

# Aspects of differentiation of global and regional climate change effects in Alpine regions

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## Abstract

Attributing changes in Alpine landscapes to supraregional climate change or land use change is difficult. In this paper, an investigation of the heat budget of Lake Königssee in National Park Berchtesgaden made it possible to analytically separate these driving forces. Ascertained environmental changes could be detected as an increase of the energy budget of Lake Königssee. Thermal stability rose up to 40% in summer months. Stratification periods are now longer than they used to be compared to earlier investigations. The nutrient budget did not change significantly. It can be stated that the National Park Berchtesgaden is a protected area, where the self-addressed rigorous criteria from its labelling as a National Park are not completely realised yet. However, according to this investigation, regional anthropogenic influences have no negative effects.

**Keywords:** climate change, heat budget, national park, nutrient budget, lake, limnophysics

## 1 Introduction

Based on the driving forces of global change responsible for the intensification of landscape changes, we can separate two regions: Intensely used regions affected by climate change and human utilisation (tourism, agriculture or traffic) and natural regions only influenced by climate change. In intensely used regions, it is more difficult to attribute landscape changes to the direct impact of climate change or to human activities. Therefore the changes in Alpine landscapes result from:

1. Climate change impacts (global) without direct regional human activity, and
2. Anthropogenic impacts (regional).

To examine these influences separately is as important as difficult. If the parameterisation, dynamic and dimension of anticipated changes can be specifically assigned to these two driving forces, management strategies could better respond to human activities. For this purpose, an examination area less influenced by humans and with a stable and well functioning natural ecosystem had to be found.

## 2 Examination area

Few Alpine regions allow such a differentiation. Appropriate sites can be found in National Parks (Visconti 2001), where strong regulations apply and land use is restricted. In those places the impacts of global climate change are assumedly domi-

nant. It is necessary to find an area where resilient material of earlier investigations can be used for a comparative study. The National Park Berchtesgaden meets these criteria because of its high level of previous investigation and the therefore already existing data material.

Sensitive measuring points and parameters to detect environmental changes are prerequisites for such a study. For the purpose of comparison having data sets from previous decades was crucial.

Various topics have been investigated in the National Park Berchtesgaden (e.g. biology, geology, geomorphology, soils, climate, history of utilisation and protection). A list of publications can be found on the homepage of the National Park Berchtesgaden (Authority of Nationalpark Berchtesgaden 2008). However, there is no overall landscape-ecological study of the entire National Park area. Some aspects of the landscape budget of the Königssee catchment area can be found in Vetter (2005).

### 3 Methods

The Lake-Project compared oxygen and temperature profiles of the Königssee and its inflows between 1999 and 2005 with data from the late seventies of the last century. The background of all considerations was the physical relations between climate driven forces and the reacting environment. An increase of air temperature influenced the energy budget of the Königssee. Livingstone (2003) for example analysed the connectivity between the behaviour of lake systems and climatic driving forces. Five heat exchange processes predominantly influence the heat budget involving four meteorological ones: Air temperature, cloud cover, water vapor pressure, and wind speed. Air temperature influences the lake temperature variability most significantly and is involved in three of the five heat exchange processes: convective sensible heat exchange, evaporative heat exchange and the atmospheric emission of long-wave radiation, all have an influence on the lake. Figure 1 shows these connectivities between a changing climate and a changing energy budget of lakes (Edinger et al. 1968; Michler 1974).

In the investigation project nutrients were measured (nitrate, sulphate, chloride, phosphate) in the tributaries to the lake and the lake itself. Meteorological data (air temperature, wind speed, precipitation etc.) and water temperature, oxygen, stability, stratification of the lake profile were examined.

Frequency, methodology and distances between measuring points in lake profiles follow standards to assess changes in the lake heat budget (e.g. Schaumburg 1996). For specific project aims, the measuring programme was extended to bi-weekly measurements in winter stratification and weekly measurements during summertime and circulation phases.

Multi-parameter-instruments from the companies WTW and SEBA measured water temperature and oxygen. Their accuracy of measuring temperature was about  $\pm 0.1$  K. Enquiries concerning instruments used in earlier investigations (1978–1980) revealed an accuracy range of even  $\pm 0.065$  K.

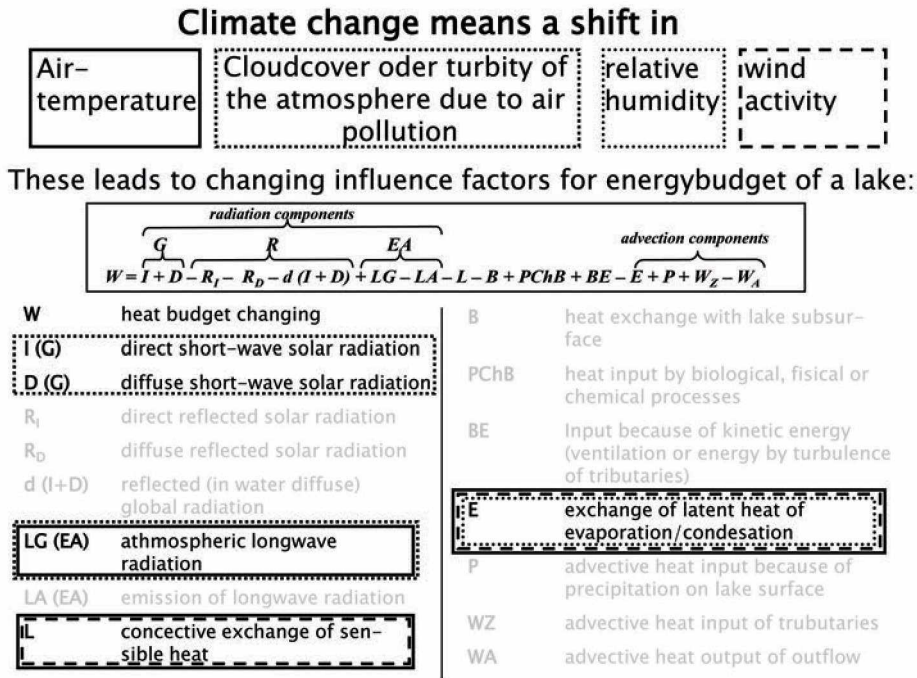


Figure 1: How climate change will lead to a reaction of the heat budget of lakes (Michler 1974, Livingstone 2003).

Historical data was linked to the GIS-data of the Berchtesgaden National Park Authority with spatial data from geology, soil and vegetation in the catchment area. After geo-statistical analysis with GIS-tools (intersection, superposition, buffer creation) maps were composed. One aim was to find out, how geological conditions or Alpine pastures influence spatial distribution of nutrients in subcatchments of the Königssee area. The tabular results published in Vetter (2005) and their consequences will be discussed in the following paragraphs.

Different investigations were concentrated in the so called LAKE-Project (Landscape-ecological Analysis of the Königssee-catchment area). The project carried out research on the Königssee and its catchment area following the aim to link ascertained changes to different driving forces. Different parameters were assigned to character of supra-regional and regional influences of climate change. These served for building up data sets based on the hydro-chemical conditions of the catchment area and the limnological situation of the Königssee. The latter works particularly well as a long-term indicator being part of the Nationalpark Berchtesgaden (Vetter 2005). Figure 2 describes the entire landscape ecological investigation approach and concept of the LAKE-Project. For various reasons only some aspects could be implemented in the field.

### Landscape ecological analysis in the koenigssee-catchment area

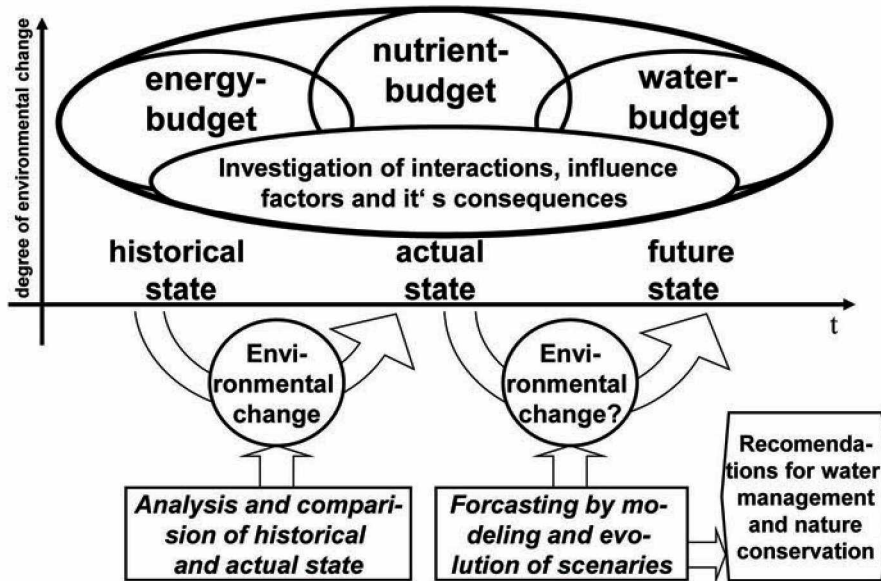


Figure 2: The concept of the LAKE-Project.

## 4 Results and discussion

Historic data on the use of natural resources in the National Park Berchtesgaden show considerable activities (timber industry, more intensified use of alp pasture, tourism, and fishing) in the past. This forms a sharp contrast to today's situation, where only minor levels of land use can be found (Vetter 2005). According to the rigorous criteria from the IUCN (International Union for Conservation of Nature and Natural Resources) normally no utilisation would be allowed in this area. However, until today tourism and alp pasture management have traditionally persisted. Fishing activities in Lake Königssee are of minor importance. It is unknown if this kind of utilisation affects the landscape-budget. Having downsized the above mentioned influences this region could be used for our investigational aims. It had to be discussed, if Alpine pastures have a measurable influence on the nutrient budget of the lake. This was analysed by GIS and statistical comparison. The different subcatchment areas were compared concerning the nutrient dynamic in the inflows of the lake. To give an example, the nitrate content of the inflowing Königsbach (Alpine pasture utilisation) is between 2.0 and 3.3 mg/l and of the inflowing Eisbach (without agricultural utilisation) is between 1.3 and 2.5 mg/l. Both are on a low level.

It had as well to be discussed, if the nutrient input of the inflows indicates a negative impact on the nitrate budget of the lake caused by anthropogenic utilisation. Every input would ultimately have to be traceable at the erosion base, the deepest point of the catchment area.



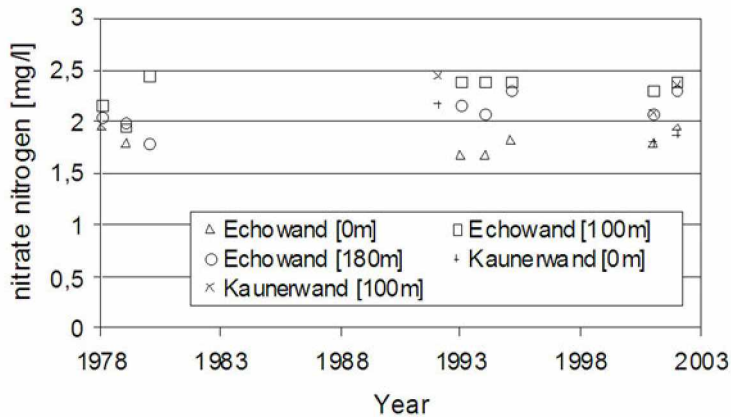


Figure 3: Nitrate contents from the water of the Königssee in several depths in all available measurements of the last 25 years (Siebeck 1982, Wasservirtschaftsamt Traunstein 1996, own measurements).

Figure 3 displays that the average nitrate values in the lake water show no significant increase during the past 25 years. Even if the values are on a low level, this does not imply that there was no influence by land use. Only for nitrate dynamic changes are not detected.

In order to study the energy budget in the landscape-ecosystem of the Königssee Valley the general climatic conditions need to be taken into account. Figure 4 shows a contemporary rise of temperature, although the displayed time period is short.

The average air temperature of Bad Reichenhall (about 15 km away, the next city to the study area with reliable long climatic data series), shows an increase in air tem-

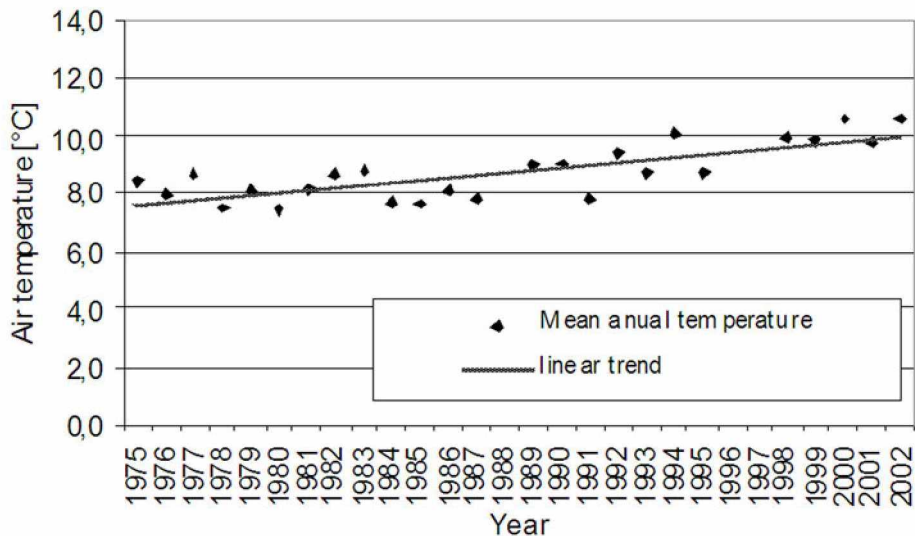


Figure 4: Annual air temperature values of Bad Reichenhall with linear trend (DWD 2003).

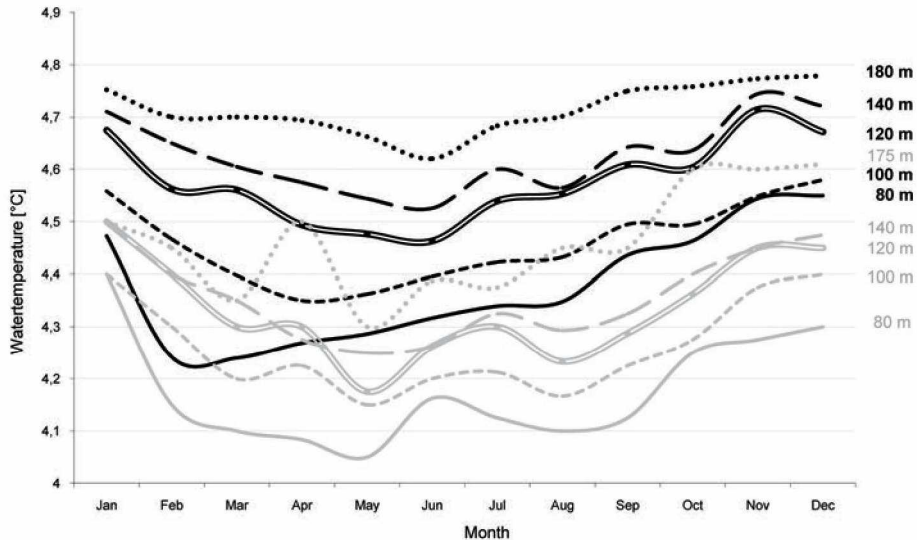


Figure 5: Changes in deep water temperature of the Königssee. Grey coloured lines: values from 1978–1980, Black coloured lines: values from 2000–2005 (Siebeck 1982 and own measurements).

perature of about 2 K in only 25 years. Assuming the doubling of  $\text{CO}_2$  content in the atmosphere, regional climatic model scenarios expect further changes of the air temperature from 0.5 to 4.5 K, depending on the initial parameters for the modeling (BAYFORKLIM 1999).

Therefore the heat budget in the Königssee has increased. This is the result of the comparison of two datasets, one from 1978 to 1980 and the other one based on recent measurements (2000–2005). The shift of water temperature in the deeper zones of the lake is particularly important (figure 5). Also Ambrosetti and Barbanti (1999) have discovered the important changes of temperature in deeper zones of lakes as a long-term indicator for climate change. The temperature behaviour in deeper parts of the lake is not influenced by daily changes at the surface. Hence, changes in hypolimnion temperature result from a long-term influence on the energy budget. Deep water has a memory of previous climatic influences in the area (Livingstone 1997). A standardised statistical test (Man-Witney-U-Test) allowed the verification by comparing data sets (Vetter 2005).

These changes tend to influence the stratification and homothermy periods in the lake. Figure 6 shows the duration of the stratification period with the dates of transition.

The duration of the stratification period today is about 30 days longer than in the seventies. In 1978, the statistical date of transition was in the middle of May, in the years 1979 and 1980 it was in the first days of May. Now we can assume that the date of transition has shifted to April. In autumn the situation is reverse. In the seventies, the date of transition from homothermy to circulation shifted from mid-September to early October. Nowadays, the transition days entirely occur in October.

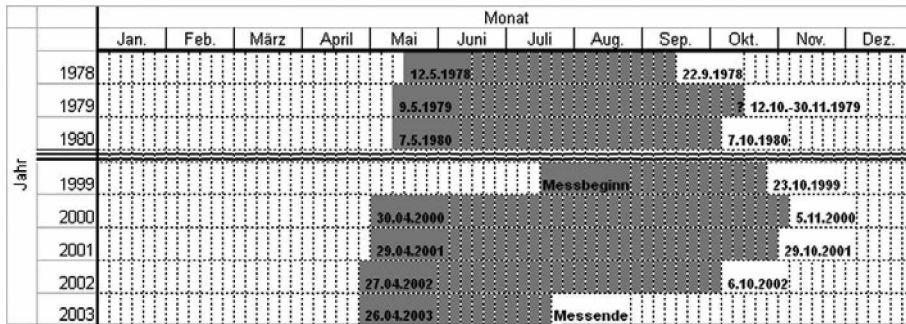


Figure 6: Stratification period (in grey colour) with the dates of transition in selected years in the Königssee. In one case, where we find the question mark, autumn 1979, the possible date of transition could not be reconstructed, therefore only a time period of transition could be displayed (Siebeck 1982 and own measurements).

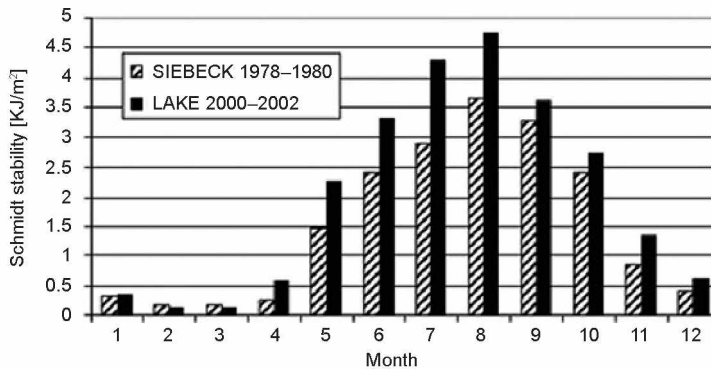


Figure 7: Comparison of the Schmidt stability index in the Königssee (Siebeck 1982 and own measurements).

Not only has the stratification duration increased, but also the thermal stability. The Schmidt stability (Schmidt 1928) in the months between April and December, for instance, rose up to 40% (figure 7). In this context a shifting of the thermocline (the barrier layer between upper epilimnion and deeper hypolimnion) can be observed (figure 8). At present, in June, July and September, the thermocline is about one meter lower in comparison to earlier observations. Only in August the statistical analysis does not show this development.

Another interesting aspect is the direct comparison of water and oxygen profiles from different examination dates. Siebeck (1982), for example, observed that the metalimnion is located directly below the surface of the lake. When comparing typical temperature profiles of today's measurements with earlier data, it is noticeable that this statement today does no longer apply (figure 9).

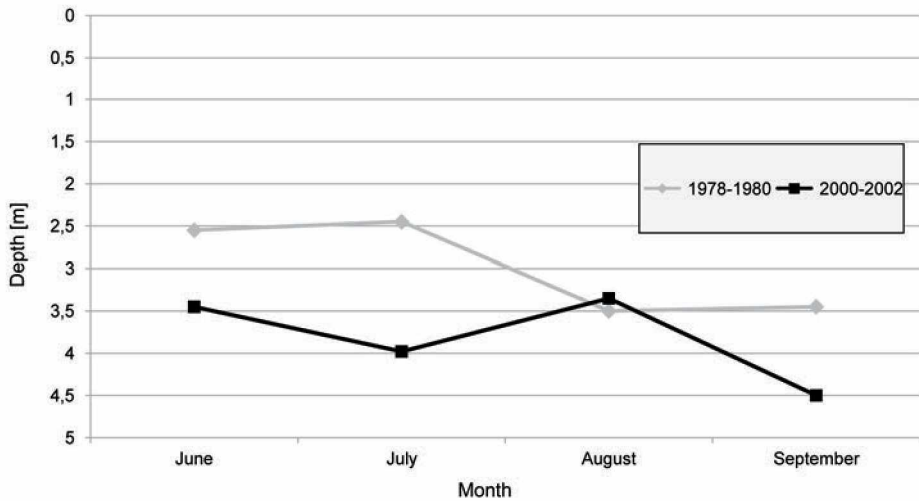


Figure 8: Comparison of the location of the thermocline in the Königssee (Siebeck 1982 and own measurements).

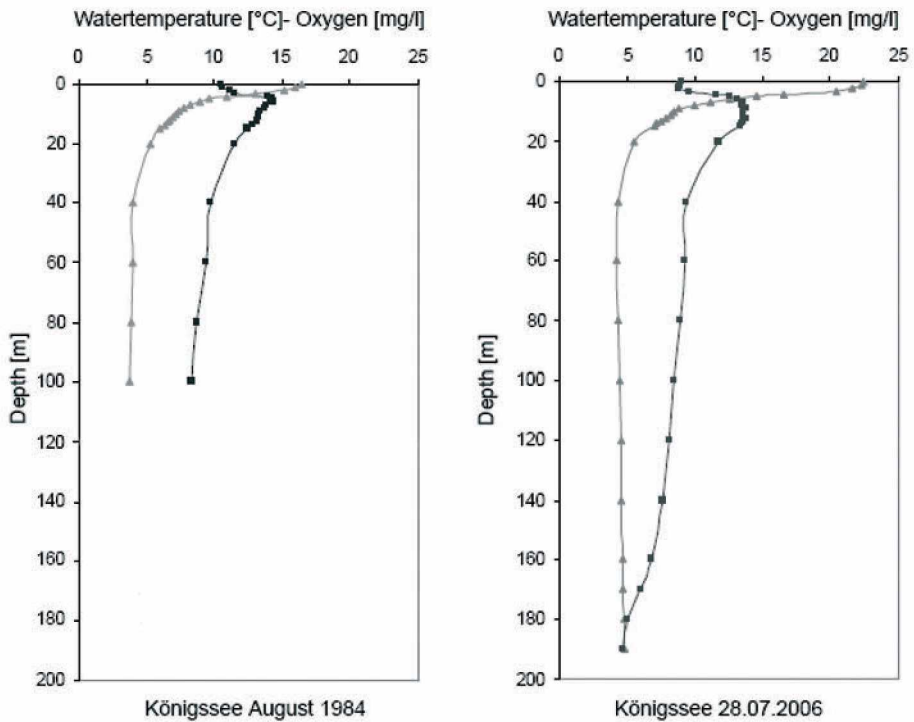


Figure 9: Comparison of two typical temperature (triangles) and oxygen (squares) profiles from different measuring events (Königssee). In August 1984 (exact date could not be reconstructed) the measurements were made to a depth of 100m (Michler 1987, Frei 2007).



## 5 Conclusion

Even if we have some influence from alp pasture management in some subcatchment areas of the Königssee, the influence is comparatively marginal. If we compare stronger utilised parts of catchment areas with less stronger ones, it becomes evident that the influence on the nitrate budget is very low. With regard to the lake itself, we can assume that nitrate will stay on a stable level (figure 2) if there is no change in the management of this area, which is likely. It is possible to characterise this phenomenon as something like an “ambient noise” in this region.

To summarise, changes in stratification and homothermy periods in the lake can be observed. The duration of the stratification period is nowadays about 30 days per annum longer than during the earlier period of observation (1978 to 1980). This could possibly have an impact on the lake ecology: Only in the time period of homothermy the lake can circulate fully and transport oxygen from the surface to deep waters.

One of these consequences of heat budget changes is that the thermal stability is higher. It rises up to 40% during summer months. A stronger thermal stability means that it is more difficult to break up the stratified layers in the lake. As a consequence circulation is not as effective as in periods of thermal stability. In this case, the ecology in deeper zones of the lake will be affected. In this context a shifting of the thermocline was as well observed. This could in addition have consequences for the ecological situation, because the aquatic environment in the part of the lake which is above the thermocline is now larger.

Finally it can be assumed that the heat budget in the Königssee has increased over the last 25 years. It is possible to ascertain temperature differences in several depths between 100 m and 160 m from 0.18 K to 0.26 K in the above mentioned periods.

The investigated time periods of this study are too short to allow a generalisation of the results directly linked to consequences of climate change. But the changes we can measure nowadays can be interpreted as a first signal of change, which has to be further observed critically. Thus it is recommendable to build up a monitoring net taking the measuring points of the LAKE Project as a basis, also for the discussion about the implementation of the “EC-Water Framework Directive”. Likewise it can be recommended to add the long-term-monitoring of limnological systems with regard to climatic changes to the parameter catalogue, which is directed at observing ecological systems in protected areas. It is also necessary to link limnological results to those from biological studies. For this purpose a close collaboration between our research group and the Bavarian State Agency for Environment was created.

According to the results of the LAKE-Project, no final impact by utilisation could be found, neither in the inflow to the lake nor in the lake itself. Therefore ascertained environmental changes are not attributed to direct influences in the catchment area.

We can summarise that the sensitive hydrological catchment area of the Königssee and especially the lake itself in the mountain environment National Park Berchtesgaden are very suitable for research on local environmental change because of global change, since regional anthropogenic influences are marginal.

Forthcoming investigations have to undertaken. In particular, prognoses by physically based models of future behavior of the heat budget have to be carried out. In the current investigation project LAGO (2007–2009) of the Department of Geography at the University of Munich, the heat budget of Lake Ammersee affected by climate change will be prognosticated.

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