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onal impoundment. We also feel that after only two years of post-project data, the results should be viewed cautiously and that firm conclusions should not be drawn for some time. This is because some potential ecological effects such as changes in plant communities occur slowly.

There were some trends in the data thus far that would indicate possible negative environmental impacts (Table 1). At this time, we view these trends cautiously but are not alarmed as the differences are not great.

Vegetation in the wetland has not changed significantly since the construction of the dam. Canopy cover of plant species in the fixed plots has remained similar over the three years of the study and gross observations of the wetland indicate no change. One impact on the vegetation that was observed in 1987, was that a number of trees in the wetland had sustained damage to thelr bark. Apparently the surface ice in the impoundment oscillates as water is removed for snow-making and then refills, thereby scraping the bark from trees. This damage could result in tree mortality although none has been observed. Damage to low tree limbs and shrubs was heawier in 1988. Tree mortality could lead to impacts by the resultant loss of tree-top foliar habitats, and by an increase in sunlight reaching the water (less shade) with subsequent warming. On the other hand, tree mortality would increase availability of snags and cavity trees which are important and often limiting habitat factors for many wildlife species.

Water quality does not appear to be seriously degraded in Poor Farm Brook. It is still a cold, clear, stream with high dissolved oxygen content and a slightly acid but near neutral pH. Our data do however, indicate a decrease in D.O. and an increase in water temperature. These trends may be due to natural variation, and warying sample dates. For example, mean ambient air temperature at the stations increased more than did mean water temperature, and 1988 had above-average summer temperatures. Samples were taken from the stream on June 5 in 1986, on August 7 and September 17 in 1987, and on July 7 and 8 in 1988.

The diversity of terrestrial and aquatic organisms in and around the stream and wetland has not exhibited any clear trend over the three study years. There have been some changes in the species of aquatic invertebrates in our samples since 1986 but there is no pattern to these changes. It would appear that the populations were undersampled.

There was a steady decrease in relative and absolute abundance of brook trout in our fish samples. This may also be an artificial trend as less than one half as many trout were stocked by the New Hampshire Fish and Game Department in the stream in 1988, as vere stocked in 1986 and 1987. This stocking is conducted at the bridge on the main access road approximately 1190 meters downstream from the steel dam. Stocked trout as well as wild trout were captured with the electro-shocker although stocked fish were taken only about 100 meters above their stocking point. Stocking dates may have also been closer to sampling periods in the two earlier years. In 1988, electro-shocking was conducted at a time of very high water. Stream water was over the banks in the wetland, hindering the process. There were many avenues of escape for trout and it was extremely difficult to see fleeing or shocked fish.

On the negative side, we did have a sediment problem in 1987 which could have adversely affected trout reproduction, as could the trends in D.O. and temperature.

Wildlife usage of artificial nesting structures was high indicating their efficacy and that avian populations continue to thrive in the wetland. Of the nest boxes that were checked, 75 percent of the passerine boxes received some use, and 50 percent of the duck nest boxes were utilized.

## CONCLUSIONS

Despite some cautionary trends in the data, we remain optimlstic that check-dam subimpoundments and dormant-season-only flooding regimes are effective methods for mitigating the potential ecological impacts of snow-making ponds and other typeg of water source impoundments. Skiing is done on mountains, and by definition mountainous terrain is high in a watershed. That means that only modest amounts of water will be available naturally, and that the water that is there, will be in ecologically sensitive and valuable, cold-water streams and wetlands. There are ever-increasing pressures protection. We feel that alternative designs and mitigation techniques such as these may, in some cases, be viable alternatives by which we can maintain these streams and wetlands as they are, without significant ecological damage. Without techniques such as these, either the wetland would have been destroyed converted to a pond, and the stream undergone ecological changes (possible warming), or, the project would have been denied the appropriate permits, thus depriving the county of the additional recreation opportunities.

We are not at this time drawing firm conclusions on the degree of success of our mitigation efforts. Some trends in the data are disconcerting, and the variability of the results indicates that we need greater sample sizes and more years of post-project data. If at all possible, we will intensify our monitoring efforts in the future and with additional, years of data be able to firmly evaluate their effectiveness.

# ECOLOGICAL EFFECTS AND FISHERY PROBLEMS RELATED TO RESERVOIRS IN THE ALPS: THE PRESENT SITUATION

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ABSTRACT In Switzerland, a total of over 1100 hydroelectric power plants generate 60% of the electric energy consumed domestically. Main conflicts between hydroelectric power production and ecological interests arise from the negative effects on fish and invertebrates of dam construction, water level fluctuation in the reservoirs, alteration and diversion of flow, the creation of dry river sections, and sediment discharge into rivers. For each of these problems, the situation in the alpine region is briefly discussed by giving a number of examples mainly from Switzerland. Possible measures for mitigating the most negative effects are discussed.

## INTRODUCTION

Sixty percent of the electric energy produced in Switzerland is generated by hydroelectric power plants (SWV, 1988). Out of the approximately 1150 hydroelectric plants existing in 1990, 449 had an energy output of more than 300 kW. High pressure is used in mountainous regions, while the power plants on the lowland rivers operate on low head. In addition to dhe existing plants, 9 new power plants of over 300 kW are presendy under construction (pers. comm. by Bundesamt für Wasserwirtschaft, Bern).

Potential conflicts arising from hydroelectric power production in mountainous regions are many. However, aspects relating to fish and fish food organisms will be discussed here only. Thus, this paper attempts to review some of the actual fishery problems related to reservoirs in the alpine region by providing a number of examples typical for Switzerland. Furthermore, dhe possibilities for mitigating some of the most adverse effects are oudined.

## AREAS OF CONFLICT: SOME EXAMPLES

Basically, the following effects of reservoir construction and operation on the fish and invertebrate fauna can be identified (see also Aass, 1990):

*Impairment of fish migration*
A dam which is erected for accumulating water inevitably interrupts fish migration. Furthermore, in many cases, the water licence held by the power plants does not call for any residual flow at all. Likewise, water intakes and diversions of the entire flow create dry river sections which not only interrupt fish migration, but disrupt the stream continuum with its associated physical, chemical and biological features such as sediment transport or invertebrate drift. Even though such dry sections may occur only during part of the year, they encompass the spawning time of trout and other species which may give way to significant genetic isolation. A major problem constitutes the common situation where the high flow of water coming from the turbines is discharged back into the river bed where it attracts fish and keeps them from finding their way up through the river section with a generally very low residual flow. The waters originally flowing in high-mountain valleys which are converted into reservoirs are usually low-order and high-gradient streams. Their fish fauna typically consists of the dominant brown trout (*Salmo trutta fario* L.), accompanied by minnow (*Phoxinus phoxinus* (L.), bullhead (*Cottus gobio* L.) and stone leach (*Noemacheilus barbatulus* (L.). In the lower reaches of the mountain streams, grayling (*Thymallus thymallus* (L.), nose carp (*Chondrostoma nasus* (L.), barbel (*Barbus barbus* (L.) and other cyprinid fish may be present. In addition, lake-resident brown trout (*Salmo trutta lacustris* L.) may enter these reaches from an underlying lake for spawning. In fact, lake-resident brown trout have been affected most of all species by the erection of migration barriers, and huge efforts are now being undertaken to enhance lake trout stocks of e.g. Lake Constance (Ruhlé *et al.*, 1984). For this purpose, obstacles such as weirs will be removed or fish ladders will be added to existing dams. In high-mountain rivers turned into reservoirs, spawning migration of brown trout and other native fish is limited and usually functions in the stream above as well as below the dam, provided that the residual flow is sufficient. Therefore it appears difficult to argue for fish ladders circumpassing the enormous height of these high-head dams. However, dams in larger mountain rivers are less high, and fish passage upstream could be restored by fish ladders or - more easily - fish lifts.

*Alteration of the flow regime*
Effects on the fish are due to profound modifications of habitat components: current patterns, depth, cover, and living space may be altered in unfavourable ways, both temporally and locally, downstream of a reservoir or of a water intake in a brook. Extremely high spring and summer discharge flows from the reservoir during the reproduction season of fish, such as nose carp or grayling, may cause the destruction of entire year classes (Dedual, 1990).
A central issue within this complex is the residual flow necessary to maintain adequate fish and invertebrate habitat (Bundi *et al.*, 1990), and riparian vegetation (Hainard *et al.*, 1987). Bundi *et al.* (1990) have analyzed three cases of Swiss rivers where not only the quantity of water left in the rivers was inadequate, but also the seasonal variation in flow. It was found in particular that it is not so much a constant minimum flow that is required, but a residual flow that mirrors the natural seasonal cycle, with flushing flows in late summer for regenerating the stream substrate which serves as spawning ground for salmonid fish. The most extreme but nevertheless quite common case of flow regulation is the diversion of the total flow of brooks and rivers. In the resultant dry sections, practically all the stream organisms, and in particular the fish, are lost. Such sections are void of any ecological or even recreational value.
It is evident that the question of the legal regulation of minimum flow creates the most serious conflict between the interests of hydroelectric power production and the need for environmental conservation. The seriousness of this conflict has gained full public attention in the course of the revision of the Swiss Water Protection Law, currently under way in the Swiss Federal Parliament.

*Problems associated with water level fluctuation in reservoirs*
Above a dam, the original river (or small lake) is converted into a large stagnant body of water, characterized by pronounced water level fluctuations. Problems usually arise afrom the fact that naturally spawned fish eggs are exposed to drying and freezing during winter draw-down, from increased turbidity due to bank erosion, and from relative shortage of benthic food occurring a few years after fill-up (Grimås & Nilsson, 1962; Pechlaner, 1989; Aass, 1990). The question as to how the fish stocks in such artificial systems be managed best has been treated, among others, by Roth (1971) and Ruhle (1980) for high mountain lakes and reservoirs in Switzerland, and by Pechlaner (1989) for Austria.
Reproduction of arctic char (*Salvelinus alpinus* (L.) seems to be affected much more than that of brown trout which uses affluents for spawning, as opposed to char that spawn in the lake along the upper slopes. In certain, but not all cases, such waters will have to be restocked periodically in order to maintain fish populations and yield. Overpopulated and stunted char or trout stocks have to be thinned out in order to improve growth and yield (Pechlaner, 1989). The introduced North-American lake trout (*Salvelinus namaycush* (Walb.) seems to reproduce successfully in some reservoirs with only moderate winter draw-down (Ruhle, 1980). Its potential for managing Swedish reservoirs has been discussed by Nilsson (1985). As a basic rule, however, fishery management of reservoirs should resort to native fish species.
Apart from the negative aspects of reservoirs, a positive aspect should be mentioned here. The construction of a dam in a mountainous area often creates a new type of environment which did not exist before: a lake. This new environment provides food and space for coldwater lake fish such as brown trout, arctic char and lake trout, and room for an appealing sport fishery. This positive aspect is somewhat dimmed by the fact that in winter, fish are concentrated in a relatively small body of water. This may induce fish to leave the reservoir through the turbine intake pipe which causes high mortality and may lead to significant losses of the fish stock (Pechlaner, 1989).

*Ecological damage caused by suspended solids from sediment discharge*
Over the years, all resevoirs accumulate sediments which have to be removed periodically in order to assure proper functioning and safety of the equipment (ground outlet, intake valves) and to restore the storage capacity. Intervals between purging may vary from one year to over 20 years.
There are basically two ways for removing the sediments: a) by lowering the lake level and then opening the ground outlet, and b) by controlled suction dredging and discharging the sediments at a fixed concentration into the underlying stream. The former scheme is faster (a few days) and seemingly cheaper than the latter one which may take several months and involve considerable manpower. However, due to the often much higher and largely uncontrollable concentration of solids, the former scheme usually entrails severe damage to both the fish fauna and the invertebrates serving as fish food organisms in the stream below the dam. Mainly due to the economical advantage of scheme a) over scheme b), almost all purges have been executed according to scheme a) so far. Most commonly, the living organisms are destroyed over a more or less extended stretch of the river. Damage to the fish has to be paid for by the power companies, if such a damage is being claimed on the basis of an expert evidence (e.g. Peduzzi & Grimaldi, 1986). In recent years, such events have met with considerable public criticism. Thus, a monitoring program for the relevant physical and chemical parameters during the purging operation, and a survey of the fish and invertebrate fauna prior to and after purging is nowadays required for licensing such actions by many cantonal authorities (Gartmann, 1990). A typical example of such an operation is provided by Polli (1990). However, the concentration of the suspended solids is often much higher than in this case.
Concentrations higher than 20 $ml l^{-1}$ and prevailing several days may largely destroy fish and invertebrate life. Concentrations even much lower may result in considerable silting, thereby clogging the interstitial spaces in the stream bed (Neveu, 1980; Polli, 1990). Alabaster & Lloyd (1980) found that waters with a permanent concentration of suspended solids above 400 $mg l^{-1}$ were unable to support adequate fish life.
The most recent example for controlled sediment removal from a reservoir by suc-

tion dredging is the Eugenisee reservoir near Engelberg, Central Switzerland. In this case, our institute, acting as an advisory agency to the cantonal authorities, has recommended a maximum allowable concentration of 5 $ml l^{-1}$ of suspended solids, concomitant with a water flow of 2 $m^3 s^{-1}$ or more at any place of the receiving river (Engelbergeraa). Purging takes place in summer 1990 over a total of three months, five days per week, 12 hours per day. Preliminary observations after four weeks of dredging indicate that fish and invertebrates are still present in the river. However, final conclusions based on a comparison of the situation before and after purging can be drawn only about one year after the end of the dredging operation.

## MITIGATION SCHEMES

It is conceivable that the increasing need for hydroelectric energy in the past decennia has outweighed ecological arguments against new reservoirs. This is not necessarily so any more, as the discussions of the proposed new Water Protection Law have shown. Nevertheless, there are a large number of already existing reservoirs, managed according to quite different objectives which are not always compatible with the requirements of fish and invertebrate life. The negative ecological effects of reservoirs outlined above may be mitigated to some degree by taking certain measures.
The impairment of fish migration is difficult to overcome at dams with high heads. In certain cases, however, fish ladders or fish lifts are useful means for re-opening access to the spawning grounds of endangered fish species such as the lake-resident brown trout (e.g. trout stock of Lake Constance, migration barrier at Reichenau GR). The problems inherent to the water discharge from the turbines to the river, and arising from the instinct of the fish to swim upstream against the main flow, can be circumvented only by the addition of more water flowing in the residual section well before and during the spawning season, and by certain technical improvements that would allow the fish to find the entrance to the fish way higher up.
The alteration of the natural water flow regime represents the essential management operation of a hydroelectric power station. Since the ecologically most cTitical aspects (dry sections, residual flow, lack of flushing flows, excessive discharges) are laid down in the water licence, any improvement in the ecological sense can be negotiated for at the time of licence renewal only. The outcome of the new Swiss legislation on water protection will ultimately decide about the possibilities of changing the artificial water regime.
Water level fluctuations in reservoirs in mountainous regions are inherent to power production at the time of high demand (winter). A number of management schemes for such waters have been proposed (Ruhlé, 1980; Pechlaner, 1989). Difficulties arise from the specific demand of sport fishermen for trout and char, fish species which suffer most from the particular environmental conditions in reservoirs (e.g. shortage of benthic food, impairment of reproduction). It would nevertheless be worthwhile to explore the possibility of introducing native whitefish species (*Coregonus* sp.) which could utilize the pelagic food resources quite efficiently. Furthermore, some whitefish spawn in the open water from where the eggs sink to the bottom, outside the areas which are exposed in winter. It has been mentioned by Ruhlé (1980) that whitefish can maintain self-sustaining stocks in reservoirs (e.g. Klöntalersee). Whitefish are esteemed fish and can be caught fairly well by angling, as the example of Lake Lungern shows. A limiting factor could be temperature which might slow down growth to some degree. Introductions of exotic fish (e.g. land-locked sockeye salmon, Kokanee) and food organisms (e.g. the shrimp *Mysis relicta*; Ruhlé, 1980) for improving food utilization by fish in reservoirs should definitely be rejected.
Sediment removal from reservoirs may cause ecological damage of rather variable extent, depending on the concentration of suspended solids in the receiving river. On one hand, Gartmann (1990) is of the opinion that sediment evacuation by purging through the ground outlet is generally superior to suction dredging, taking into account all relevant aspects. The crucial point seems to be the proper control of sediment flow through the ground outlet, in relation to the available water flow, in order to achieve adequate dilution of the solids. Periods of high natural flow during snow melt in spring or early summer would facilitate dilution and transportation of the sediments discharged into the river. Furthermore, this timing would largely prevent excessive silting of spawning grounds for salmonid fish (Polli, 1990). On the other hand, suction dredging allows for a more gentle removal of sediments without lowering the water level in the resevoir. Future experience will have to show which method is most compatible with the ecological requirements at any specific situation.
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