Overview Article

Green Hydropower: The contribution of aquatic science research to the promotion of sustainable electricity

Bernhard Truffer^{*,1}, Christine Bratrich¹, Jochen Markard^{1,2}, Armin Peter¹, Alfred Wüest^{1,2} and Bernhard Wehrli^{1,2}

¹ Swiss Federal Institute for Environmental Science and Technology (EAWAG), Limnological Research Center, CH-6047 Kastanienbaum, Switzerland

² Swiss Federal Institute of Technology (ETH), ETH-Zentrum, CH-8092 Zürich, Switzerland

Received: 31 October 2002; revised manuscript accepted: 20 March 2003

Abstract. Hydropower use is responsible for a wide range of environmental disturbances to river systems. Over the past decades, aquatic science research has been successful in identifying a considerable number of relationships that exist between plant operation and ecosystem quality. This increase in scientific knowledge was, however, not matched by a corresponding reduction in environmental impacts stemming from hydropower. In the present paper, we show how aquatic science projects may be defined and implemented to better link scientific knowledge with the resolution of environmental problems.

We base our analysis on a major aquatic science research project in which an eco-label for “sustainable hydropower” (Green Hydropower) was developed for Switzerland. We first assess the state of aquatic science

research on alpine river systems. The Swiss history of hydropower shows that the limited adoption of this knowledge was due to a severe coordination and action problem. The Green Hydropower project aimed at establishing an environmental product label for hydropower plant operation, which should help overcome these problems. It had to deal with two major challenges: the integration of widely differing knowledge stocks and the management of a network of diverse stakeholders operating in a conflict-laden political environment. By carefully dealing with these two problem areas, the project was finally able to define a scientifically-based and broadly-accepted standard for Green Hydropower operation. We conclude by discussing lessons for the improvement of problem-oriented aquatic science research, in general.

Key words. River ecology; hydroelectric power generation; eco-labeling; stakeholder involvement; transdisciplinary research.

Relating scientific knowledge to environmental action

The standard view on the relationship between science and problem resolution is that the availability of adequate knowledge is the limiting factor for action. Science is, therefore, called to deliver the necessary facts and relationships from which decision makers may determine pri-

orities and choose the best set of alternative solutions. This “role model” has been responsible for an amazing range of success stories, such as banning particular substances, in the field of environmental management. However, it has proven much too simple for dealing with many recent and more complex environmental problems (Nowotny et al., 2001).

When confronted with the limitations of this information transfer model, academic officials often propose two kinds of remedies: either the scattered and inaccessible nature of most scientific facts must be overcome or the highly specialized language of scientists must be

* Corresponding author phone: +41 41 349 21 11;
fax: +41 41 349 21 68; e-mail: truffer@eawag.ch
Published on Web: July 3, 2003

translated into popular language. In the first case, efforts to review, conceptualize and interlink knowledge have been developed over the past few years. The Intergovernmental Panel on Climate Change (IPCC) serves a high-level role model in this case (Houghton et al., 2001). The second approach has led to a considerable increase in public relations expenditures by most academic institutions.

In the present paper, we state that both strategies, valuable as they may be, are often not sufficient to bridge the gap between scientific knowledge production and practical problem solution. In many instances, the problem is not one of lacking information but rather a coordination and action problem (Wiesenthal, 1990). As will be shown in the following, besides efforts to synthesize scientific knowledge from a wide variety of academic and non-academic actors, a careful analysis of coordination and action problems was crucial for the development of solutions to mitigate environmental impacts from hydropower plants.

In the following section, we first document the state of aquatic science research dealing with impacts from hydropower on aquatic ecosystems. We then identify barriers for mitigating these impacts in Switzerland by referring to the political history of the public debate on hydropower. This analysis shows that the key actors were confronted with a so-called social dilemma. A product label for “Green Hydropower” was perceived by many actors as a way to overcome this social dilemma and thus to promote sustainable operation modes for hydropower plants. In section 4, we elaborate on the motivation and major challenges of a transdisciplinary aquatic science research project, which aimed at developing such an ecolabel for Switzerland. Major working areas were the synthesis of diverse sets of knowledge in order to realize a workable assessment procedure and the coordination and trust-building process with the different stakeholder groups. The result is a widely agreed upon standard for sustainable hydropower use, which shows some first results in the improvement of alpine river ecosystems. We conclude by discussing the lessons to be drawn from this experience for aquatic science research.

The impact of damming on aquatic ecosystems

Reservoirs and dams are responsible for a wide variety of environmental problems (WCD, 2000). According to a recent review by Gleick (1998), almost 500'000 square kilometers of land are inundated worldwide by reservoirs. This area is larger than the surface area of the Caspian Sea (374 000 km²). Sixty percent of the 227 largest rivers on earth are strongly or moderately fragmented by dams and diversions (Revenga et al., 2000). Most of the dams in mountain regions are used for hydropower production.

In some mountain regions, the river systems are almost completely dammed. Switzerland, Austria, Norway and Japan have the highest hydroelectricity production per surface worldwide (Truffer et al., 2001b). This high density of power plants may have considerable impact on biodiversity and ecological stability of mountain ecosystems: In the European Alps, 79% of the river reaches are influenced by hydropower operations (Tödter, 1998).

At the local level, hydropower construction and operation is associated with a number of serious environmental problems: water diversion, interruption of fish migration, hydropeaking, reservoir flushing and inundation of landscapes, and alterations in bio-geochemical cycling (Friedl and Wüest, 2002). Most of these environmental impacts have increased considerably over the past few decades. The average residence time of river water in regulated basins has tripled to more than one month worldwide (Vörösmarty et al., 1997a). Large reservoirs trap 30% of the global suspended sediments (Vörösmarty et al., 1997b). Such physical alterations have already drastically changed the conditions of aquatic ecosystems, which harbor an exceptionally high number of species. Although approximately 300 new freshwater species are discovered each year, amphibians, fish and wetland birds are at high risk of becoming extinct in many regions of the world (Revenga et al., 2000). More than 20% of all freshwater fish species are now considered threatened or endangered (Gleick, 1998), mostly due to damming.

This assessment led early on to dedicate a considerable amount of research activity to the ecological impact of dams (Friedl and Wüest, 2002). Different research agendas were developed in recent years to understand and assess the functioning of natural and modified aquatic systems and to predict their reaction to river restoration projects. Ward (1998) reviews recent advances in the conceptual development of river ecology. His fundamental approach is focused on the description and understanding of natural river systems, which are quite rare in many alpine regions of the developed world. Among the large rivers of the Alps, only the Tagliamento in Slovenia/Italy is left in a pristine state.

A quantitative comparison of modified vs. natural rivers is therefore assigned a high priority in the research agenda. The integrative concept of “river health” has been proposed to provide such measures. However, it is not an easy task to develop an operational protocol for the assessment of “river health”. This concept spurred a heated debate, which is documented in an issue of *Freshwater Biology* (Karr, 1999; Boulton, 1999; Bunn et al., 1999; Fairweather, 1999). Nonetheless, in order to obtain quantitative measures of river degradation, many researchers are developing integrated assessment methods (Boon, 2000). Such efforts have been translated recently into

monitoring programs run by political authorities such as the European Union Water Framework Directive (Blösch, 1999; Chovaneck et al., 2000) or the Swiss Modular Concept for River Assessment (Bundi et al., 2000). Such initiatives will engender massive activities for monitoring rivers during the coming decade.

Despite the massive efforts expended to develop concepts for river assessment and to determine the negative effects of damming and hydropower operation on aquatic ecosystems in the Alps, very few success stories can be found regarding the actual mitigation of these impacts. This failure of linking scientific results with actual problem resolution was not due to a lack of public awareness. Quite the contrary is true, at least in Switzerland.

The sociopolitical environment for sustainable hydropower in Switzerland

The mitigation of hydropower impacts on Alpine ecosystems has been a topic of considerable public debate in Switzerland. Several attempts over the past 20 years to solve these problems have had only limited success.

The political history of hydropower in Switzerland

The public discourse about hydropower in Switzerland went through a number quite clearly demarcated phases. In a first phase, which started between 1880 and 1914, the electrical utopia based on the “white coal” sparked a national consensus to develop alpine hydropower plants (Gugerli, 1997). However, due to technical limitations, the majority of currently running large-scale hydropower plants in the Swiss Alps was constructed in the 1950s and 1960s. Hydropower was then seen as a clean, indigenous energy source, which had to be exploited as much as possible to meet an exponentially growing demand for electricity after World War II. As a result of this rapid expansion, almost all major streams in the Alpine region are now impacted by hydropower plants and their operation (Fig. 1).

Due to the negative impacts of these developments on ecosystems, landscapes and local communities, national public opinion began to turn against plans to invest in new hydropower plants in the late 1970s and early 1980s. A number of spectacular grass roots movements against new hydropower projects gained widespread public support. The further expansion of hydropower was criticized

Figure 1. Major rivers in the Swiss Alps and their impacts from hydropower operation (after Truffer et al., 1998).

as destroying the last intact river ecosystems of the Alps. It was interpreted as the expression of an overly technocratic way of dealing with nature. This change in public perception culminated in a fierce political struggle over the renewal of the Swiss Water Protection Law at the end of the 1980s. The proposed law fixed, among other subjects, minimal flow requirements for Alpine streams impacted by reservoirs. In 1991, the revision of the law was accepted in a popular vote and since then the environmental improvement of hydropower is a legal requirement.

The renewal of the Water Protection Law led to a strong political opposition between several parties: Environmental organizations struggled for the protection of the last untouched river stretches in the Alpine mountain valleys while electric utilities lobbied against “unproductive” water running down the river. The debate was strongly conditioned by the institutional form of the electricity sector: The sector was – and still is – largely constituted by vertically integrated firms and regional monopolies for electricity distribution. In Switzerland, public authorities hold some 75% of the shares of electric utilities. Therefore, interest conflicts also arouse between federal authorities, supporting the Water Protection Law, and regional (cantonal) authorities in their role as shareholders and tax receivers of hydropower plants. This conflict became all the more important as regional authorities are responsible for enforcing the new Water Protection Law.

After the law passed, the political debate about the sustainable management of hydropower came to a standstill. The law could only be applied in the context of a renewal of the water use licenses. In Switzerland these licenses typically run over 80 years and therefore no major changes in operation could be expected before the year 2020. Furthermore, the deregulation of electricity markets begun to shape expectations in Switzerland. This new market order put pressure on hydropower operators to reduce cost and to act as competitive firms. Requirements, as those demanded by the revised Water Protection Law, were considered as a direct threat to economic survival of the plants.

The different periods in the political discourse about hydropower in Switzerland are depicted in Figure 2. The attention axes should be read in a qualitative way, which could be quantified by such measures as the number of newspaper articles, number of political initiatives in the parliament, etc. Seen in this way, the prospect of deregulating the electricity market led to a redefinition of incentives for plant operators and local administrations in a way that contradicted more environmentally responsive ways of action. As a consequence, the proliferation of more and better presented scientific knowledge risked deepening the existing interest conflicts between the parties rather than contributing to the solution of the environmental problems.

Figure 2. The development of the public discourse on hydropower in Switzerland over the past 70 years.

Green Power products as an incentive for sustainable hydropower operation

Nevertheless, the new market order also opened up new opportunities for utilities to deal with the environmental question. Experience from other countries with deregulated electricity markets showed that consumers are willing to pay extra for electricity with low environmental impact. A number of incumbent electric utilities, as well as newly emerging Green Power marketers began to develop Green Power products to differentiate themselves from other suppliers (Wüstenhagen et al., 2003; Wiser et al., 1999; Holt, 1997).

Studies of the market potential for Green Power, however, predicted that about 20% of private households would be willing to pay a premium of 20% on top of current prices (Bird et al., 2002; Wiser et al., 2001). If firms and communities are included as potential market segments, market shares of 20% of the total delivered electricity may be achieved (Truffer, 1998). Current sales, however, cover only a tiny share of the actual electricity market. In Switzerland, market shares in regions where Green Power is supplied are below 1% (Wüstenhagen et al., 2003). The difference between actual market share and market potentials gave rise to a number of studies that identified key conditions for success (Markard, 1998; Holt 1997; Farhar and Ashley, 1996): 1) Green Power should be conceived as a competitive product, not a mere donation, 2) It should be marketed professionally, 3) The electric utility should position itself as a trustworthy promoter of environmentally benign electricity, and 4) The surplus-payments should be invested in a transparent and credible way (Truffer et al., 2001a).

The last success criterion has specific implications for hydropower compared to other renewable energy sources. The latter technologies have in common that production costs are, in general, high and quantities produced are negligibly small compared to the overall mix of electricity. There are widely held beliefs, that these technologies hold promising prospects for achieving substantial economies of learning (through research and development) and economies of scale (through increase in market volume). Consumers may therefore directly promote these technologies in order to speed up their large scale market introduction. Hydropower, however, is fundamentally different in all these respects (Markard et al., 2001): there are considerable production capacities at competitive prices all over Europe. Economies of scale and economies of learning have been reaped throughout the last century. Furthermore, building new power plants is often confronted with fierce political opposition, especially for the reason of protecting intact aquatic ecosystems. Therefore, the environmental benefit associated with buying electricity from hydropower plants could not be achieved by building new power plants. Rather, existing power plants should adopt less environmentally dis-

rupting operation modes. In order to credibly communicate the adoption of specific operation modes, a widely shared standard was needed. However, up until late in the 1990s there was no standard for sustainable hydropower operation available internationally (Markard et al., 2001).

The Green Hydropower label as a means to overcome a social dilemma

The political history of hydropower in Switzerland defined an extremely inhospitable environment for defining a broadly-supported standard for sustainable hydropower operation. However, the changes associated with market liberalization also partly motivated actors to reconsider their classical interest positions.

In order to better understand the interlocked nature of the decision problem with which the different parties where confronted, we may analyze it in terms of a classical "social dilemma" (Wüstenhagen et al., 2003; Rasmussen, 1989). In order to simplify our analysis, we may limit ourselves to discussing the positions of two major actor groups: hydropower operators and environmental NGO's. A social dilemma is present if decisions of two actors depend on each other and if both actors select a sub-optimal strategy of conduct to minimize their potential losses. An optimal solution would only be realized if each party could trust the other.

In the Swiss hydropower "game" either party could not trust the other. If it cooperated with the other party, it would run the risk of being forced giving up its vital interests. The specific payoffs for the two parties are described in Table 1. The signs (++ , + , - , --) stand for an ordinal measure of the positive and negative payoffs for each party if it chooses the respective strategy, while the other party is still free choosing its own. Analyzing Table 1 reveals that an equilibrium is reached if both parties "stick to their position". In this case, the potential losses for each party are smaller compared to a unilateral cooperation of one party while the other would chose to stick to its position. However, this defensive "optimal strategy" is still inferior to the solution, where both parties would cooperate.

Applied to our example, cooperation would mean to accept claims about "standards of good practice" for sustainable hydropower operation put forward by the opposing party. A common standard would have to lie somewhere in between the extreme positions having developed in the political debates in the 1980s. In 1996, we carried out a series of interviews with major stakeholder groups in Switzerland. Both plant operators and environmental organizations emphasized, that given the challenges of market liberalization, there was an urgent need to find new and less antagonistic ways for dealing with the public image and environmental impacts of hydropower plants. For environmental NGOs, for instance, it became

Table 1. Social dilemma with regard to adopting a Green Hydropower standard (modified from Wüstenhagen et al., 2003).

		Hydropower operators (H)	
		<i>Stick to position</i>	<i>Cooperate</i>
Environmental NGOs (E)	<i>Stick to position</i>	H Positioning Hydro products will be opposed by consumers and NGOs in the market. Negative image will be reinforced (–)	H Pressure on production cost would increase as a consequence of increasing environmental demands from NGOs (– –)
		E Application of water protection law will be confronted with strong resistance. Hydropower would have to be fought in the public arena despite its positive environmental characteristics. (–)	E Application of Water Protection Law would be eased. Even higher standards would be feasible for protecting the environment (++)
	<i>Cooperate</i>	H Image of hydropower would be improved after long years of criticism (++)	H Positioning Hydro products as Green Electricity. Credibility and image import from NGOs (+)
		E Give up the advocacy position as a protector of natural ecosystems and landscapes (– –)	E Explicit definition of environmental quality standards for electricity. Accepting utilities as partners (+)

clear that with market liberalization new approaches for regulating the environmental impacts of the electricity sector had to be found. Hydropower was perceived as much less destructive as most of the low-cost fossil fuel alternatives, which could flood the open market. On the other hand, abandoning their position of being the protectors of landscapes and ecosystems was not feasible. For hydropower operators, market opening was associated with increasing pressure on the cost side without much opportunity to improve on the income side. Differentiation along environmental criteria seemed at least one promising way, especially as willingness to pay studies of green consumers seemed to cover additional costs for environmental upgrading measures. However, actively positioning themselves in a green goods market was perceived as a risky endeavor. Consumers would, in general, be very reluctant to accept environmental claims from a traditional electric utility (Truffer et al., 2001a). Therefore, a credible partner supporting their claims was needed. Environmental NGO's would fulfill this role perfectly well. However, utilities feared that once they would accept claims from the NGOs they would be forced to accept ever increasing demands to respect the environment.

The production of a standard in the Green Hydropower project

Having defined the dilemma structure of the situation, the preconditions for promoting less damaging ways for hydropower operation could be formulated much more sharply: A Green Hydropower standard would have to be developed in interaction between hydropower operators

and environmental interest groups in a stepwise procedure building on trust and credibility. Given the complexity of this task and the lack of trust between the parties, a scientific research institute could position itself as a mediator.

A team of researchers at the Swiss Federal Institute for Environmental Science and Technology (EAWAG), therefore, started a "Green Hydropower Project" (Truffer et al., 1998). It identified the problem field of Green Electricity as an interesting research opportunity because a whole series of ecological and economical questions had to be clarified. Furthermore, the development of an eco-label for Green Hydropower seemed to be a promising field for testing new forms of problem-relevant aquatic science research (Truffer et al., 1998; Truffer et al., 2001c).

Setting up the internal structure of the project

This analysis led to the definition of the following project goals:

- A certification procedure for hydropower plants should be developed which should be applicable in Switzerland and internationally.
- A broadly-based constituency should be built up to decide about the highly value-laden questions involved in the development of such a standard and for supporting the eco-label scheme.
- Social and natural scientific research projects should be carried out in an interdisciplinary way.

The Green Hydropower project, which was officially launched in April 1998, encompassed about 30 individual

projects, divided into four working groups that tackled specific problem areas:

- A first group focused on developing new tools for determining minimum flow regimes. It coordinated its research activities towards a proposal for assessing minimum flow regimes for alpine river stretches (Moosmann et al., 2002). The group developed numerical models to predict and analyze changes in habitat quality for fish and benthic organisms (Jorde, 1997; Schneider et al., 2001) and changes in the temperature and chemical regime as a function of minimal flow requirements (Meier et al., in press).
- A flood-plain group analyzed exchange processes between ground water and riparian ecotones (Holocher et al., 2001). The biodiversity of benthic organisms and the importance of sediment transport were analyzed.
- A market and policy group concentrated on the emerging Green Power market. It analyzed successful marketing strategies (Wüstenhagen, 2000), analyzed preference formation and learning processes of consumers (Truffer et al., 2002a), analyzed eco-labeling initiatives world-wide (Truffer et al., 2001a) and looked at complementary policy measures to enhance the effectiveness of Green Power markets (Markard and Timpe, 2001; Markard and Truffer, 1999).
- A fourth group was responsible to develop the assessment procedure for operation and design alternatives of hydropower plants (Bratrich and Truffer, 2001).

Work began with a case-study phase. The natural science research groups located their empirical work in the Blenio valley in the southern Swiss Alps. The Blenio valley is the catchment area of the river Brenno, which is used by a major power plant with 400 MW production capacity and a seasonal storage reservoir of 100 Mio m³. Its environmental features formed an ideal learning space for carrying out an integrated study of several aquatic science aspects of hydropower use. The lessons from this integrative approach were used as input into the assessment procedure.

Managing external relationships

Managing the external relations proved to be more challenging. The starting point for an initiative was in 1998 when the Swiss National Ministry of Energy set up a working group to define a Swiss electricity label. The EAWAG team was participating actively as an expert for aquatic ecosystems. Out of the experience of this working group, two well known representatives from Swiss utilities and the NGOs – the WWF Switzerland and the electric utility of the city of Zurich (EWZ) – commissioned a private consultant to develop a business plan for an association that would own and operate an eco-label for elec-

tricity. This led to the foundation of a private association, the VUE (Verein für umweltgerechte Elektrizität, Swiss Association for Environmentally Sound Electricity) in October 1999. The board of the VUE was constituted in a way to achieve a balance of power between the different interests (electric utilities, environmental NGOs and consumer organizations), and thus to generate credibility for a wide audience interested in Swiss energy policy.

In the preparing discussions, it became clear that two major challenges had to be resolved for achieving a broadly-shared standard: First, criteria for hydropower as Green Electricity should be defined. Second, the label had to guarantee that the “new renewables” (i.e., wind, solar, biomass and geothermal energy) received enough support despite the cost advantage of large hydropower plants.

The development of the hydropower standard was initiated by and commissioned to the research team of EAWAG. It developed the basic scientific concepts and tried to mediate between the different interest positions. Some interest groups were strongly critical towards the compromises proposed by the project team. In particular, they did not trust the new cooperative spirit between the different parties. Trust and concept development happened, therefore, in tight interaction with the members of the VUE board. However, the test of acceptance had to be sought beyond the limits of the supporting institutions.

In summer 2000, the Green Power label was publicly launched. It consisted of two major elements which dealt with the key problems associated with the integration hydropower into Green Power products:

First, a two-level label was defined (for details see www.naturemade.org). The first level, *naturemade basic* was conceived as a declaration of origin for renewable electricity. Naturemade basic should differentiate conventional hydropower plants from power stemming from nuclear or fossil fueled power plants. The second level, *naturemade star*, was defined for environmentally preferable electricity. Here plants may be certified that fulfill additional criteria with regard to their lifecycle characteristics and have low local environmental impact. Hydropower plants may achieve this level if they adopt an environmentally optimized operation mode, i.e., by accepting the criteria set developed within the EAWAG project (see below).

Second, in order to protect the “new renewables” from cost competition of large hydropower plants, a “promotion model” was set up. The marketers of naturemade certified electricity products must guarantee that at least 5% of their sale of certified electricity is covered by *naturemade star* products. By this, a strong incentive to actively promote environmentally less disrupting energy systems was installed.

By the end of 2000, the first plants and products had been certified. By the end of 2002, the VUE had certified

approximately 7'100 GWh of electricity (about 16% of the electricity produced by hydropower) of which about 237 GWh were of naturemade star quality (communication by VUE).

Results of the project

The interdisciplinary cooperation within a clearly defined project structure and the careful management of external relationships with stakeholders led ultimately to the achievement of all the initially set goals (see 3.1 and Truffer et al., 2002b).

The concrete product

The development of a concrete certification procedure had to avoid the pitfalls of both aquatic science assessment protocols and existing hydropower certification procedures. The protocols in the ecological literature are very extensive and detailed but mainly serve for assessing “deficits”. Often it is a long way to go from there to proposing actual mitigation measures. This means that existing protocols are mostly scientifically adequate but not easily applicable in practice. The existing eco-labels for electricity, on the other hand, used short hand criteria (such as size or age). These criteria have virtually no relationship to environmental impacts of the respective plant. Therefore, these approaches are easy to apply but meaningless.

The EAWAG team developed criteria related to the mitigation of local impacts from hydropower plants while being eager to formulate these in an operational way. As a first step, “basic requirements” were defined along two dimensions (Fig. 3):

- The first vector lists the relevant ecological domains of the river system: the hydrological character; the longitudinal, vertical and lateral connectivity; aspects

of sediment transport and morphology; landscape features and biotopes as well as relevant aspects of aquatic ecosystems.

- The second vector outlines the action fields for hydropower operators: regulations for an environmentally compatible minimum flow regime; measures to mitigate negative effects of hydropeaking; management advises for reservoir and sediment management; and conventions on how to design power plant structures like channels, fish passes or turbine inlets.

Standards were formulated for each of the 25 fields of the matrix by defining environmental goals, specific criteria as well as methodological hints (Bratrich and Truffer, 2001). The matrix approach helped to structure the problem area and to convert ecological know-how (the rows of the matrix) into management goals for hydropower operation (the columns). However, the individual criteria were quite difficult to quantify for a general case. The local combination of an individual power plant in a specific river catchment requires tailor-made optimizations.

As a consequence, basic requirements were complemented with the additional demand that a certain amount of money should be invested into local upgrading measures with the best cost-benefit ratio at the site. These so-called eco-investments are set as a fixed mark-up on the price of a kilowatt-hour and have to be invested in proportion to the green kilowatt hours sold to customers. Hydropower operators may signal to their customers that their Green Power purchase “makes an actual difference” to the environment.

Although this procedure had been developed in tight interaction with the relevant interest groups, hydropower operators had strong reservations concerning cost and time demands when applying such an encompassing procedure. The concepts were therefore intensely tested on half a dozen pilot plants involving experts from environmental consulting firms that already had worked on environmental impact studies of hydropower plants. In order

Management Fields	Minimum flow	Hydro-peaking	Reservoir management	Bedload regime	Power plant structures	Individually adapted restoration measures
Environmental fields	basic requirements					eco-investments
Hydrological character						
Connectivity of river system						
Sediments and morphology						
Landscape and biotopes						
Biocenoses						

Figure 3. Structure of EAWAG assessment procedure for Green Hydropower (see Bratrich and Truffer, 2001).

to keep the evaluation simple, a pre-study step was defined that helps operators to decide whether or not to further pursue the Green Hydropower labeling. Once this decision is made, the procedure helps to identify operation modes with low impact on local ecosystems.

Achievements at the level of research

The core products of the Green Hydropower project needed a strong interaction with actors outside academia. On the other hand, developing new approaches to assess the ecological optimization of hydropower plants and to evaluate the market prospects of Green Hydropower required a substantial input from interdisciplinary research projects.

The “minimum flow group” developed simulation models which might sometimes be too demanding for routine use in a small-scale Green Hydropower assessment. However, their results provide a firm scientific basis for the ecological optimization of minimal flow regimes in complex settings. During the project, major successes were achieved by customizing the software to small-scale conditions.

The research group on floodplain ecosystems did not achieve the goal of producing an assessment procedure for Green Hydropower. A major reason for this was that the analysis of water ages by the helium-tritium dating in the Brenno-floodplain showed that groundwater flow in this narrow valley is dominated by sources from the steep lateral slopes (Hollocher et al., 2001). This feature limits the impact of the hydropower plant on the riparian forests, thus protecting the high aquatic biodiversity in floodplain habitats (Brunke et al., 2000).

For the market and politics research group, the emerging Green Power market proved to be a productive research environment. Three main areas of research were tackled: (1) Success criteria for Green Power marketing were analyzed (Wüstenhagen, 2000) and the analysis of market demand for firms (Truffer, 1998) and households (Truffer et al., 2002a). (2) An in-depth analysis was carried out of the function and different forms of eco-labels for electricity (Truffer et al., 2001a). (3) the interaction of eco-labels, when seen as policy instruments with other policy instruments (Markard and Timpe, 2000) led to a specific design alternative for the Swiss and a German eco-label for electricity and a proposal for the construction of national disclosure scheme for electricity (Markard and Holt, in press).

Lessons learned for aquatic science research

A research institute like ours was able to play a decisive role in the specific political constellation of developing a widely recognized solution to long standing conflicts.

From this point of view, the Green Hydropower project was a considerable success. In order to achieve the above mentioned results, two critical conditions for success were identified: first the integration of different knowledge stocks to develop a feasible product standard, and second, the way of dealing with facts and values. We briefly discuss these two in the following. In a final paragraph we draw some conclusions on the way aquatic science research could take advantage of these findings.

Synthesizing insight from different knowledge sources

Regarding the assessment procedure, the goal of the research team was not to invent a completely new procedure. The assessment group was, therefore, confronted with the task to synthesize available knowledge and gain new insights for the specific context of Green Hydropower. Relevant knowledge for the five environmental topics shown in Figure 3 was scattered among different research institutes and private consulting firms. The challenge was to integrate the different requirements set by theoretical discourses (e.g., the river health concept) with standards of good practice followed by public administrations and environmental management systems (ISO 14001 or EMAS standards) and the sometimes highly context specific know-how of consulting firms knowing about the intricacies of individual power plants.

Such knowledge integration proved a major challenge in our research project and most collaborators were prepared poorly for it. However, this kind of capability was recently identified as a new mode of operation in the production of knowledge. Gibbons et al. (1994) coined the term “mode-2” for this context-sensitive science. Flyvbjerg (2001) postulated the ability to position expertise in specific application contexts as a third critical ingredient of today’s science, besides epistemic scholarship and technological craftsmanship.

How to deal with facts and values

In the course of the project it became clear that the challenge was not only to assemble existing knowledge into any sort of integrated assessment. Additionally, there were a great number of value questions that could not be addressed by scientists alone, but that had to be settled in tight interaction with the relevant interest groups. The explicit dealing of tension between facts and values proved to be a second uncommon capability which was poorly developed in our research team. In general, however, the involvement of different stakeholder groups into decision making processes has recently found a strong resonance in many research and policy areas. A wide range of participatory methods have been developed (Rowe and

Frewer, 2000). Examples for these approaches have been applied to public policy issues (Joss, 1999), technology assessment (Grunwald, 2000) and the assessment of environmental impacts (Kasemir et al., 2003; Rotmans et al., 2000).

A good example is the assessment of environmental impacts from hydropower: it has an extraordinarily favorable record regarding greenhouse gas emissions and other life cycle characteristics, whereas it can perform very poorly with respect to local impacts on ecosystems. Hydropower operators emphasized the global environmental characteristics, whereas environmental NGO's (and especially fishermen) emphasized local impacts. To resolve this dispute, the VUE and the EAWAG team decided to judge all renewable energy systems along the same kind of criteria, both at the local and the global level. Minimum conditions were fixed for all criteria (for a full account of the concept see www.naturemade.org).

Another key question concerned the quality level of the basic requirements; this was intensely debated within the VUE. After a long negotiation process, the level of basic requirements was set similar to the ecological quality which would be reached for a newly licensed power plant – i.e., one that fulfilled the requirements of the renewed Water Protection Law in Switzerland. This in itself was a major breakthrough transgressing the conventional conflict lines. Other examples for politically determined parameters of the procedure were: specific criteria for newly built plants, communication rules for the marketing of Green Hydropower, special conditions for small hydropower plants, compensation rules for non-reversible damage to local ecosystems, and determination of the mark-up payment of Green electricity sales (eco-investments).

Is a different research culture needed for this kind of projects?

In retrospect, we can identify some critical skills and competencies in which a learning institution in the field of aquatic sciences (and probably also beyond) must develop to meet the practical challenges of the future:

1. Scientists have to manage projects with unusually clear and binding goals. Binding commitments are required for developing products on schedule and within budget for use by outside actors. These demands require some adaptation in an academic setting where most research projects are driven by a completely different set of expectations: no binding character of project goals.
2. Being able to understand propositions, goals, methodologies and results from a wide range of different disciplines and actor groups is a crucial capability. These skills are needed to integrate knowledge stocks of different action domains (both within academia and be-

tween research and other societal actors), and to develop solutions that respond to the expectations of different actor groups.

3. Researchers have to be able to synthesize and conceptualize knowledge in their respective scientific discipline, often far beyond the level which is usually required in a mono-disciplinary research project.
4. Social competence in order to interact with diverse stakeholder groups in a productive way must be acquired. Critical self-reflection is needed to judge when scientific evidence is solid enough to allow decisions and when the boundary to value questions is crossed.
5. Finally, it is important for project managers to be directly involved in specific environmental research projects in the field. Only this on-hand experience sharpens the view for the quality criteria of a state-of-the-art product and its requirements in terms of time, money and man-power.

Only by combining these different capabilities can an effective transfer between scientific knowledge production and problem resolution be achieved. This observation calls for some changes in scientific education and also in the reward system of environmental research institutions. In her presidential address to the American Association for the Advancement of Science, Jane Lubchenco (1998) called for a new social contract for science to face complex environmental problems. "There is a concomitant requirement to train interdisciplinary scientists and to provide the skills and savvy to work at the policy-science or management-science interface. Changes in university curricula and the reward system for professional scientists (...) would greatly facilitate achieving these goals." While the interdisciplinary training in environmental science curricula has been developed in different contexts during the last decade (Wehrli and Schwarzenbach, 1997), the reward system in our field still needs some work.

In conclusion, we are now in a position to put forward a number of claims that hopefully will provoke enlightening debates. Aquatic science research is more frequently called to contribute to the resolution of problems where the simple model of information transfer is insufficient. It will be increasingly seen with criticism by the outside world if it is not able to contribute to actual solution finding. Problem constellations as those illustrated by the Green Hydropower project will become more common. Besides information production, scientific institutions will have to care more for the contexts of valuation and use of scientific results. If this challenge is neglected, aquatic science research will run the risk of being seen as a largely useless "art". In addition, research results will be (ab)used by different stakeholders in society to support whatever claims seem most appropriate to them.

The Green Hydropower project may not be considered as a one-to-one model for these new challenges. Each sociopolitical context of a problem will be different. Still, we believe that the Green Hydropower project had a number of new characteristics in the way it handled the definition of a problem as well as in sketching-out and navigating the course towards a solution. The collaboration between the social and natural sciences as well as the co-production of knowledge between scientific and other experts in society were key in this respect.

Acknowledgments

This project would not have been possible without the continued intellectual and financial support by the board of directors of EAWAG, especially Ueli Bundi and Alexander Zehnder. The list of contributors to the Green Hydropower project encompasses some 120 names. We thank all the project teams for their enthusiasm for carrying out research in a practically relevant context. The finishing of the present paper, profited from the thoughtful comments of two anonymous reviewers, as well as from the language editor C. Robinson.

References

- Bird, L., R. Wüstenhagen and J. Aabakken, 2002. Green Power Marketing Abroad: Recent Experience and Trends. National Renewable Energy Laboratory, NREL, Golden, Colorado.
- Blösch, H., 1999. The European Union Water Framework Directive: Taking European water policy to the next millenium. *Water Sci. Technol.* **40**: 67–71.
- Boon, P. J., 2000. The development of integrated methods for assessing river conservation value. *Hydrobiologia* **422/423**: 412–428.
- Boulton, A. J., 1999. An overview of river health assessment: philosophies, practice, problems and prognosis. *Freshwater Biology* **41**: 469–479.
- Bratrich, C. and B. Truffer, 2001. Green Electricity certification for Green Hydropower plants. *Ökostrompublikationen Band 7*. 123 S. EAWAG, Kastanienbaum.
- Brunke, M., T. Gonser and E. Hoehn, 2000. River/ground water interactions with two contrasting flood plains and benthic invertebrates communities. *Bulletin of the North American Benthological Society*. **17**, 134.
- Bundi, U., A. Peter, A. Frutiger, M. Hütte, P. Liechti and U. Sieber, 2000. Scientific base and modular concept for comprehensive assessment of streams in Switzerland. *Hydrobiologia* **422/423**: 477–487.
- Bunn, S. E., P. M. Davies and T. D. Mosisch, 1999. Ecosystem measures of river health and their response to riparian and catchment degradation. *Freshwater Biology* **41**: 333–345.
- Chovanec, A., P. Jäger, M. Jungwirth, V. Koller-Kreimel, O. Moog and S. Muhar, 2000. The Austrian way of assessing the ecological integrity of running waters: a contribution to the EU Water Framework Directive. *Hydrobiologia* **422/423**: 445–452.
- Fairweather, P. G., 1999. State of environmental indicators of 'river health': exploring the metaphor. *Freshwater Biology* **41**: 211–220.
- Farhar, B. C. and H. H. Ashley, 1996. Willingness to pay for electricity form renewable energy. National Renewable Energy Laboratory, Golden Colorado. September 1996
- Flyvbjerg, B., 2001. Making Social Science Matter. Why social inquiry fails and how it can succeed again. Cambridge University Press. Cambridge pp. 204.
- Friedl, G. and A. Wüest, 2002. Disrupting biogeochemical cycles – Consequences of damming. *Aquat. Sci.* **64**: 55–65
- Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzmann, P. Scott and M. Trow, 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage. London.
- Gleick, P., 1998. The World's Water 1998–1999. Island Press, Washington DC.
- Grunwald, A., 2000. Partizipative Technikfolgenabschätzung wohin? Einführung in den Schwerpunkt. *TA-Datenbank-Nachrichten* **9**: 3–10.
- Gugerli, D., 1997. Redeströme. Zur Elektrifizierung der Schweiz 1880–1914. Chronos. Zürich, pp. 350
- Holocher, J., V. Matta, W. Aeschbach-Hertig, U. Beyerle, M. Hofer, F. Peeters and R. Kipfer, 2001. Noble gas and major element constraints on the water dynamics in an alpine floodplain. *Ground Water* **39**: 841–852.
- Holt, E., 1997. Disclosure and Certification. Truth and labelling for electric power. REPP Issue Brief No. 5. Renewable Energy Policy Project, Colledge Park, MD.
- Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell and C. A. Johnson (eds.), 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, pp. 881.
- Jorde, K., 1997. Hydraulisch-morphologische Modellierung von Fließgewässern mit dem Simulationsmodell CASIMIR. *Wasserwirtschaft* **87**: 368–371.
- Joss, S., 1999. Public Participation in Science and Technology Policy- and Decision-Making: Ephemeral phenomenon or Lasting Change? *Science and Public Policy*. **26**, 290–373.
- Karr, J. R., 1999. Defining and measuring river health. *Freshwater Biology* **41**: 221–234.
- Kasemir, B., W. C. Clark, M. T. Gardner, C. C. Jaeger, J. Jaeger and A. Wokaun, 2003. Public Participation in Sustainability Science. Cambridge University Press.
- Lubchenco, J., 1998. Entering the century of the environment: A new social contract for science. *Science* **279**: 491–497.
- Markard, J., 1998. Green-Pricing – Welchen Beitrag können freiwillige Zahlungen von Stromkunden zur Förderung regenerativer Energien leisten? Freiburg, Öko-Institut-Verlag.
- Markard, J. and E. Holt, in press. Disclosure of Electricity Products: Lessons from consumer research as guidance for energy policy issues. *Energy Policy in press*.
- Markard, J. and C. Timpe, 2000. Ist Ökostrom ein Auslaufmodell? Die Auswirkungen des Erneuerbare-Energien-Gesetzes auf den Markt für Grünen Strom. *Zeitschrift für Energiewirtschaft (ZfE)*. Köln. **4**: 201–212.
- Markard, J. and B. Truffer, 1999. Der lange Weg zu einem Euro-Label für Strom. *Energiewirtschaftliche Tagesfragen. Zeitschrift für Energiewirtschaft, Recht, Technik und Umwelt*. **49**: 724–729.
- Markard, J., B. Truffer and C. Bratrich, 2001. Green Marketing for Hydropower. Market dynamics and Eco-Labeling initiatives. *Hydropower and Dams*. **8**: 81–86.
- Meier, W., C. Bonjour, A. Wüest and P. Reichert, 2003. Modelling the effect of water diversion on the temperature of mountain streams. *J. Environ. Eng. in press*
- Moosmann, L., K. Jorde, M. Schneider, W. Meier, A. Peter and A. Wüest, 2002. Restwasserbemessung für Ökostrom mit Beispiel Brenno (Bleniotal, TI) Ökostrom Publikationen 9. EAWAG, Kastanienbaum.
- Nowotny, H., P. Scott and M. Gibbons, 2001. Re-thinking science. Knowledge and the Public in an Age of uncertainty. Polity Press, Blackwell Publishers, Cambridge, UK.
- Rasmussen, E., 1989. Games and information. An introduction to game theory. Basil Blackwell, Oxford.

- Revenga, C., J. Brunner, N. Henninger, K. Kassem and R. Payne, 2000. Pilot Analysis of global ecosystems-freshwater systems. World Resources Institute. Washington DC. 65 pp.
- Rotmans, J., M. van Asselt, C. Anastasi, S. Greeuw, J. Mellors, S. Peters, D. Rothman and N. Rijkens, 2000. Visions for a sustainable Europe. *Futures* 32: 809–831.
- Rowe, G. and L. J. Frewer, 2000. "Public Participation Methods: A framework for evaluation." *Science, Technology and Human Values* 25: 3–29.
- Schneider, M., J. Giesecke, F. Zöllner and F. Kerle, 2001. CASIMIR – Hilfsmittel zur Mindestwasserfestlegung unter Berücksichtigung von Ökologie und Ökonomie. *Wasserwirtschaft* 91: 486–490.
- Tödter, U., 1998. Wildflusslandschaften – Spitzenreiter unter den gefährdeten Ökosystemen. In: CIPRA (ed) *Alpenreport 1*. Paul Haupt Bern, 178–182.
- Truffer, B., 1998. Market demand for Green Power products, in: *The Greening of Industry Network: Partnership and Leadership: Building Alliances for a Sustainable Future*, conference proceedings, Rome, November 15–18, 1998.
- Truffer, B., J. Bloesch, C. Bratrich and B. Wehrli, 1998. "Ökostrom": Transdisziplinarität auf der Werkbank. *GAIA* 7: 26–35.
- Truffer, B., J. Markard and R. Wüstenhagen, 2001a: Enhancing Customer Demand for Green Electricity – Perspectives of Eco-Labeling in the European Market. *Energy Policy* 29: 885–897.
- Truffer, B., J. Markard, C. Bratrich and B. Wehrli, 2001b. Green electricity from alpine hydropower plants. *Mountain Research and Development* 21: 19–24.
- Truffer, B., C. Bratrich, J. Markard and B. Wehrli, 2001c. Ökostrom: The Social Construction of Green Electricity Standards in Switzerland. In: *Transdisciplinarity: Joint Problem Solving among Science, Technology and Society. An Effective Way for Managing Complexity*. Edited by Thompson Klein J., et al. Birkhäuser, Basel, pp. 153–158.
- Truffer, B., S. Bruppacher and J. Behringer, 2002a. Nachfrage nach Ökostrom – Fokusgruppenbefragung in den Städten Stuttgart, Bern und Zürich. EAWAG-Ökostrompublikationen, Band 8, EAWAG, Kastanienbaum 120 Seiten.
- Truffer, B., J. Bloesch, C. Bratrich, T. Gonser, E. Hoehn, J. Markard, A. Peter, B. Wehrli and A. Wüest, 2002b. Ökostrom aus Wasserkraft – ein transdisziplinäres Forschungsprojekt. Schlussbericht (1997–2001). EAWAG, Ökostrompublikationen, Band Nr. 10. EAWAG, Kastanienbaum. 80 Seiten.
- Vörösmarty, C. J., M. Meybeck, B. M. Fekete and K. P. Sharma, 1997b. The potential impact of neo-castorization on sediment transport by the global network of rivers. In D. Walling and J. L. Probst (eds.) "Human Impact on Erosion and Sedimentation". IAHS Press. Wallingford, U.K. 261–272.
- Vörösmarty, C. J., K. P. Sharma, B. M. Fekete, A. H. Copeland, J. Holden, J. Marble and J. A. Lough, 1997a. The storage and aging of continental runoff in large reservoir systems of the world. *Ambio* 26: 210–219.
- Ward, J. V., 1998. Riverine landscapes: biodiversity patterns, disturbance regimes, and aquatic conservatoin. *Biological Conservation* 83: 269–278.
- WCD, 2000. Dams and Development. A new framework for decision making. The report of the World Commission on Dams. Earthscan, London.
- Wehrli, B. and R. P. Schwarzenbach, 1997. From molecules to ecosystems: Topics challenges and players in environmental chemistry. *Chimia* 51: 865–870.
- Wiser, R., J. Fang, K. Porter and A. Houston, 1999. Green Power Marketing in Retail Competition: An Early Assessment. National Renewable Energy Laboratory, NREL, Golden, Colorado.
- Wiser, R. H., M. Fowlie, and E. A. Holt, 2001. Public goods and private interests: understanding non-residential demand for Green Power. *Energy Policy* 29: 1085–1097.
- Wiesenthal, H. 1990. Ist Sozialverträglichkeit gleich Betroffenenpartizipation? *Soziale Welt*, 41: 28–46.
- Wüstenhagen, R., 2000. Ökostrom – von der Nische zum Massenmarkt, Entwicklungsperspektiven und Marketingstrategien für eine zukunftsfähige Elektrizitätsbranche. Vdf Hochschulverlag, Zürich.
- Wüstenhagen, R., J. Markard and B. Truffer, 2003. Diffusion of Green Power products in Switzerland. *Energy Policy* 31: 621–632.

To access this journal online:
<http://www.birkhauser.ch>