Cost-Benefit Analysis of River Regulation: The case of Emån and Ljusnan.

Part three of the research program HYDROPOWER – environmental impacts, remedial measures and costs in regulated waters

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1 The Research Programme and Evaluation

The 3[d] phase of the program has run for a period of three years, 2007 – 2010. The program is cross disciplinary, in which economics, natural scientist and mathematical statisticians have worked together to shed light on the costs and benefits of river regulations. The program is financed by Elforsk, The Energy Agency, the Fishery Board and the Swedish Environmental Protection Agency.

The research program presents an integrated natural-social science approach to Cost-Benefit Analyses (CBA) of river regulation, with primary focus on the Emån and Ljusnan Watersheds. Each watershed requires a slightly different analytical focus: water flow considerations in the Ljusnan and fish passage in the Emån.

The program uses input from three groups of scientists, and an architecture for interdisciplinary was applied to work helping to combine cutting edge research from each of the disciplines. The program has been stipulated to last for 36 months with a budget of 20.5 million SEK

We have followed the evaluation guidelines given by Elforsk.

1.1 Goals and strategy

In the project proposal the ultimate goal of the project was to provide a framework for state of the art CBA of river regulation. This ambitious goal is divided into subsidiary goals including:

- Develop generally applicable theory and methodology for CBA in regulated rivers, in particular with regard to Emån and Ljusnan
- Carry out empirical studies that supply the necessary biological background for innovative CBA
- Generate methodologies to handle uncertainty in natural science and economic models and apply it in the empirical studies
- Develop tools to be used to quantify the ecological effects of measures in hydropower regulated rivers

In addition to developing generally applicable methodologies, the project provides site-specific information for the Emån and Ljusnan watersheds. Therefore, an important goal is to disseminate findings and provide decision-support to policy makers in these locations.

The general strategy is to construct policy-relevant scenarios and to subject these environmental measures to a carefully integrated conceptual and empirical analysis that draws upon natural sciences, mathematical statistics, and economics. These areas are linked together by the four work packages described in section 5 of the report from the program.

In developing this strategy a number of factors were considered. First, the duration of the project is 36 months, which calls for careful planning and sequencing of the analysis. For example, there is a natural constraint arising from the fact that biological assessments in the Emån must take place in the spring-summer season. Furthermore, the valuation studies are especially time consuming and must be informed by the analysis done by the natural scientists and the mathematical statisticians. The solution to this sequencing is outlined in the Time plan of the proposal.

1.2 Overall evaluation

The work was divided into four work packages. Economics has been the central part of the program and WP 1 has been the workhorse with both an administrative part and a scientific part.

The coordination and administration of different scientific environments at different locations is challenging. In programs of this size the coordination part could be a separate work package in order to release more time for scientific work. It seems that the team leader of WP1 who is also the overall coordinator has had a busy time. Much of the coordination work is difficult to observe from the outside, and this kind of work is seldom given the credit it deserves.

The overall impression of the program is that much work is done, with a heavy burden on a few key persons. However, there are some difficulties in validating the scientific production from the program because several publications are still in the referee process and some publications are not available because the program is not yet finished.

Scientific quality

Unfortunately not all the references listed in the final report exist, even not in a draft format, which we had expected. Considering this is a cross disciplinary and applied project the scientific quality is at an acceptable level. The number of papers in referee journals is much lower than envisaged.

Much work is reported in internal reports and the quality of the work has potential to be published in referee journals. Most of the scientific reports are from the study in Emån which has been part of the whole project period. The work done at Ljusnan and the cost benefit analysis is new in this phase of the program and had a shorter time to fulfill their goals.

The lack of referee journal articles in the field of economics is, however, compensated by the publication of two books at well known international publishers.
The scientific output from WP4 seems limited. This is partly due to their function to deliver data and model to wp1 and wp3.

The strength of the scientific team is that they are open to cross disciplinary work and their ability to combine the individual strength of the different teams. The main strength of the economists are in theory and methodology, and for the fish biologist their ability to perform applied science in addition to basic science.

Relevance

The goals and objectives of the program have a very high relevance both to the energy industry, the energy and environment governments and policy makers. The relevance is high because these matters are questioned in the Water Framework Directive, especially in concern to heavily modified waters. These matters are also important dealing with revision of terms of regulated rivers and the implementation of the Renewable Energy Directive. What will be the future price of water is a key question.

The tools developed are highly applicable both in a short and long term, but is not complete. This holds both for the CBA and the population model. The research teams seek for a holistic, realistic and complex model. This model is difficult to parameterize, and further work should focus on developing simpler and more user friendly models. In this context the handling of uncertainty is crucial. The transferability of the result has not been tested nor validated. This needs to be done to get applicable tools for use in regulated rivers.

Cooperation

There seems to have been good cooperation throughout the program between the project leader and the program board. The interaction between the various WPs also seems to be good, which is essential to this program.

Based on the frequent meetings there has been good interactions between both the research teams and the Board. The Board has been very active in defining the goals and objectives, and also in the decision of the scenarios. Overall it is very good to have an actively involved Board with a good sense of ownership of the program and great interest in making use of the results and the tools developed. However these close interactions are time consuming which might have delayed the scientific output of the project. This partly caused prolongation of the project from June to October 2010.

Local reference groups representing NGOs and the local community have been positively involved in the work. All research teams have good relations into international networks, and these contacts seem to have been applied in the research work.

Goal achievement

Assuming that the reports work referred to as prepared in the final reports will be finalized the overall program goals have been fulfilled (except for the methodologies to handle uncertainty in natural science and economic models and apply it in the empirical studies)

Administration

The program has been well organized. The program board and the project leader has actively discussed the progress of the project. The administration of the program has been very good, and the information plan has been successfully executed.

2 Work packages

2.1 WP1 Economics – Cost-benefit analysis

Team leader Bengt Kriström,

Objectives

- Provide a detailed welfare analysis of policy changes affecting selected river systems.
- Refine and extend existing methodologies for cost-benefit assessment in human dominated ecosystems.
- Develop cost benefit analysis with emphasis on handling uncertainty in input/output data

We have identified 10 internal reports as the scientific output of this WP, including two books by Johannsson and Kriström (one monograph and an edited volume, both to be published by reputable international publishers; Edward Elgar and Springer) which can be viewed as the main output of WP1, together with the special report by Førsund and Hjalmarsson on the value of balance regulation power (requested by the program board, and an important input to the CBA). No paper from WP1 has been published in a refereed journal. However, books seem to be the best way of publishing both the developed CBA tool and results from cross-disciplinary projects like this. It is also very useful for both academics and the end users to have this blueprint for a CBA of river regulation/hydropower published in a book rather than in papers in different journals.

The general equilibrium CBA tool developed is an original contribution to the literature on applied CBA, and the papers show clear potential for publication in refereed journals (although in applied journals, as the program does not have the methodological twists often needed to be publishable in refereed journals within a single discipline, but this is acceptable in cross-disciplinary user-oriented projects like this).

The CBA tool developed is very relevant to the end user and very generalizable, but the information generated is not. However, the two rivers seem not to have been selected (by the Program Board) from the perspective of being representative of groups of rivers in Sweden for which Cost-Benefit consideration will have to be performed as part of the implementation of the EU Water Framework Directive..

Overall WP1 have almost achieved their goals and their deliverables, but only the CBA case of the Dönje power plant in Ljusnan is completed in terms of being available as reports for the evaluation committee. The write-up of the other two case studies, on "-2+1" in the Ljusnan and Emån rivers have not been completed yet, and only a summary of the work to date in the final report is available, which makes it difficult to evaluate the output.

Much focus of WP1 and 2 have been on getting the best estimate for mean WTP, rather than the equally important or even more important question of determining the "extent of the market", i.e. the number of affected households in terms of their utility (or level of wellbeing) being affected by the impacts of measures analyzed for the regulated rivers, which is used to calculate the total non-use benefits of the measures. While changes in use values, especially impacts on recreational fishermen, are relatively easy to assess in terms of extent of the market, the number of households having non-use values needs more scrutiny in terms of well-designed sampling design to check for distance-decay in WTP (i.e. how WTP decrease as we move away from the river, and the number of substitutes (in terms of rivers providing similar ecosystem services) increases, and thus households are willing to pay less or nothing for the improvements in ecosystem services in the rivers analyzed. By accident the survey firm hired to conduct the survey in the Dönje case study also got responses from the communities close to the directly affected community of Bollnäs, showing a very distinct distance decay in WTP since nearly no households in the neighbouring communities had any WTP. However, such study to determine the extent of the market should have been planned from the outset in all case studies. It is also unfortunate that the case study in the River Emån did not look at non-users (this was approved by the program board) as the non-use values usually constitute the majority of benefits because there are more non-users than users (i.e. recreational fishermen) even if the WTP of non-users are lower than for users (However, users could also have non-use values and Stated Preference methods like CV and Choice Experiments would uncover these, whereas Revealed Preference studies as the Travel Cost method would not). Thus for the River Emån a complete assessment of the social benefit is not possible based on original research, but could potentially be assessed by benefit transfer (i.e. transfer of non-use values for a similar improvement from a similar type river).

The overall idea and aims of WP1 of developing a generalizable CBA methodology for evaluating measures in regulated rivers including marginal changes in river ecosystems is noteworthy even in an international setting. Even if there are similar ongoing projects in the USA on costs and benefits of removing dams and the economic benefits in terms of improved ecosystem services and contingent valuation (CV) studies of the overall ecosystem function, recreational fishing and landscape aesthetic impacts of hydropower developments in other European countries like Norway and France, this WP is an original contribution to the international literature in this field by performing a CBA of *marginal* changes in use and nonuse values from quantified changes (from WP 3 and WP4) in fish populations and other biodiversity in regulated rivers. (whereas most previous valuation studies in this field have looked at the environmental costs of having hydropower developments or not, i.e. a discrete change in environmental quality). In addition they perform the CBA in a General Equilibrium context, addressing all impacts on other sectors of the society. Thus, the project is very ambitious, especially considering the rather short time frame of such a cross-disciplinary project. The project seem to have achieved the first two objectives, although is difficult to fully assess whether they have reached these objectives in the two of the three case studies as these reports are not finalized, and we can only judge from what is outlined in the final report. We find it strange that they refer to a paper which does not exist, even in draft format.

Our evaluation is based on the existing reports, but to some extent also on an assumption that they will deliver what is outlined they will do before the extended deadline in October. However, it seems likely that WP1 will not fully achieve their goals, especially their third objective of this WP, which involves developing a CBA with emphasis on handling uncertainty in input/output data. This is unfortunate as the project has a well qualified team of statisticians that could have performed this task (see also our comment on this under WP2).

The strength of the WP 1 research team is clearly theoretical, methodological and survey design, but not implementation of the survey. Thus, the efforts going into constructing and testing the Dönje power plant CV survey is impressive, and an example of excellent co-operation between economists and ecologists in this research program, and between both these research teams and the end users (including the Program Board) in designing the scenarios to be valued. However, the implementation of the valuation surveys is not satisfactory due to very low sample size in the Dönje case) and seemingly low quality of the work of the survey firm in the "-2+1" case in River Ljusnan (i.e nearly all of the non-respondents contacted by phone had not received the web-survey). However, the sample of the River Ljusnan survey seem to be representative, but the research team needs to closely assess the quality of the data collected.

2.2 WP2 Statistics - Uncertainty

Team leader Bo Ranneby

Objectives

- Develop methods for evaluation of quality in models, data and the final CBA
- Develop a strategy to handle the problem with none responses in the determination of WTP
- Develop methods to handle uncertainty in preferences

The attempt to develop methods to evaluate the uncertainty for the whole chain including the uncertainty in the final CBA

The **objectives** of this WP were:

- Develop methods for assessing error propagation (e.g., model quality, data, and CBA);
- Develop strategies to handle survey non-responses in determination of WTP
- Develop methods to handle preference uncertainty

The planned **deliverables** of this WP were:

- Paper on handling non-response in survey research
- Paper on handling preference uncertainty in valuation studies
- Paper on statistical methodology for point/interval data

We have been given four papers written as part of this WP (which the research group submitted only after the evaluation committee asked for documentation for the work performed in WP2). Ekström (2010), Ranneby and Yu (2010), and Belyaev and Kriström (2010) all address the issue of point estimates and interval estimation of willingness-to-pay (WTP) in Contingent Valuation (CV) studies. Yu and Leonardsson (2010) address the important issue of the uncertainty in expressed fishing time from recreational fishermen. All of these are internal reports/conference presentations and none have been published in refereed journals. Ranneby and Yu (2010) is, however, planned as chapter 5 in the forthcoming book edited by P.O. Johannson and B. Kristrom (2010): Modern Cost-Benefit Analysis of Hydropower Conflicts. The final report also mentions Kuljus & Ranneby (2010) that model future electricity prices, an important component of these CBAs, without using previous prices. However, this paper is not finished yet, and not even a draft paper is available although it is referred to as a publication in the final report. Therefore, it is not possible for us to evaluate this work. The CV survey performed in Ljusnan of the “-2+1” scenario did unfortunately not provide data to test whether the proposed new WTP elicitation method of point estimates and self-declared intervals can reduce non-response in CV surveys, compared to a standard payment card elicitation format (with constructed intervals). This was partly due to unexpected problems in the survey implementation and poor quality of the work performed by the survey company, but also due to the survey design where a split sample comparing the proposed elicitation method with a standard payment card would have been the preferable option. Overall, the output in terms of both reports and results seem to be on the low side relative to their budget (which is difficult to assess as only an overall budget for WP1/2 is given in the annual reports, but the program leader Bengt Kriström) reports that this budget can be divided by 2 to reach the WP2 budget). Also, the strength of the WP2 research team seems to be on the theoretical side rather than on the research design and empirics, at least judged from the papers currently available to the evaluation committee. Also, since the handling of uncertainty in CBA was a focus of the initial proposal it is disappointing that this was not implemented in a Monte Carlo simulation in the overall CBA of the case studies (but rather straight forward sensitivity analysis, which however can be argued to be more user friendly and less data demanding and less of a black-box method than simulation models). We have been informed by the program leader Kriström that Monte Carlo simulation has been performed in the population dynamic model performed as part of WP2 but the documentation of this work is not ready yet. However, this is still only a part of the overall CBA.

The interaction with WP1, and to some extent also WP4, seem to have been very good. To conclude, WP2 have only partially attained their goals according to the project plan, and the output in term of papers is limited but of acceptable scientific quality.

2.3 WP3 Emån

Team leader Larry Greenberg

Objectives

- Quantify the function of natural fishways as a way of re-establishing upstream connectivity
- Identify downstream passage problems for fish migrating past hydroelectric facilities and evaluate remedial measures that increase downstream connectivity.
- Predict the overall ecological effects of reestablishing longitudinal connectivity past power plants in Högsby and Blankaström using population models

In WP 3, the team from the University of Karlstad investigated downstream migration of anadromous brown trout *Salmo trutta* and Atlantic salmon *Salmo salar* as well as freshwater resident chub *Leuciscus cephalus* passed hydropower plants in the River Emån. Their investigation shows the importance of including possibilities for downstream and not only upstream passages, when assessing the possibilities for success of anadromous fish in regulated rivers. Furthermore, they have partly estimated, partly acquired parameters from the scientific literature, for use in the population model developed for Atlantic Salmon in WP 4, but here applied for anadromous brown trout. They estimated the production of brown trout smolts, which migrate to sea younger than estimated in previous investigations. Possibly this is due to climate change, but also the application of a new method analyzing the density of strontium in the sacculus otoliths, showing that also young-of-the-year migrate to sea (but not included in earlier investigations). Experimentally, the group has participated in migration experiments on European eels illustrating how this fish behave when meeting obstacles in the river, and how they seek turbulent water when moving downstream, avoided by most other migratory fish in fresh water.

The quality of the work done is very good. They have published 5 refereed papers in international journals, although one of them is financed from another source. The papers are published in Ecology of Freshwater Fish (2) and River Research and Applications (3). This indicates that the studies are appreciated by colleagues and of sufficient high quality and of general interest for an international audience. The evaluation panel feels that this is very satisfying for applied work produced within a relatively short time. It also visualizes the advantage of continued research on similar and related questions over a relatively long time period allowing in depth studies.

The methods used in the project are adequate for the purpose and their efforts to lead fish passed the water intakes to hydropower plants shows initiative and creativity. The strength of the group is their ability to use scientific knowledge to solve applied problems in water courses.

Although they have not reached the final solution to how to lead downstream migrating fish passed power plants, the project is of high industrial as well as environmental relevance. By use of the lenses and tarpaulin cover, it is possible for the industry to guide at least a part of the downstream migrating salmonids passed power plant gates and thereby increases survival and migratory success. Increased survival and enhanced population size are also environmentally relevant and can be readily applied.

The aims of WP 3 are fulfilled. However, the parameterization of the population model should be based on better data material and longer time series are needed before proper functions can be included for stock recruitment relationships, smolt age, and probability of repeat spawning. Also survival at different life stages should be studied further.

WP 3 has contributed little to the other WPs, and most of the work has been performed without interference with the other teams.

2.4 WP4 Ljusnan

Team leader Kjell Leonardsson

Objectives

- Develop a framework for quantitative predictions of ecosystem restoration in dewatered channels, as a function of discharge and flow regimes – for use in CVBA analyses and in restoration processes in general, and for a case study in the research program in particular
- Develop a population model of migrating fish population in rivers with connectivity issues.
- Provide an analysis between regulated and unregulated flows in the framework of IHA (Indicators of Hydrological Alteration)

WP 4 discusses scenarios on environmental improvements for Atlantic salmon, brown trout and European grayling *Thymallus thymallus* in the Ljusnan, a 440 km long river regulated river (except in the middle part which is protected against the building of hydropower stations). This river used to be an important producer of anadromous fish, but today all anadromous fish are stocked salmonids of hatchery origin. The scientists involved in the scenarios maintain that wild Atlantic salmon can be reintroduced given that the two power plants closest to sea are eliminated. But to maintain hydropower production, they suggest building of a new plant upstream of the new habitat made available for Atlantic salmon in the lower part of the river. Self-sustaining populations of brown trout and European grayling can be formed in Klumpstrømmen, just north of Bollnäs. However, to obtain this the minimum flow during winter should be increased from 0.25 to 3 m^3s^{-1} and during summer to 10 m^3s^{-1}. This will both enhance the quality of the ecosystem services produced and improve the esthetic value of the river.

A holistic population model for Atlantic salmon was produced in WP 4. A preliminary version of the model is tested, but the evaluation committee feels that it is unclear to what extent fixed values or probability functions are used for the various population traits. There is little if any relationship between environmental variables such as temperature and population traits. The Shephard three parameter model might be more appropriate as stock-recruitment function than the Ricker or Beverton-Holt two parameter models where the user a priori has to determine whether the function is asymptotic or bell-shaped. When finished, the model should be published in an international journal.

The scientific quality of the work in this WP is difficult to evaluate. Little is published in international refereed journals, and the one paper listed from the project is from another river where the methods used for habitat classification in Ljusnan are described, and therefore judged relevant. They also give an international paper on survival of hatchery produced smolts in nature, and a book chapter on monitoring of juvenile Atlantic salmon and brown trout in another river, but financed by others. Furthermore, two master theses are listed because the results of these have been useful when the population model was parameterized.

But the scientific output from WP 4 is low. The team will fulfilled their aims by preparing institute reports from the work, but this is not proper communication from a scientific project.

The strength of the present group of scientist is their modeling skills and ability to contribute to the other WPs. Both the habitat classification and the population model have been most important in this respect. They have also contributed to other parts essential for the cost-benefit analysis.

The project has industrial relevance in relation to downstream migration of fish passed hydropower stations. Environmentally, it is relevant to estimate possibilities for building sustainable populations of anadromous fish species in the river by increasing water flow.

The population model is most relevant as an important input to CBA, and in relation to the EU Water Framework Directive and the Habitat Directive.

3 Conclusion and Future work

3.1. Conclusion

All in all the project has given good value for money, assuming that all reports listed will be finalized. We are impressed by the amount of work performed within a short time, considering the complexity of this cross-disciplinary project. The project teams show great ability to combine scientific theories and methodologies across disciplines, and there is great potential for developing a fully integrated CBA tool. In hindsight it was probably overly optimistic to expect that all the ambitious goals of the project would be achieved within three years. A logical next step would be to build on the good work performed and further develop and validate all parts of the CBA tool. The strength of the economic team is the strong theoretical basis of their work, and hypothesis testing. The population ecology studies are based on observational fundament, and we would recommend a similar theoretically driven research with testing of scientific hypotheses for this group.

3.2. Future work

The further refinement of the cost-benefit analysis should be an important part of a future program. This part of the present program is not finished, and continued close co-operation between biologists and economists is needed. There has been a good start, but it is time consuming to learn each other's way of thinking and production of relevant and useful products. There have been methodological problems, but after this preliminary phase, they can be overcome.

Although it is noteworthy that the research project tries to develop an advanced CBA tool, this makes it more difficult and time- and resource consuming to apply for the end users. Thus, there is a trade-off between making the CBA tool more complete and advanced, and making it simpler but more user-friendly for policy makers (in terms of e.g. an excel sheet adapted CBA tool with transferable unit value for all input data (preferably based on tests of transferability of both biological and economic data, and with attached intervals for the uncertainty of each input factor). Making the CBA tool more user friendly, generalizeable/ transferable to more groups of rivers with regards to both biological data/population dynamics and economic data, and develop a more comprehensive treatment of uncertainty in the overall CBA would be our recommendation for a potential new phase of this research program. The current phase of 3 years seems to too short for the development a CBA tool with these characteristics, that can be used in assessments related to the EU Water and Habitat Directives and national environmental goals.

Thus, we recommend that the successful cross-disciplinary work performed in the current phase is continued in order to develop an applied CBA tool, methodologies for generalizing biological/population dynamic and economic data, and select case studies aimed at producing generalizable and geographical transferable biological and economic data.

In a future programme one should also continue the biological work started in phase 3 of the programme. One should continue the population monitoring in the River Emån to build time series on population characters such as smolt age, age at maturity, repeat spawning and longevity of anadromous brown trout. This should be used to further parameterize the population model and relate abundance variation to environmental variables such as flow and temperature, two parameters we know will change with time, global warming or not. This will reduce uncertainty and more realistically include variability in the model estimates. One can also expand the work to other types of river systems to better be able to judge the generality of the results; i.e. to what extent findings in the River Emån are general or special adaptations reflected by the particular population. This latter point can be strengthened by a study of the scientific literature. In parallel, one should continue the work with refining the population model, making it even more realistic and usable as a tool for predicting population change in dynamic environments.

The promising experiments at the River Emån with different techniques how to prevent migrating fish entering turbine intake should continue. These techniques may be decisive as remedial actions when aiming at increasing the population of migratory fish in regulated rivers.

In the River Ljusnan, -2 + 1 has been suggested. We do not know to what extent this is a viable plan. But if one decides to close down any of the downstream power plants and re-establish selfsustaining populations of anadromous salmonids, one should monitor the population establishment. There is as yet little knowledge about salmonid establishment in rivers with no prior anadromous fish, how density, growth, size and age distributions change with density.