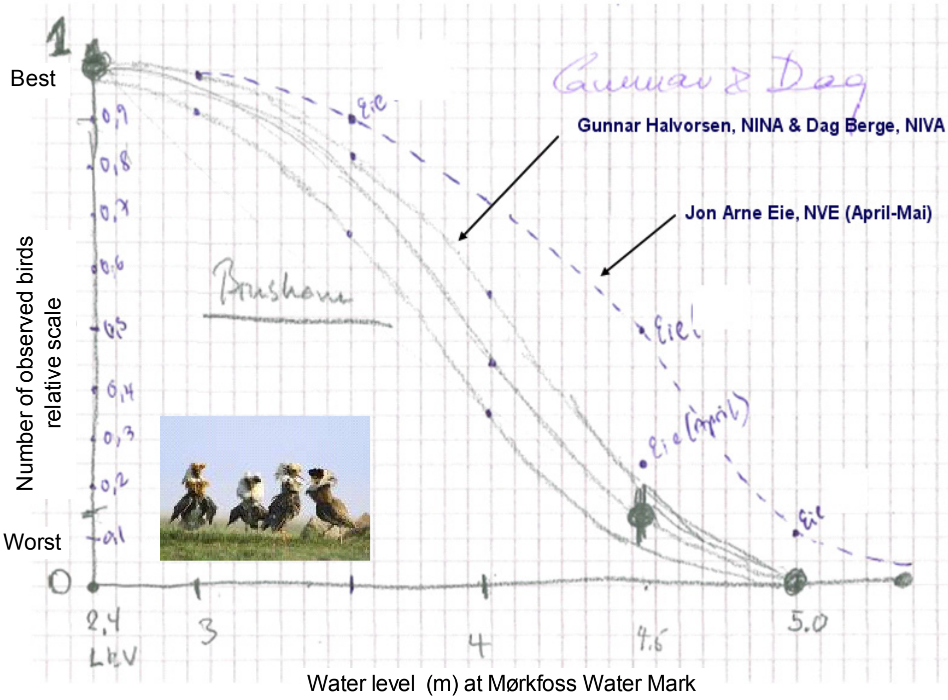


Figure 14-9. Pressure – impact curve for water fowl constructed by the bird experts in the Øyeren Expert Panel Meeting. Number of migratory water fowl visiting the delta at different water levels, represented by *Philomachus pugnax*.

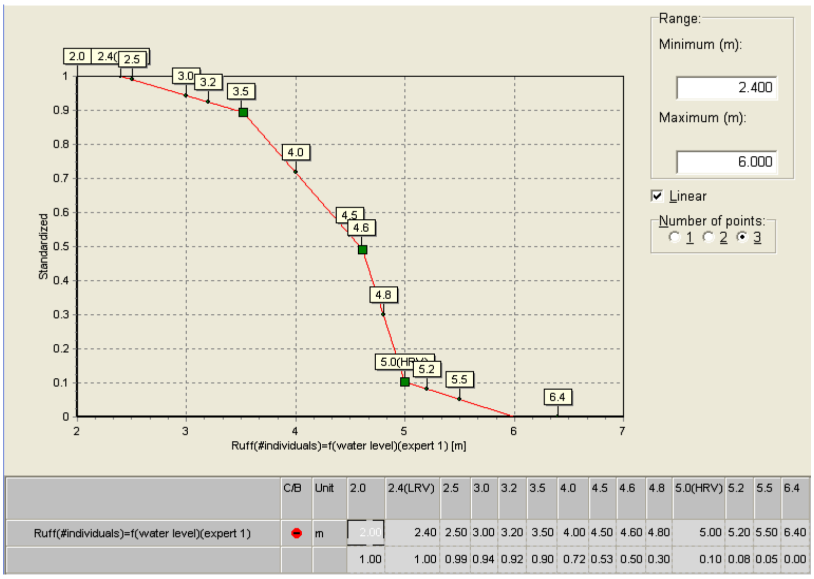


Figure 14-10. The Pressure impact curve for water fowl *(Philomachus pugnax)* how it is shown in the DEFINITE software multi criteria analysis tool.

The technical details can be found in the Technical Brief describing the method (Barton et al 2008).

- The experts were able to construct optimum water level curves for their respective river values, as well as identify critical periods
- The experts were able to construct pressure impact curves for the critical periods
- The co-weighting technique of the river values by the multiple criteria analysis tools still needs some refinement.
- Both the ecological experts and the river use experts (local and professional), as well as the water management authorities found the method interesting and we even heard words like ”promising”.

14.4.2 The Høyegga test case

In the summer, the concession says that it should be released an amount of water over the Høyegga dam which secures that the flow at the water mark at Koppang should be above 40 m^3/s. However, most of the summer more water is flowing in the river. Eidsiva Power Company has increased the swallowing capacity of Rendalen Hydropower Plant and wants to take all flow that exceeds the concession limit during the summer. The local fishing association is, however, strongly against these plans. It should be noted that the STRIVER expert panel exercise is not part of the formal treatment of this new want, but we have invited typical authorities and affected river users that will take part in such a treatment. This in order to make the exercise as realistic as possible.

An expert panel of the members shown in the Table 14-2 (Figure 14-11) was elected and had their meeting in Hamar the 8th of May 2008.

Figure 14-11. From the Høyegga expert panel meeting May 2008.

Table 14-2 The Expert Panel used in the Høyegga case

Name	expertise	Represents
Dag Berge	Limnology	STRIVER
Markus Lindholm	Limnology	STRIVER
Torleif Bækken	Freshwater ecology	STRIVER
Ingrid Nesheim	Riparian ecology	STRIVER
....	Farmer /agricultural expert in the municipality adm.	Stor-elvdal Municipality (Authorities local level)
Tore Qvenild	Fish biology, several studies in Glomma River	County Governor of Hedmark (Authorities county level)
Ola Gillund	Sanitary engineer, Responsible for pollution prevention	County Governor of Hedmark
Jon Arne Eie	Freshwater biology	NVE, Norwegian Water Resources and Energy Directorate (Authorities National level)
Trond Taugbøl	Fish biology	GLB (Glommen and Lågen Water Management Association) ”The association of hydropower Owners”
Jens Kristian Tingvold	Hydro power/hydrology	GLB
Roar Lundby	Local River user	NJFF Hedmark (Norwegian Association for Hunters and Anglers, County level) – Important NGO
Per Rønningen	Local River user	Local Fisherman (Local NJFF member)

Five expert panel groups were established for treatment of river values

Ecological values: Fish(Trout, Greyling)
Bottom animals
Riparian Vegetation

User values: Conditions for fishing
Power production

The group members were already well acquainted to the area and to the impacts by the regulation. They were aware of the natural flow at the site, how much water was diverted over to Rendalen HPP, and some of the members knew the outcome of several studies on how different ecological conditions have developed after the regulation. It should be noted that in this test case no studies were performed with the aim of serving as baseline for assessment of Environmental Flow, which had been done in the Øyeren test case.

The groups started with evaluating what would be an optimum water flow (or level) for the river value they treated, and identified the critical periods. Thereafter they tried to construct what they meant was the most likely pressure impact curve for the most critical period. Figure 14-12 and Figure 14-14 show the results from the fish group.

They identified the low flow period during the winter where large areas of the river bottom lie (see Figure 14-13) dry for several months as the critical period for fish. The pressure impact curve is based on no diversion - no impact whereas full diversion gives total damaging impact. The 10 m^3/s minimum release, which is the present regulated situation, gives according to three different studies all decline in fish stock, but at different levels (from 80 % reduction to 30 % reduction). The studies are conducted at different times after the regulation, and are not aimed at being used to adjust the minimum release. However, the studies give an indication of the uncertainty in the estimates of fish declines. The group meant that the condition could be improved considerably if 20 m^3/s could be released from the dam during winter instead of 10 m^3/s as to day. The power companies could as compensation take somewhat more of the summer surplus flow over to Rendalen Hydropower Power Plant.

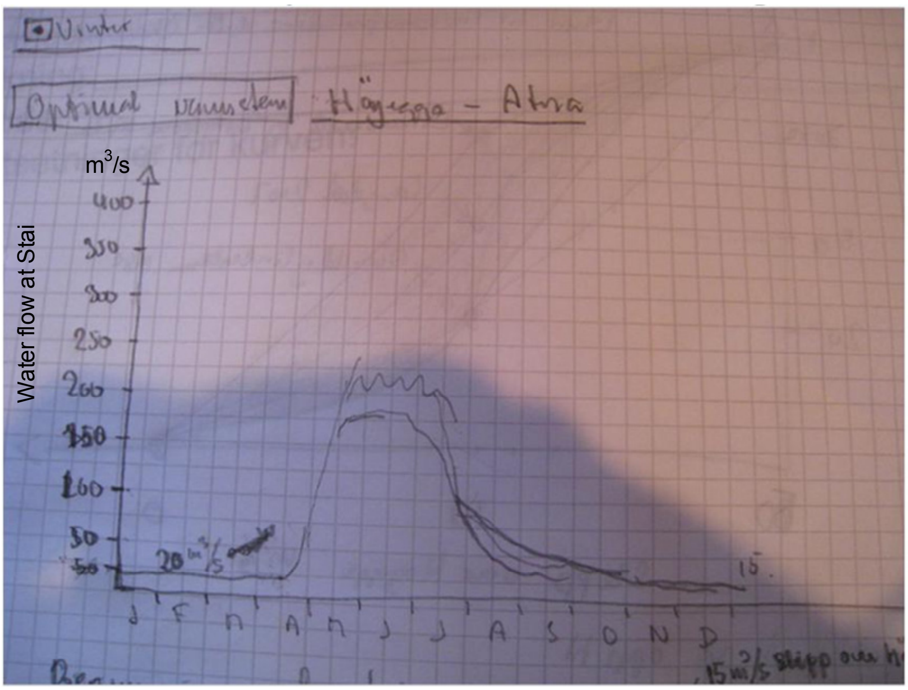


Figure 14-12. Optimum water level curve drawn at the expert panel meeting by the fish group

Figure 14-13. Glomma in the Koppang area in April when there still is winter low flow. Large areas of the river bottom lie dry during the winter (Photo: Per Rønningen).

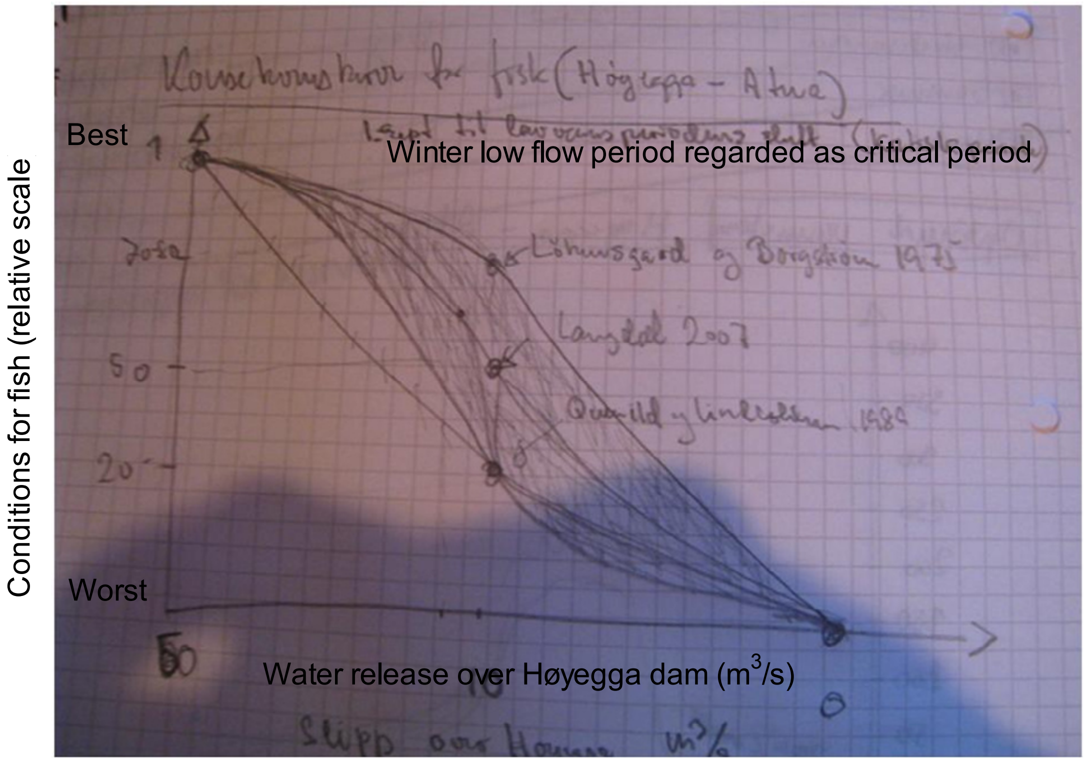


Figure 14-14. Pressure impact - curve for fish conditions as a function of water release over Høyegga dam drawn at the expert panel meeting. Three studies after the regulation in 1972 showed all decline in fish, but at different level. 50 m^3/s was the normal, unregulated, winter flow at Høyegga dam.

The group dealing with conditions for fishing, also included skilled fish biology experts, and they were not convinced that the winter was the only constraining period for fish production. They had indications that the reduction in summer flows also was important. However, in a real case this would have been investigated. Thus, in this exercise they meant we had to little data to give clear advice on how fish conditions could be best improved by assessment of environmental flow.

The group dealing with bottom animals said that the productivity of bottom animals first of all is impacted by the how much river bottom are dried up as a consequence of different amounts of diversions, and as a coarse rule of thumb, it could be anticipated proportionality. To be able to draw both the optimal water level curve and the pressure impact curve, they needed information on dry-up areas by different flows (or diversions).

With respect to optimum water flow curve over the year the bottom animal experts meant it was important to have a spring flood and an autumn flood, with quiet waters both in winter and in summer. They draw an optimal water level curve as given in Figure 14-15.

An idea that came up during the meeting was to utilise the ortho-photo (vertical air photo) taken by the Norwegian Mapping Authority (Statens Kartverk) every 5th year, and the daily water flow measurements performed by GLB, to construct a function between dry river bottom and flow. We visited the national archive for air photo at the Norwegian Mapping Authority, but all pictures were taken in May, just after the snow melt on high water flow (full river bed). Air photos for mapping is best after snowmelt but before the leaves comes on the trees. Out of many photo series only two had significantly different flow. These are shown in Figure 14-16 for the Messeltfoss area downstream of Koppang.

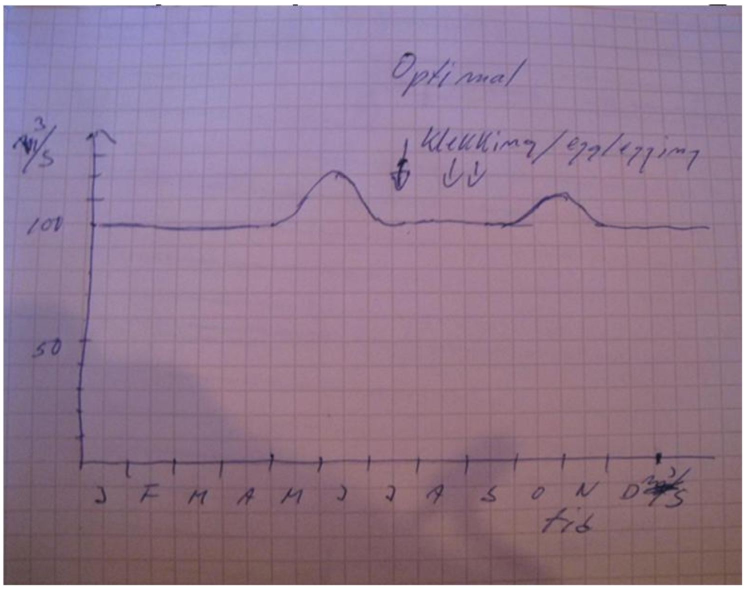


Figure 14-15. For bottom animals it is important to have a spring and autumn flood, and relatively quiet waters the summer and winter.

The water covered area in the lower picture is approximately 0.7 km^2, while it is reduced to 0.4 km^2 in the upper picture, which is a 43 % reduction.

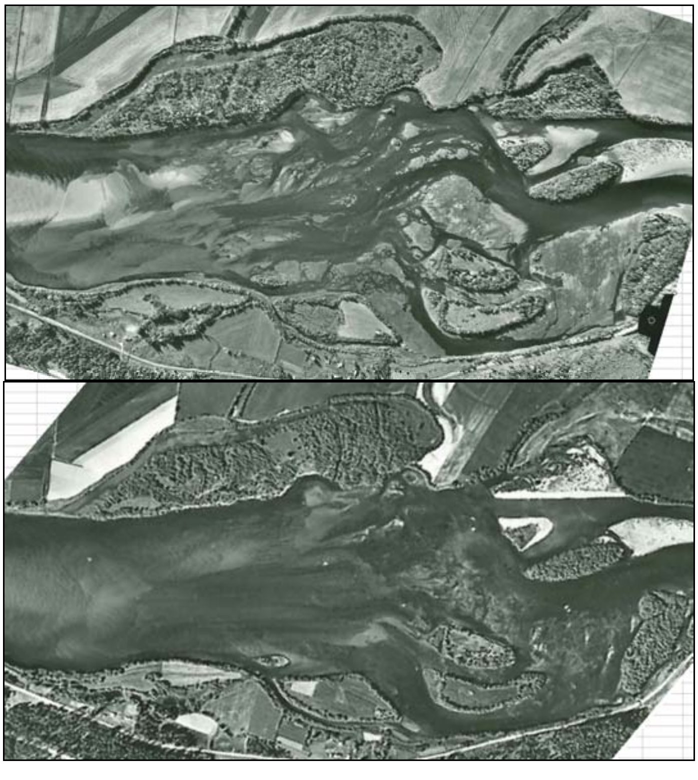


Figure 14-16. Vertical air photos from Glomma River at Messeltfoss downstream of Koppang at two different water flows. The upper picture is from 23.09.1976, while the lower is from 20.06.1960.

14.5 Testing the PIMCEFA method in Sesan River

14.5.1 Test case Dak Bla River in Kon Tum – Vietnam

The PIMCEFA method for assessing Environmental flows has been tested in Dak Bla River, just upstream of Kon Tum Town , see Figure 14-17 and Figure 14-18.

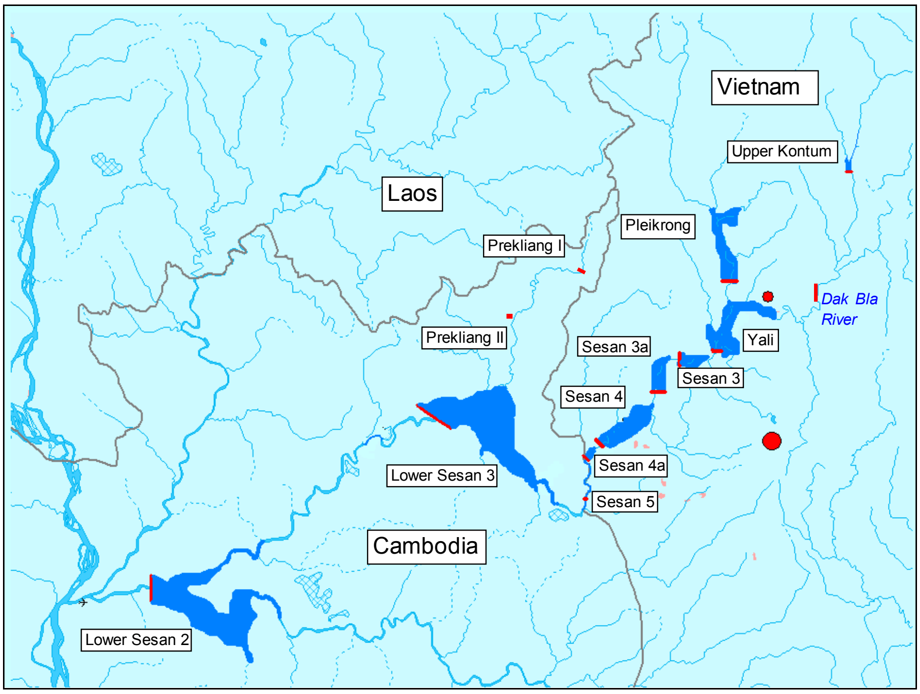


Figure 14-17. The test stretch in Dak Bla River upstream of Yali Reservoir. This stretch will get very little water if Upper Kon Tum HPP is built (not yet finally decided)

Figure 14-18. Satellite image of the Dak Bla River upstream of Yali Reservoir with the test stretch in the upper right corner (from Google Earth).

It was appointed an expert panel consisting of the persons given in Table 14-3.

Table 14-3 Expert Panel for Kon Tum test-case

Name	*Expertise*	*Represents*
Dang Kim Nhung	Environment (EIA)	STRIVER
Phan Van Mach	Fresh water ecology	STRIVER
Nguyen Kiem Son	Fish biology	Institute of Ecology and Bio-Resource, VAST
Vu Thu Lan	Hydrology	STRIVER
Dinh Quang Hien	River use (irrigation)	Irrigation office – DARD Kon Tum province
Do Thi Hai Ly	River user (farmer)	People Committee of Sa Thay district
Phan Doan Khanh	River user(hydropower)	Management Board of Hydropower Project No 4
Nguyen Van An	River user (fishing)	Farmer living in riparian area

The expert panel meeting was held the March 2008 in Kon Tum with the following aims:

- Construction of preliminary optimum water level curves based on baseline studies. Identification of critical periods.
- Construction of pressure impact curves.
- Introduction to the multi criteria analysis for weighting and evaluating the different impacts against each other.

Figure 14-19. From the expert panel meeting in Kon Tum March 2008. Right panel shows interview with a local fisherman living along the river.

The river values that were treated in the Kon Tum Expert Panel Meetings were: Aquatic Macrophytes (Ecological values), Fishing, Farming and Hydropower production. The optimum water level curves had been created during the meeting, see Figure 14-18.

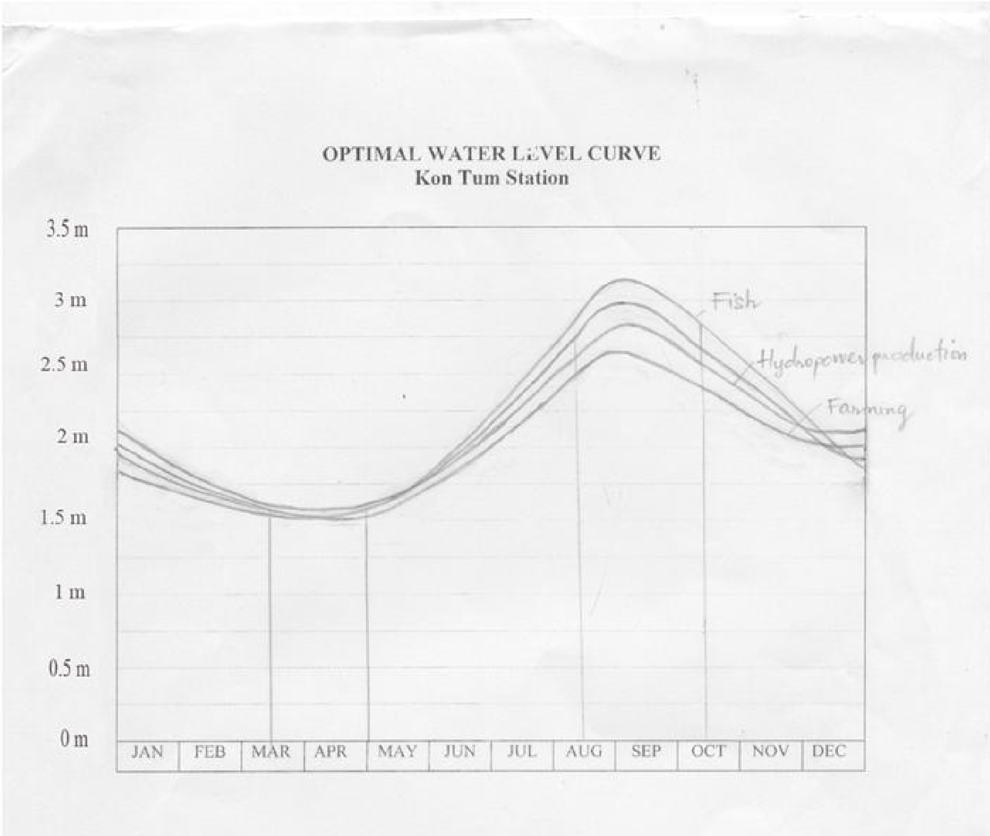
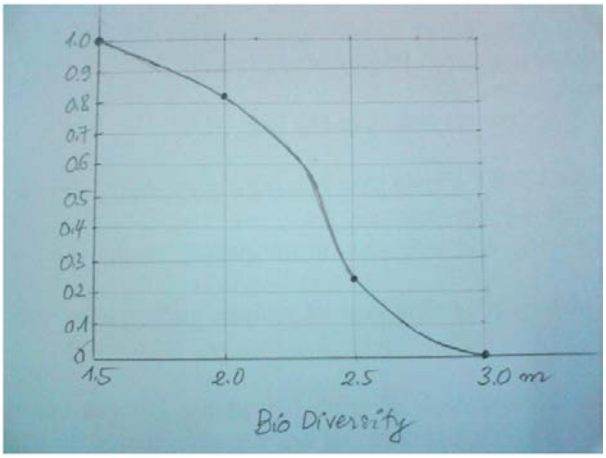


Figure 14-20 The optimal water level proposed by the experts.

After that the different experts went to the construction of the pressure impact curves. Figure 14-21 shows an example on how the "raw" versions of these were created by the participants, where as Figure 14-22 shows how the curves look like when they are taken into the DEFINITE multi criteria software. All the raw versions of the pressure impact curves can be taken into the software and analysed as a measure of un-certainty.



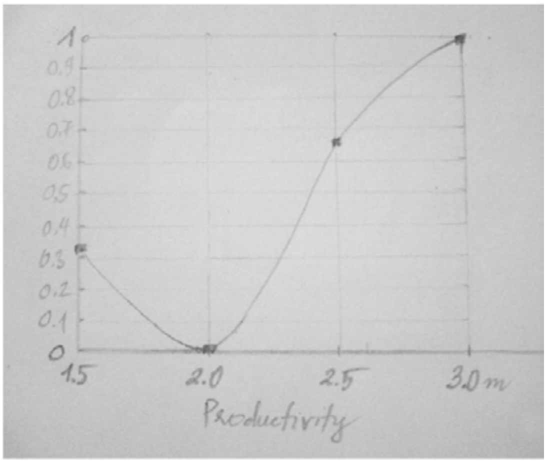
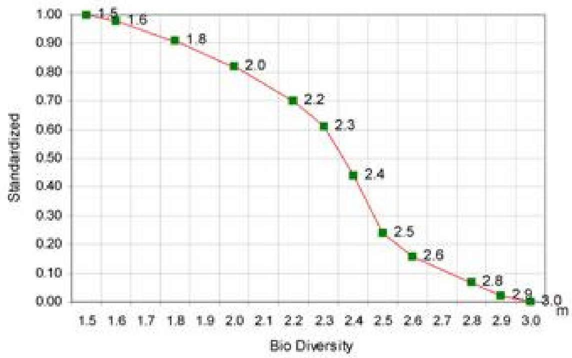
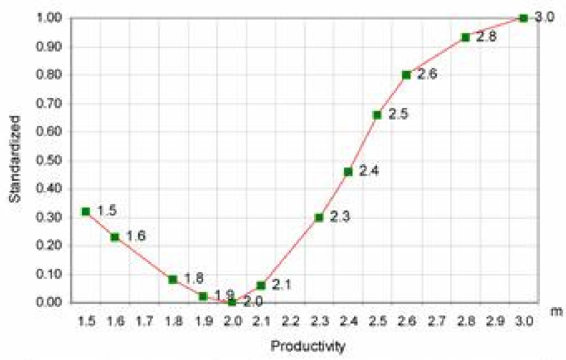


Figure 14-21 Pressure – impact curve for Biodiversity value (linear type) and Fish catch (not-linear type) constructed by the Fish ecology experts and local water user in the Kon Tum Expert Panel Meeting.



	1.5	1.6	1.8	2.0	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0
Macrophytis (Bio Diversity)	1.00	0.98	0.91	0.82	0.70	0.61	0.44	0.24	0.16	0.07	0.02	0.00



	1.5	1.6	1.8	1.9	2.0	2.1	2.3	2.4	2.5	2.6	2.8	3.0
Fish catch (Productivity)	0.32	0.23	0.08	0.02	0.00	0.06	0.3	0.46	0.66	0.8	0.93	1.00

Figure 14-22. The Pressure impact curves for Biodiversity value and Fish catch how are shown in the DEFINITE software multi criteria analysis tool.

We found out that the Pressure-impact curves for indicators “Hydropower Capacity” and “Bio Diversity (Aquatic)” are linear. Their illustrations show that the higher the water level, the less impact there is. Both curves of “Fish Productivity (Fish Catch)” and “Farming” are more complicated. The highest water level doesn’t cause the least impact.

To sum up:

- The experts were able to construct optimum water level curves for their respective river values, as well as identify critical periods
- The experts were able to construct pressure impact curves for the critical periods
- The method was regarded as interesting but requires more information about river values and more special studies about biodiversity, fresh water ecology as well as hydrology.

We also recommend that the expert panel meeting should be held with more experts from both water use and professional, including policy makers.

The technical methodological details can be found in the STRIVER Technical Brief No. 7 (Nhung D.K et al 2008).

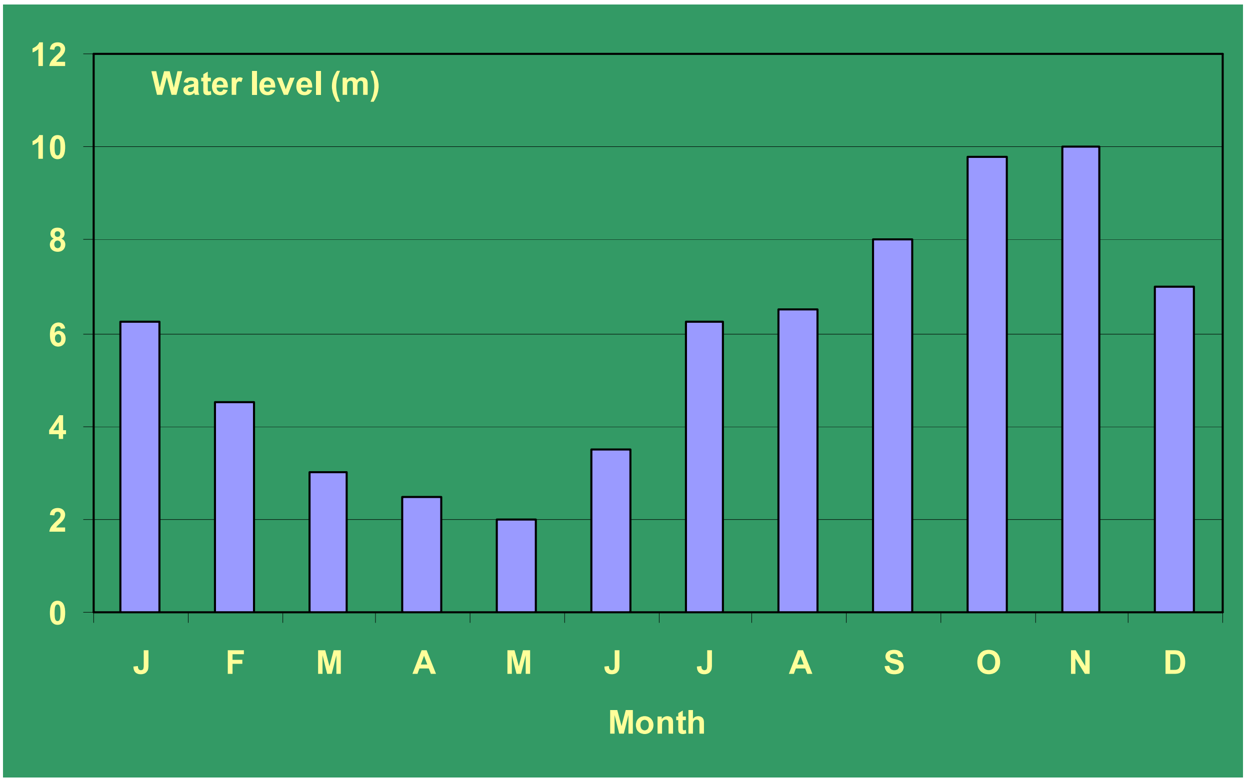
14.5.2 Test case Veun Sai Cambodia

In March 2008, we tried to arrange an expert panel meeting in Ban Lung, the capital of Ratanakirri province, which is the province that has been most negatively impacted by the hydropower regulations in Sesan River. Mobilisation of professional experts from Phnom Penh to a 3 days meeting in remote Ban Lung was for logistical reasons found to be difficult. The meeting was therefore arranged solely consisting of local experts and experienced river users (two combined fishermen/farmers and two professional fishermen). These have been involved in a recent fishery study (Baird and Mean 2005) organised by 3 SPN (Three S-Rivers Protection Network). Mr Meach Mean at the 3SPN office in Ban Lung kindly assisted us in the arrangement.

We started with a 3 hrs meeting at the Sesan River Resource Centre, where we presented the methodology and aims of assessing EF. The local experts explained what they meant was the main problems confined with the regulation. After the meeting we went out in the field to the MOWRAM water gauging station which is situated in the upstream end of Veoun Sai Village. Here the experienced river users constructed what they meant was the optimum water level curve for the river, see **Figure 14-23**.

From the expert panel meeting in Ratanakirri March 2008 (Sesan Competence Centre)

The MOWRAM Water gauging station in Veoun Sai



The Optimum water level curve constructed by the local experienced river users (from the expert panel meeting in Veoun Sai, Ratanakirri, March 2008

Figure 14-23. The experienced river users had a clear opinion of what was the optimum water level for Sesan River, and constructed this curve.

Due to language problems, and the fact that no domestic professional experts were allocated to the meeting, the construction of pressure-impact curves became too complicated for the local experts. However, they had a clear opinion of what water level they should have the different months of the year (Fig. 14-23). More specifically this curve is the natural water levels from the period before the regulations started.

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