Heavily Modified Waters in Europe

Case Study Bregenzerach

Robert Konecny, Arno Aschauer & Andreas Chovanec
Federal Environment Agency
A-1090 Vienna, Spittelauer Lände 5, Austria
Phone: ++43 1 31304 3581, Fax: ++43 1 31304 3700
Email: konecny@ubavie.gv.at, http://www.ubavie.at

Reinhard Wimmer
ORCA, A – 1080 Vienna, Piaristengasse 2-4/2/4, Austria
Phone & Fax: ++43 1 40 28 430
Email: orca@magnet.at

Stefan Schmutz
Department of HYDROBIOLOGY, FISHERIES and AQUACULTURE; UNIVERSITY of AGRICULTURAL SCIENCES
A-1180 Vienna, Max Emanuel-Strasse 17, Austria
Phone: 43-1-47654-5202, Fax: 43-1-47654-5217,
E-mail: schmutz@mail.boku.ac.at, http://www.boku.ac.at/hfa

Table of Contents

List of Tables, Boxes, Maps etc.

PART I

3 Introduction

3.1 Choice of Case Study

The case study Bregenzerach was chosen because of the hydropower use with alteration of this alpine river system by hydropower peaking and diversion-type power stations.

Another aspect for the choice of this river for this heavily modified case study was the fact that a variety of rehabilitation measures has been done showing improvements of the ecological conditions in the upstream river sections. The downstream part of the river is still heavily impacted by hydropower peaking and will be used as a model for the designation process of heavily modified water bodies.

Several investigations have been performed in this catchment area before and after the establishment of rehabilitation measures and therefore a large amount of information, for example surveys on algae, macroinvertebrates and fish, are available.

3.2 General Remarks

The Bregenzerach with its tributaries is located in the Western part of Austria. This small alpine catchment area in the province of Vorarlberg is significantly impacted by hydropower peaking and diversion-type power stations causing several hydromorphological changes like reduced flows which remain in the river bed.

The case study Bregenzerach is part of the **hydropower subgroup** of the heavily modified case study project.

This draft is the preliminary report of the heavily modified case study Bregenzerach and covers the chapters 3 – 7.1 of the terms of reference.

4 Description of Case Study Area

4.1 Geology, Topography and Hydrology

The geology of the catchment area of the Bregenzerach is dominated by Flysch and Helvetikum belonging to the landscape units Flysch or sanstone Foothills and the Helvetikum in Vorarlberg.

The Bregenzerach is a 4th to 6th order alpine river with mainly a nival discharge regime, located in the most western part of Austria. It originates at an elevation of about 2000 m above sea level (a.s.l.) and flows 68 km before emptying into Lake Constance (ca. 400 m a.s.l.). The mean annual flow (MAF), in the study reach (the lowest 40 km of the river), ranges from 13 to 47 m^3/s, with a ratio of minimum/maximum flow of 1:400.

4.2 Socio-Economic Geography and Human Activities in the Catchment

The population in the catchment is about 9000 people with a population density of 54 persons per km^2. The largest town is Bregenz with 27900 inhabitants.

The main human impacts on this system are caused by hydropower operation, weirs, and some channel regulation. Until 1986, the lower part of the Bregenzerach was primarily affected by two hydropower plants. The uppermost plant, Andelsbuch, is located at river kilometer 28 (counted upstream). This plant used the entire flow of the Bregenzerach (up to 29 m^3/s, or 200% MAF) and produced peaks up to 30 m^3/s several times a day. Seven kilometers downstream another plant, Langenegg, also used the water of a tributary of Bregenzerach - Bolgenach - adding another 30 m^3/s surge to the total discharge. The peaking amplitude below Langenegg was thus 1:60. These peak flows heavily impacted the aquatic fauna in downstream reaches (Jungwirth et al., 1998). The water quality of the tailwater was not affected by these operations.

The following management and development plan was realized in 1992 (Figure 1). A re-regulating reservoir (350 000 m^3) was built below Andelsbuch. The water is used for a new run-of-river plant, Alberschwende, constructed beside Langenegg. The bypass reach receives seasonally varied compensation flows. Below these two plants a second re-regulating reservoir was constructed. The capacity of this impoundment is 150 000 m^3 with a maximum in- and outflow of 60 m^3/s. Additionally, a flow management system for the reduction of peak amplitudes was introduced.

This dual flow release management regime divides the ramped releases into two parts. First, base flows are increased in proportion to the planned generation flow within a 24-hour period prior to a surge release. The magnitude of this base flow is approximately set to fill the bed. Since the planned surge releases are relatively frequent, this base flow remains relatively stable compared to the pre-mitigation situation. The remaining part of the peak occurs at the pre-modification frequency, but with a lower absolute magnitude.

4.3 Identification of Water Bodies

The catchment of the Bregenzerach has been divided into 4 sub-water bodies due to the degree of hydromorphological disturbances.

1. Hydrologically unaffected reach – with a slight deviation from the reference condition
2. Reach 1 – residual water reach after minimum flow allocation
3. Reach 2 – residual water reach after the re-regulating reservoir in Andelsbuch
4. Hydropeaking reach – after the power plant Langenegg

Classification of the water bodies was made according to system A and B according Annex II of the WFD.

Table 1 Result of classification according to system A and B (See WFD Annex II, 1.2 "Ecoregions and Surface Water Body Types).

Descriptors	**Classification**
Ecoregion	Alps
Altitude	200 – 1500 lowland to high
Size typology	Small
Geology	Flysch, Helvetikum

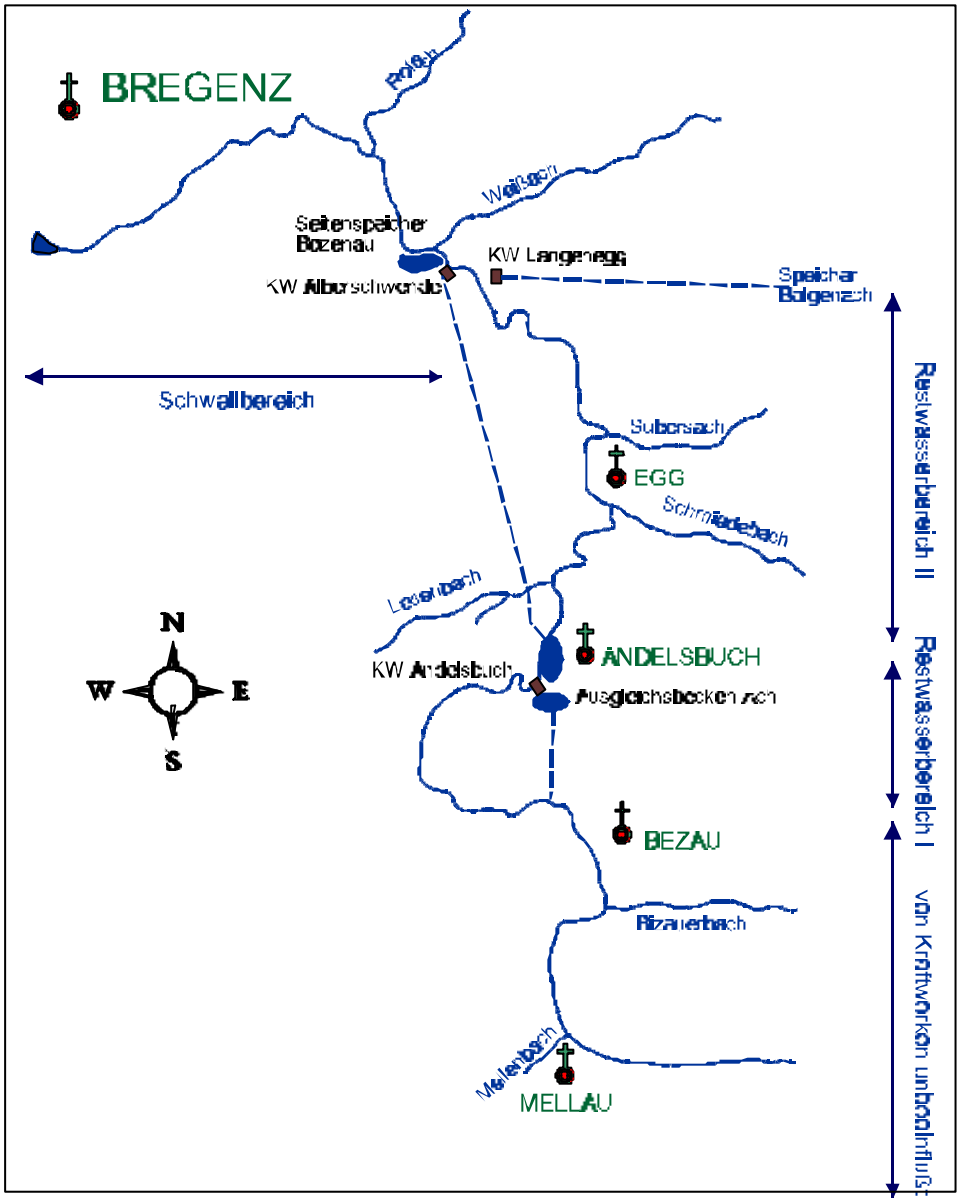

Figure 1 Overview of the study site at the Bregenzerach ("von Kraftwerken unbeeinflußt": Hydrologically unaffected reach; "Restwasserbereich I": Reach I; "Restwasserbereich II": Reach II; "Schwallbereich": Hydropeaking reach; "Seitenspeicher ": reservoir; "Speicher": reservoir; "Ausgleichsbecken": re-regulation reservoir; "KW": Power plant)

4.4 Discussion and Conclusions

The study area has been divided into sub-water bodies (reaches) by means of the dominating morphological disturbance/lack of morphological disturbance, which indirectly provide different ecological conditions. Each water body should be an area, which if possible, is only influenced by one kind of morphological disturbance. The hypothesis to classify the whole catchment as one water body is used, because in this case study the whole catchment is influenced by hydropower generation plants.

PART II

5 Physical Alterations

5.1 Pressures and Uses

The main human impacts on this system are caused by hydropower peaking operations, weirs and some measures of channelisation. Until 1986, the lower part of the Bregenzerach was primarily affected by two hydropower plants. The uppermost plant, Andelsbuch, is located at river kilometer 28 (counted upstream). This plant uses the entire flow of the Bregenzerach (up to 29 m³/s, or 200% MAF) and produces peaks up to 30 m^3/s a few times a day. Seven kilometers downstream another plant, Langenegg, uses the water of a tributary of the Bregenzerach – Bolgenach – adding another 30 m^3/s surge to the discharge. The peaking amplitude below Langegg is thus 1:60. These peak flows heavily impact the aquatic fauna in downstream reaches.

5.2 Physical Alterations

The following physical alterations can be identified as the dominant impacts in this river system:

- Dams/weirs
- Channelisation/longitudinal straightening
- Reduced flow in the river bed up to totally dry up due to water abstraction
- Variation in water levels
- Mechanic damage of aquatic fauna caused by turbines
- Artificial discharge regime, with extreme peaking amplitudes (only found in the hydropeaking reach in the downstream part of the Bregenzerach)
- Reservoir flushing in the tributary Bolgenach

5.3 Changes in the Hydromorphological Characteristics of the Water Bodies and Assessment of Resulting Impacts

Especially in the downstream part of the river, which is affected by hydropower peaking, changes of the hydromorphological characteristics are obvious and are listed below:

- Changes in the river profile
- Disruption of the river continuum
- Disruption of the sediment transport
- Change in the flow regime of the river

The main effects of the hydromorphological changes can be summarized as follows:

- Habitat limitation due to reduced space during low flow periods (dried out areas)
- Faunal depletion

- Reduction of the biomass of benthic invertebrates
- Reduction in the fish fauna (decrease of fish biomass and changes in the population structure of the fish communities)

5.4 Discussion and Conclusions

The major influences on the morphology of the Bregenzerach are three hydropower plants.

Rehabilitation measures: In the study area a re-regulating reservoir (350000m^3/s) was built below the power plant Andelsbuch. The second re-regulating reservoir was constructed downstream of the second plant. The capacity of this impoundment is 150000m^3 with a maximum in- and outflow of 60m^3/s. Additionally, a flow management system for the reduction of peak amplitudes on the basis of dual flow logistics was introduced. The effects of these measures will be discussed with regard to the maximum ecological potential.

6 Ecological Status

6.1 Biological Quality Elements

Methods

Macroinvertebrates

The assessment of the macroinvertebrate coenosis of the Bregenzerach is based on the studies of Jungwirth et al. (1998) and Moog (1997). The biological status of the benthic community has been defined by analysing the ecological integrity, sensu ÖNORM M 6232 (1996), adapted to the WFD.

Following parameters are considered for assessment:

- benthic species inventory
- dominance structure (species, higher taxa)
- biomass
- functional feeding groups
- longitudinal zonation patterns
- saprobic quality index

Fish fauna

In principal, the assessment method used follows the procedure proposed by Schmutz et al. (2000) using 7 biological criteria according to the normative classification of the ecological status in the WFD. However, as the study site inhabits mainly brown trout (*Salmo trutta*) and bullhead (*Cottus gobio*), criteria 3 to 5 are omitted.

Table 2 Criteria and verbal definition of 5 levels of ecological status (Schmutz et al., 2000)

Criteria	Ecological integrity levels				
	1 high	2 good	3 moderate	4 poor	5 bad
(1) Type-specific species	none or nearly none missing	some species missing	several species missing	many species missing	most species missing
(2) Self-sustaining species	none or some missing	several species missing	many species missing	most species missing	nearly all species missing
(3) Fish region	no shift	no shift	shift	shift	shift
(4) Number of guilds	no guild missing	no guild missing	single guilds missing	many guilds missing	most guilds missing
(5) Guild composition	no alteration	slight alteration	substantial alteration	complete alteration	complete alteration
(6) Biomass and density	no or nearly no changes	slight changes	substantial changes	heavy changes	extremely changed
(7) Population age structure	no or nearly no changes	slight changes	substantial changes	heavy changes	extremely changed

Quantitative fish sampling was carried out over a 10 years study period at 10 sites (about 200 m long): hydrological unaffected sites (1,1a), abstracted reach I (site 2 and 3) without (1986, 1992) and with (1994, 1996) minimum flow, hydropeaking (max. 30 m³/s) reach before (1986, 1992) and after (1994, 1996) flow restoration (site 4-6) and hydropeaking reach (max. 60 m^3/s) (sites 7-10) (compare Figure 1). Additional data on sport fishing and stocking were collected from angling associations and analysed. Further details are given in the project reports (Parthl & Schmutz, 1998).

In addition to the fish-based assessment a fish-habitat model was established following an adapted PHABSIM approach (Parasiewicz & Schmutz, 1999) to predict effects of the proposed flow schemes in residual flows reach I and II (Parasiewicz et al., 1997). Historical data were analysed in combination with river typology and comparison with similar rivers to establish reference conditions.

Reference conditions

The BA in the study area is characterised as a rhithral river. Study sites 1 and 1a lie within the epi-/metarhithral, followed by the metarhithral in sites 2-6 and the hyporhithral in sites 7-12. Reference conditions for population age structure were taken from a near-natural river of similar typology (Wagrainer Ache, Slzb.)

Results

Hydrologically unaffected reach

Macroinvertebrates

In this reach the investigated parameters show almost undisturbed conditions:

- The saprobic quality index shows a value of I-II, which corresponds to the saprobic

reference condition of this river type (Moog, 1995).

- Dominance structure, longitudinal zonation and functional feeding groups show more or less the typical reference conditions of a 5th order mountain stream in the epi- metarhithral transition zone.
- Therefore, the ecological integrity has a value of 1-2.

Summarizing the results for this reach of the Bregenzerach, the ecological status is classified as high (1).

Fish fauna

Although sites 1 and 1a are situated upstream of the hydro power plants they do not reflect reference conditions as there is evidence of morphological alterations. Although all type-specific species are occurring (brown trout *Salmo trutta*, bullhead *Cottus gobio*) the lake-dwelling migratory form of the brown trout, *Salmo trutta lacustris*, formerly exhibiting spawning migrations up to this area, is missing. Therefore the criteria number of type specific species is classified as 1.5. Although low in density and biomass (some 20-50 kg/ha) the brown trout reproduce successfully as documented by the 15 % proportion of 0+ fishes. Therefore the criterion self-sustaining-species is also classified as 1.5, however biomass and density are classified 3. In addition to the deficits of 0+ fishes, the low proportion of adults (25%) compared to reference conditions leads to the classification 3 (substantial changes).

In summary the hydrologically unaffected sites are classified as 2 (Index 2.25) demonstrating a slight deviation from reference conditions that could be attributed to morphological alterations.

Reach I

Macroinvertebrates

Compared to the reference conditions, there are slight changes in the composition of the benthic coenosis evident:

- A dominance of insensitive taxa, especially chironomids
- Smaller amount of Plecoptera; Most of the occuring Plecoptera are sensitive species and indicate good conditions (oxygen, temperature) in the interstitial
- The saprobic index shows values between II and I-II, which means a slight tendency for deterioration compared to the saprobic reference condition for this river type (Moog, 1995).
- Qualitative and quantitative differences in the biocoenosis compared with the reference conditions result in a value for the ecological integrity of 2.

Summarizing the results for the assessment of the benthic coenosis, the ecological status of reach I is classified as good (2).

Fish fauna

Again brown trout and bullhead are the two species originally and actually occurring and the migratory form of brown trout is missing (criteria type-specific species: 1.5) The age distribution at site 2 shows a nearly complete lack of adults **before minimum flow allocation**. Hence, the criteria self-sustaining-species and population age structure are classified as 4. Similarly the deficit of adults leads to very low biomass (classified as 4). In summary the situation before minimum flow is classified as 3.4.

The population at site 2 showed a significant reaction **after minimum flow allocation**, even the flow was still at a low level. Density increased by about 40% and biomass by about 70% and the proportion of adults achieved 18%. Therefore criteria 2 improved to class 1.5, criteria 6 and 7 to 3 totalling in an improvement from 3.4 to 2.25.

Reach II

Macroinvertebrates

The macrozoobenthic taxa composition (higher level) in this reach is very similar to the reference conditions.

Following results show significant alterations from the reference situation:

- The saprobic quality index shows a value of II, which is a deterioration compared to the saprobic reference condition (Moog, 1995) of half a class.
- The significant quantitative reduction of Plecoptera-species indicates a deterioration of the environmental conditions for the benthic fauna.
- The water temperature in reach II indicates hyporhithral conditions which is a regional shift of 1 biocoenotic region from the reference condition (metarhithral).
- The sequences of the stated impacts are periodical lacks of long living and oxybiont benthic organisms. Insensitive (euryoec), phytorheophile organisms dominate the benthocoenosis in this reach.
- Hence, the ecological integrity varies between 2 (summer period) and 2-3 (winter period).

In respect of these results, the ecological status for reach II is classified as good with a tendency to a moderate status (2-(3)).

Fish fauna

Under natural conditions in this area brown trout and bullhead are accompanied by low proportions of European grayling (*Thymallus thymallus*) and stone loach (*Noemacheilus barbatulus*) downstream of site 4a and soufie (*Leuciscus souffia*) and Eurasian minnow (*Phoxinus phoxinus*) downstream of site 6.

Before eliminating hydropeaking above mentioned accompanying species are completely missing. As this area represents the upper limit of distribution of these species, the criteria number of type-specific and self sustaining species are classified not worse than 3. As density and biomass is comparable low and the proportion of adult fishes is only about half of the reference conditions criteria 6 and 7 are also classified 3.

In total reach II is classified 3 under hydropeaking conditions.

After allocating minimum flow and eliminating hydropeaking grayling and stone loach show up and the number of type-specific and self-sustaining-species increases to 4 leading to a classification of 2 for criterion 1 and 2. Density and Biomass reacts to the minimum flow with an increase of up to 40% improving the classification from 3 to 2.5. However, the proportion of adult fishes still is below 50% of the reference (classification 3). In total the hydropeaking elimination and minimum flow allocation improved the ecological status from 3 to 2.4.

Hydropeaking reach

Macroinvertebrates

Following results can be stated for this reach of the Bregenzerach:

- The saprobic index shows a value of (I)-II, which corresponds to the saproobic reference condition (Moog, 1995) of this river type
- Low values for the macrozoobenthic biomass (50-80% of reference conditions) are stated in this reach of the Bregenzerach, wich are still in the range of reference conditions. At one site, there is also a significant loss in biomass (70% compared to reference condition) stated.
- A shift of the biocoenotic region from hyporhithral (reference condition for this river stretch) to metarhithral is evident (rhithralisation).
- Reasons for this changes in the benthic coenosis are the altered hydraulic situation, low water temperatures and water temperature shifts of 7°C within short periods - several times a day - because of hydropeaking.
- Hence the ecological integrity is classified as 2-(3).

The ecological status for the hydropeaking reach is classified as tending to a moderate status ((2)-3).

Fish fauna

In this area none of the 7 recorded type-specific species (*Salmo trutta, Cottus gobio, Thymallus thymallus, Barbus barbus, Noemacheilus barbartulus, Leuciscus souffia, Phoxinus phoxinus*) is self-sustaining. Criterion 1 is classified as 2 as some more than occurring species are expected. All other criteria are given a 5 totalling in an index of 4.25.

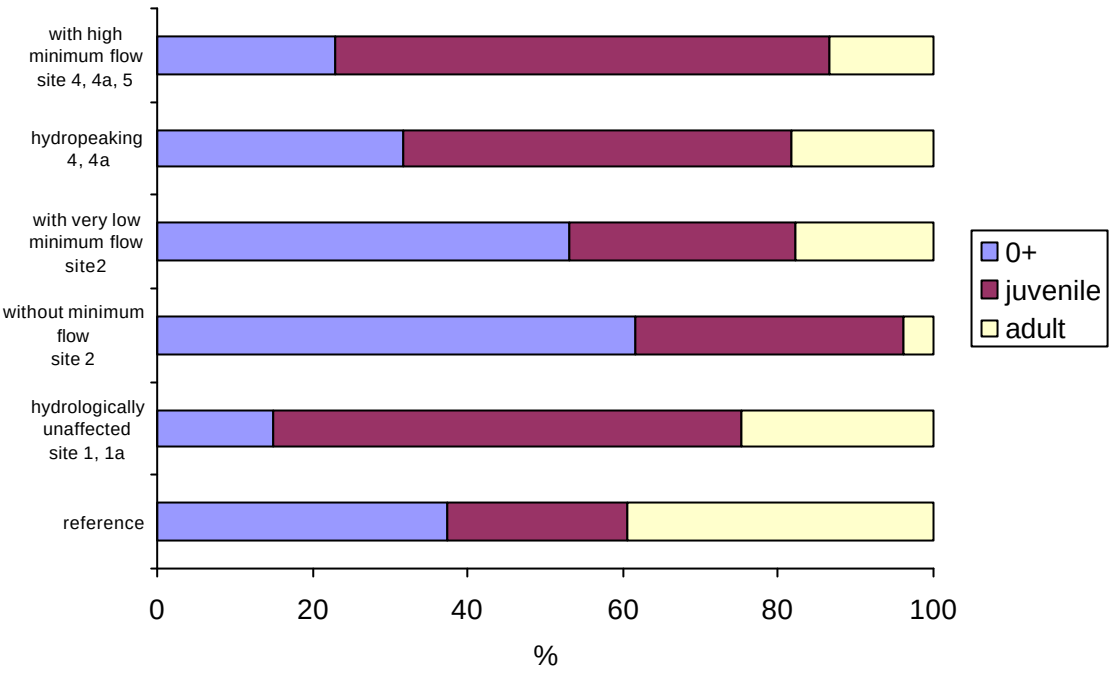

Figure 2 Relative age composition of brown trout of sites with different hydrological conditions compared to reference condition

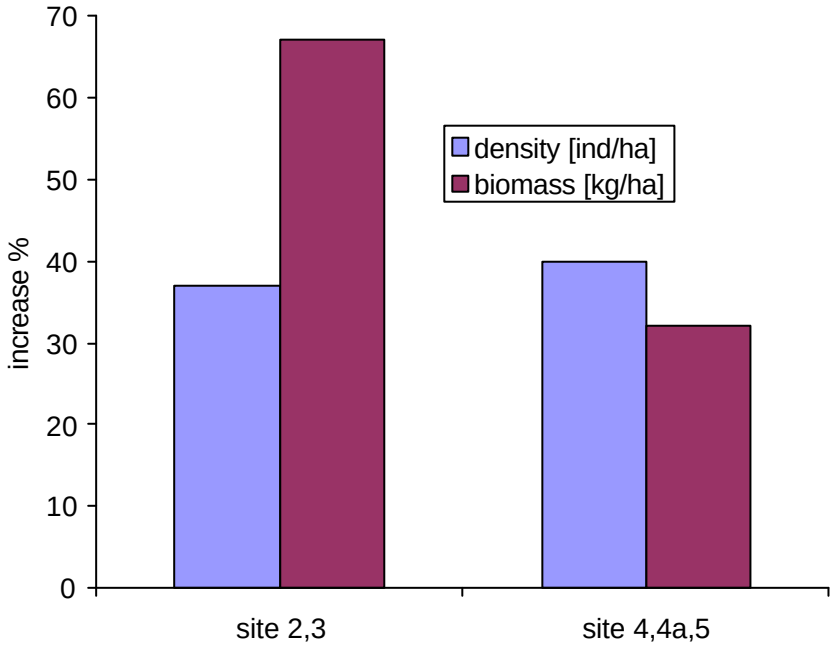

Figure 3 Relative increase of density and biomass in areas with restored minimum flow (site 2,3) and eliminated hydropeaking (4,4a,5)

6.2 Physico-Chemical Elements

A detailed information on the physico-chemical characterisation of the Bregenzerach is

provided by the national water quality monitoring system (WWK/UBA, 2000).

6.3 Definition of Current Ecological Status.

The ecological status of the catchment of Bregenzerach is influenced by hydropower generation. The most significant sign of the physical alterations can be found in the reach which is still influenced by hydropower peaking. The resulting impacts are reflected by the poor ecological status of the hydropeaking reach (see Table 3).

The definition of the ecological status for each reach was made by using the worst case from the classification with macroinvertebrates and fishes.

Table 3 Summary of the classifications for each river section (results are rounded on the first decimal place)

	Macroinvertebrates (+ saprobic quality index)	Fish fauna	**Ecological status of the stretch**
Hydrologically unaffected reach	1	2	**2 - good**
Reach I	2	2.3	**2 - good**
Reach II	2 - (3)	2.4	**2 - good**
Hydropeaking reach	(2) - 3	4.3	**4 - poor**

6.4 Discussion and Conclusions

The assessment of the ecological status quo is discussed in terms of two indicator groups, macroinvertebrates and fish, which are considered to be the most relevant groups for the assessment of hydropower generation impacts.

The assessment for each indicator group was performed using a type-specific approach.

The ecological status of three of the four sub-water bodies of the Bregenzerach is characterized by a good ecological condition whereas the downstream part of the river is still influenced by the hydropower peaking. The resulting impacts in this river section are expressed by the poor ecological status especially of the fish fauna.

7 Identification and Designation of Water Bodies as Heavily Modified

The upstream part of the Bregenzerach is characterized by good ecological status despite of some physical alterations because of hydropower use.

The hydropeaking reach in the downstream part of the river is still heavily impacted by hydropower peaking operations and shows a variety of physical alterations and changes in the hydromorphological characteristics of the river.

The ecological status for the hydropeaking reach is classified as poor (4).

This section of the river could be provisionally identified as heavily modified as a consequence of physical alterations, hydromorphological changes and the poor ecological status. However, due to the different types and intensities of impacts along the river course of the Bregenzerach and due to the fact that mitigation measures have been already implemented and monitored, this case study offers the possibility to analyse the identification and designation of water bodies as heavily modified from both a pre-mitigation and post-mitigation view and allows predictions for the further development of the still heavily impacted river sections.

7.1 Necessary Hydromorphological Changes to Achieve Good Ecological Status

The main hydrological improvements of the rehabilitation programme realised in 1992 have been:

- elimination of hydropeaking in reach II by bypassing the surges through a tunnel to the new hydroelectric plant “Alberschwende”,
- allocation of seasonally varied compensation flow to reach I and II,
- construction of a re-regulating reservoir and the implementation of a dual flow management release in the peaking reach downstream of “Alberschwende” in order to dampen the amplitude of daily flow variations (maximum relation between low flow and peak flow should be 1:7.5).

Based on the ecological monitoring (mainly demonstrated by the fish coenoses) the mitigation measures resulted in

- major improvement of the ecological status in reach I from poor (without minimum flow allocation) to good conditions (with minimum flow allocation),
- significant improvement of the ecological status in reach II from moderate (hydropeaking) to good (elimination of peaking, minimum flow allocation),
- only a slight und inefficient improvement of the ecological status in the peaking reach downstream of “Alberschwende” from bad to poor, and
- still remaining impacts caused by flushing of the Bolgenach impoundment affecting the reach downstream of Alberschwende (not covered by the mitigation programme)

Allocating ecologically justified minimum flows and eliminating hydropeaking combined with the construction with a new hydroelectric plant resulted in both an enhancement of the ecological conditions and the maintenance - and even the extension - of hydroelectric use on an economical basis. However, surge damping was inefficient in the remaining peaking reach downstream of “Alberschwende”. Therefore, the approved mitigation concept should also be applied here by bypassing the surge through a tunnel directly into the Lake Constance. It is expected that also here a good ecological status can be achieved.

7.2 Assessment of Other Environmental Options

7.3 Designation of Heavily Modified Water Bodies

In the case of the Bregenzerach the approved restoration of former heavily impacted water bodies to a good ecological status does not justify a pre-classification of hydropeaking sections as heavily modified. Consequently, the remaining hydropeaking section should not be designated as heavily modified a priory, unless major changes of the socio-economic conditions would require a re-evaluation of the specific situation.

7.4 Discussion and Conclusions

In the specific case study, Bregenzerach, heavily impacted river sections could be restored to a good ecological status. Transferability of results to situations with comparable environmental and economical conditions is given. In other situations or under different socio-economic conditions case specific analyses are necessary and eventually may result in the designation of hydropeaking sections as heavily modified.

8 Definition of Maximum Ecological Potential

The maximum ecological potential is discussed here only under the assumption that due to altered socio-economic conditions the remaining peaking section could not be restored as it was done in “reach II” (compare Figure 1).

8.1 Determining Maximum Ecological Potential

8.2 Measures for Achieving MEP

The main focus in remediation of the hydro peaking effects on the fish coenoses has to be dedicated to

- reduction of peak amplitudes
- damping of flow increases and decreases

As a premise, flow amplitudes and sudden flow increases and decreases should not go far beyond natural flow fluctuations.

8.3 Comparison with Comparable Water Body

There does not exist any water body type comparable with hydropeaking river stretches because such flow alterations does not occur that often and rapid in rivers with natural hydrographs. Daily flow fluctuations in the Bregenzerach upstream of the hydro power plant scheme hardly exceed an amplitude of 1:3 (Figure 4). The natural flow increase within 15 min is mostly less than 20 % (Figure 5).

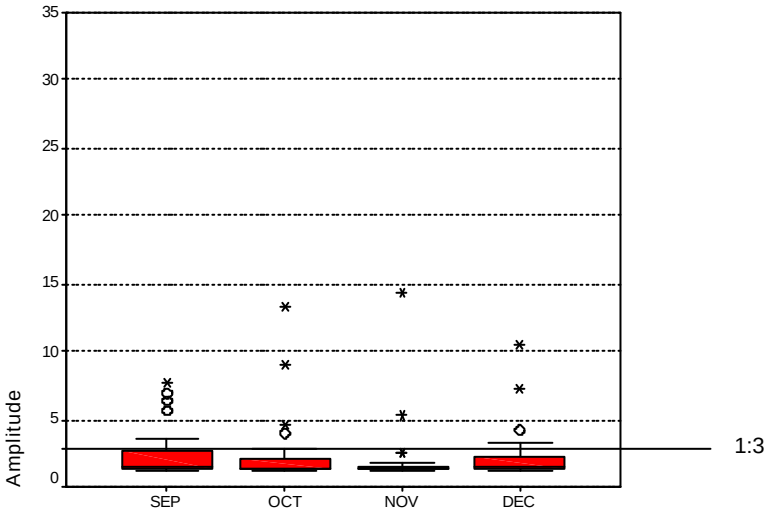

Figure 4 Natural daily flow amplitude (relation between daily minimum and maximum flow) during autumn and winter in the Bregenzerach in the year 1993 (median, 50% percentile, range, outliers, extremes)

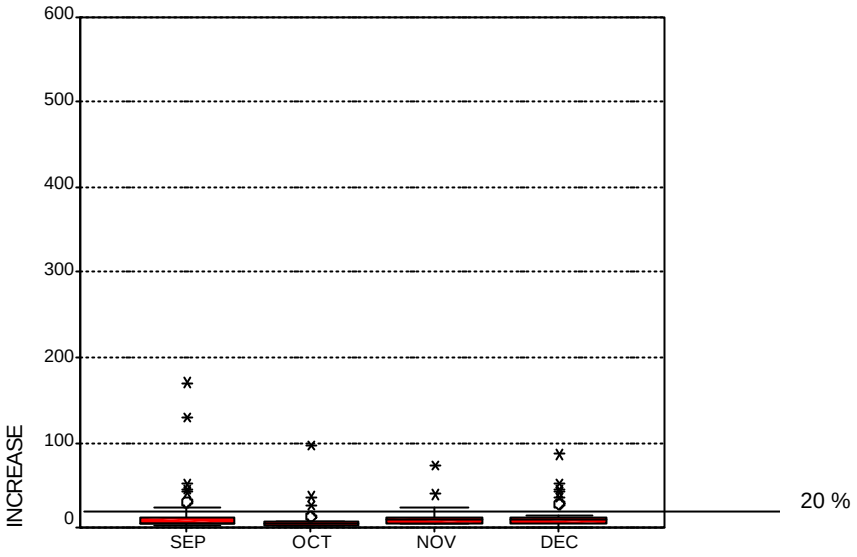

Figure 5 Natural maximum daily flow increase (%) within 15 min in the Bregenzerach in autumn and winter 1993 (median, 50% percentile, range, outliers, extremes)

8.4 Discussion and Conclusions

In the case of the Bregenzerach maximum ecological potential is derived from natural hydrographs. Hydrological values indicative for the stress should not lay far out of the natural range. Threshold values for the natural range for the Bregenzerach would be 1:3 for the maximum daily flow amplitude and 20 % maximum daily flow alteration within 15 min. These values represent preliminary assumptions based on natural characteristics of the Bregenzerach and would have to be verified and adapted according to an accompanying monitoring programme.

9 Definition of Good Ecological Potential (6 pages)

9.1 Determination of Good Ecological Potential

The good ecological potential is discussed here only under the assumption that due to altered socio-economic conditions the remaining peaking section could not be restored as it was done in “reach II” (compare Figure 1).

Good ecological potential is defined as only a slight deviation from the MEP however a considerable improvement of the actual poor ecological situation using hydrological metrics indicative for the biological stress.

The mitigation measures and hydrological limits defined below in order to achieve good ecological potential are based on realistic assumptions as threshold levels are achieved already currently most of the time and would only affect some extreme situations during the low flow winter period.

9.2 Identification of Measures for Protecting and Enhancing the Ecological Quality

The main focus in mitigating the hydro peaking effects has to be given to

- reduction of peak amplitudes
- damping of flow increases and decreases

Flow amplitudes and sudden flow increases and decreases my go beyond the natural range of flow fluctuations to enable an economic power generation but should not exceed values defined below.

9.2.1 Basic Measures

Currently maximum daily flow amplitudes exceed the defined limit (according to the dual flow regulation) of 1:7.5 during low flow periods (e.g. Nov. 1993,Figure 6). A proposed limit of 1:5 would probably represent an economically acceptable value, as this threshold is achieved already most of the year and would only affect some low flow periods. This limit would lead to a significant reduction of extreme peaks which are considered to have the most negative impacts on fish.

More effort should be taken to dampen the short-term flow increase and decrease. As shown in Figure 7 currently the flow may triple within 15 min not enabling the fish to react adequately. Consequently fishes, in particular, juveniles, are flushed away during the peak or strand when the surge goes back. Under natural conditions sudden flow alterations are limited to about 20 % increase or decrease (Figure 5). It is assumed that a reduction of short-term flow alterations to a limit of 3 to 4 times the natural variation (60-80 % flow alteration within 15 min) would lead to a significant increase of the viability of the fish population.

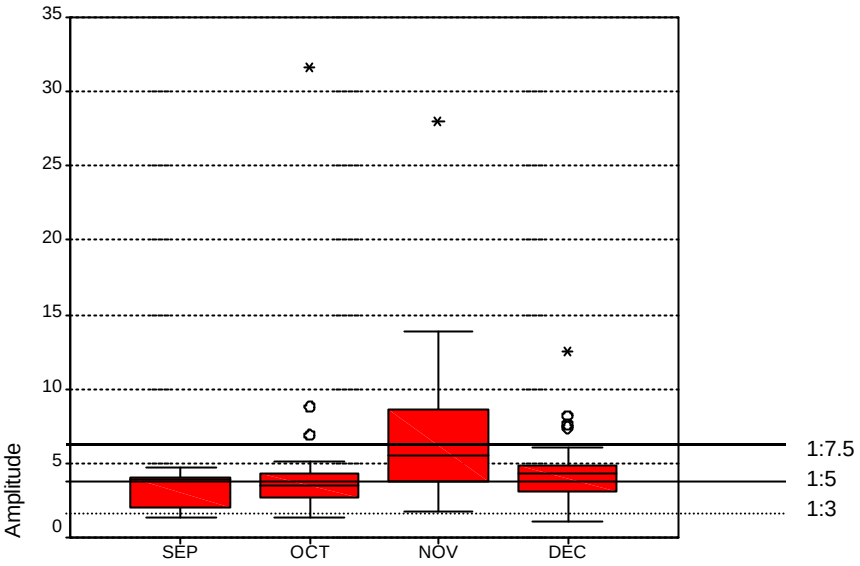

Figure 6 Real maximum daily peak amplitude (relation between low flow and peak flow) during low flow conditions (autumn and winter) in the Bregenzerach in the year 1993 (median, 50% percentile, range, outliers, extremes)

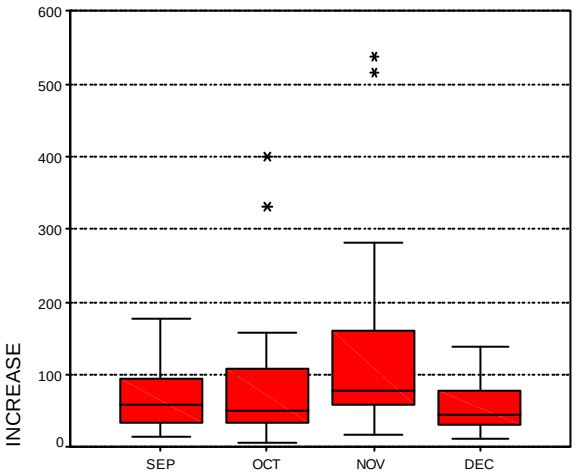

Figure 7 Maximum daily flow increase (%) within 15 min in the peaking section of the Bregenzerach in autumn and winter 1993 (median, 50% percentile, range, outliers, extremes)

9.3 Discussion and Conclusions

Good ecological potential is discussed at the basis of natural and altered hydrographs and results of the preceding ecological monitoring programme. Hydrological values indicative for the stress may lay outside the natural range but have to be significant lower than under the current poor ecological situation. Threshold values for the Bregenzerach would be 1:5 for the maximum daily flow amplitude and 60-80 % for short-term flow alterations 15 min. These values represent preliminary assumptions and would have to be verified and adapted according to an accompanying monitoring programme.

11 Bibliography

European Commission (2000): Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for community action in the field of water policy. Official Journal (OJ L 327). European Commission, Brussels.

Jungwirth, M., Moog, O. & S. Schmutz (1998): Limnologische Nachuntersuchung des KW Alberschwende. Synthesis. Studie im Auftrag der VKW-AG.

Moog, O., ed. (1995): FAUNA AQUATICA AUSTRIACA. Katalog zur autökologischen Einstufung aquatischer Organismen Österreichs. Bundesministerium für Land- und Forstwirtschaft.

Moog, O. (1997): Makrozoobenthologische Nachuntersuchung des KW Alberschwende - Endbericht. Studie im Auftrag der VKW-AG.

ÖNORM M 6232 (1996): Guidelines for the ecological study and assessment of rivers (bilingual edition). Österreichisches Normungsinstitut, Wien.

Parasiewicz, P., Schmutz, S. & G. Parthl (1997): Morphometrisch/hydraulische und fisch-ökologische Nachuntersuchung des KW Alberschwende Bregenzerach, Fachbereich Habitatuntersuchung - Endbericht. Studie i.A. der Vorarlberger Kraftwerke AG.

Parasiewicz, P., Schmutz, S. & O. Moog (1998): The effect of managed hydropower peaking on the physical habitat, benthos and fish fauna in the River Bregenzerach in Austria. Fisheries Management and Ecology, 5(5): 403-418.

Parasiewicz, P. & S. Schmutz (1999): A hybrid-model - assessment of physical habitat conditions combining various modeling tools. 3rd International Symposium on Ecohydraulics. 13-16 July, Salt Lake City, UT, USA.

Parthl, G. & S. Schmutz (1998): Fischökologische Nachuntersuchung des KW Alberschwende, Bregenzer Ache. In: M. Jungwirth, O. Moog & S. Schmutz: Limnologische Nachuntersuchung des KW Alberschwende, Bregenzer Ache. Studie im Auftrag der VKW-AG.

Schmutz, S. & G. Parthl (1995): Fischökologische Nachuntersuchung des KW Alberschwende, Bregenzer Ache. 1. Zwischenbericht, Studie im Auftrag der VKW.

Schmutz, S., Kaufmann, M., Vogel, B., Jungwirth, M. & S. Muhar (2000): A multi-level concept for fish-based, river-type-specific assessment of ecolocical integrity. Hydrobiologia 422/423: 279-289.

WWW/UBA 2000: Wassergüte in Österreich, Jahresbericht 1999. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasser., Wien.

12 List of Annexes

For further information on the methods of the fish assessment see *"schmutzetal2000.pdf*".