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2 WATER USE AND HUMAN IMPACTS ON THE WATER BUDGET

THE GLOBAL USE OF THE AVAILABLE WATER RESOURCES HAS INCREASED CONSIDERABLY OVER THE LAST HUNDRED YEARS, TWICE AS FAST AS THE POPULATION GROWTH. THIS TREND WILL CONTINUE PARTICULARLY IN THE DEVELOPING COUNTRIES.

FROM THE OUTSET OF CIVILISATION HUMANS HAVE TAKEN »CORRECTIVE ACTIONS« ON RIVERS AND THEIR CATCHMENTS E.G., BY DRAINING WETLANDS, DEFORESTATIONS, INTENSIVE AGRICULTURE, STRAIGHTENING OF WATER COURSES OR BUILDING OF DYKES. MANY OF THESE MEASURES HAVE STRONGLY AFFECTED THE WATER BUDGET AND WATER QUALITY. THEY HAVE ALSO LED TO EUTROPHICATION AND A CONTAMINATION OF WATERS WITH HEAVY METALS AND ORGANIC POLLUTANTS. TODAY SOME OF THESE AQUATIC HABITATS HAVE BEEN CLEANED UP AND RESTORED WITH LARGE EFFORTS, MOSTLY IN THE INDUSTRIALIZED COUNTRIES. MANY OF THE REMAINING AQUATIC RESERVES ARE NOW PROTECTED. THE HUMAN IMPACTS ON THE WATER SYSTEMS CONTINUE HOWEVER. THEY FREQUENTLY LEAD TO IRREVERSIBLE ECOSYSTEM DAMAGES, E.G. THROUGH SALINISATION OF SOILS, GROWING DESERTIFICATION OR DESICCATION OF RIVERS AND LAKES. THE REALIZATION OF LEARNING THE HARD WAY FOR PAST MISTAKES SHOULD BE REASON ENOUGH TO GIVE THE DEVELOPING COUNTRIES THE POSSIBILITY TO LET THEM CREATE THEIR FUTURE ON A SUSTAINABLE BASE, ACCORDING TO THE MILLENNIUM GOALS.

2.1 Surface waters under stress factors and their controlling by integrated measures[1]

RAINER KOSCHEL, HORST BEHRENDT & MICHAEL HUPFER

SUMMARY: *Highly efficient measures for freshwater ecosystem protection require complex actions. Surface waters are closely connected to their terrestrial and atmospheric environment, and therefore, preventive protection of surface waters begins in the catchment. Improvements and stabilisation of aquatic ecosystems by reduction of point and diffuse loading (redevelopment) must be balanced increasingly with structural optimisation of ecosystems (restoration and ecotechnology), and must be based on a strategy of »integrated management«. Limited financial resources for surface water protection demand an optimal combination of the principles of emissions and imissions.*

Surface waters are our future

The surface waters are essential and precious resources worthy of protection. They have to be regarded as i) economic goods – referring to their manifold functions within landscape water budgets, ii) part of the food supply – as drinking water, and iii) buffer and service systems – because of their high biological diversity. These three aspects act in concert, and determine the goals of integrated water protection and sustainable management of water resources (see Chapter 0). World-wide, surface waters, soils, and atmosphere are considered to be severely changed and destabilised by natural fluctuations and diverse human uses (industry, municipal water supply, agriculture) as well as unbalanced management (WBGU 1999). Standing and running waters are especially susceptible to eutrophication, soil erosion, toxic loads, increase in salinity, and acidification (see Chapter Kap. 1.7, 2.8, 2.9 and 2.10).

In addition, widespread disturbances of the natural chemical cycles have emerged, and it is presently difficult to estimate the consequences for the water resources. The multiple integrations of the ecosystems with natural cycles can become strongly reduced, and may, in part, vanish. In the journal »Nature«, the paper »The value of the world's ecosystem services and natural capital« was published in 1997 (CONSTANZA et al. 1997). The authors tried to evaluate the non-cost functions of ecosystems, and calculated the annual services of lakes and rivers to amount to US$ 850,000 for one km^{-2} water surface. Furthermore, the authors highlighted the meaning of surface waters for water supply, self-purification, and recreation. According to their evaluation, standing and running waters alone support communal services by as much as US$ 1.7 trillion per year, a sum equal to 10% of the world's gross economic product. These values exemplify the importance of sustaining the above mentioned non-cost services, and that from the economic point of view, it is useful to counteract the degradation of ecosystems over time.

Surface waters not only suffer from external point sources emitting nutrients and pollutants, but also from a variety of other anthropogenic impacts. These influences comprise diffuse losses into aquatic ecosystems especially from agriculture and from the atmosphere, and severe damage of the surface water structure by construction work, excessive use, spatially extended decreases in groundwater level, and leaks of petrol components in catchments. At present, diffuse loading are increasing rather than decreasing, and result from both former and present land use in catchments. The diffuse losses cause problems for the protection of standing and running waters as well as for estuaries and ocean via long-distance influences.

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However, the »emission principle« has started to counteract the negative developments of external loading, and refers to both point sources from communal and industrial waste water treatments, and diffuse losses especially due to agricultural activities. Nonetheless, the present external loading is still about 10-fold higher than the geogenic background. In addition, long residence times in groundwater delay the effects of reduced emissions on diffuse loading for several decades. The application of emission-oriented measures alone for the improvement of water quality has limited success. Internal mechanisms may counteract a rapid and efficient improvement of water quality, for example by nutrient and pollutant release from sediments, alterations of the food web, and long residence times of the water bodies (see Chapter 1.7). The nitrogen elimination in waste water treatments exemplifies that in some cases, emission-oriented measures are often not useful from the economic and ecological point of view. First, nitrogen loading can efficiently be eliminated in the water body by natural microbial nitrate reduction especially in combined lake-river systems, and second, the decrease of nitrate emissions promotes phosphate mobilisation from sediments. Thus, the measure is counterbalanced.

For these reasons, highly efficient measures for surface water protection require complex and integrated actions (*Fig. 2.1-1*). Improvements and stabilisation of aquatic ecosystems by reduction of point and diffuse loading (redevelopment), must be balanced with structural optimisation of ecosystems (restoration and ecotechnology in surface waters and catchments). This combined strategy will be elucidated by exemplifying important problems and trends of the water quality of standing and running waters in Germany.

Pollutant exposure in rivers, lakes, and coastal waters

Aquatic ecosystems are prone to numerous natural and anthropogenic stress factors of a physical, chemical, and biologic nature, resulting from loading of energy, waste waters, and bacteria. The most common problems in surface waters, causing significant restrictions of their use, are loadings of nutrients and pollutants (see Chapter 2.8 and 2.9). Pollutant loading can be evoked by a broad spectrum of inorganic and organic chemicals. Anthropogenic sources of toxic metals comprise ore processing, metal industry, road traffic in urban centres, the use of herbicides, and emissions of gases rich in sulphur and nitrogen, the latter of which lead to corrosion of metal surfaces.

Organic pollutants consist of pesticides, organic tensides, pharmaceutical chemicals, and petrol components. Metals and organic chemicals, such as polychlorinated biphenyls (PCB), become enriched in sediments and food webs, and may exceed toxic concentrations. Chemicals that act as pseudohormones, and influence the reproduction and development of vertebrates, are released in high concentrations in urban areas; these substances are defined as hormone-active substances or endocrine disruptors. Synthetic-active substances are part of pharmaceuticals and industrial chemicals (e. g. organochlor-pesticides, PCB, derivates of tensides, and phtalates). For example, synthetic estrogens, which are part of contraceptives and other hormone treatments, are released into the environment via waste water and waste water treatments.

The emissions of gases containing sulphur and nitrogen

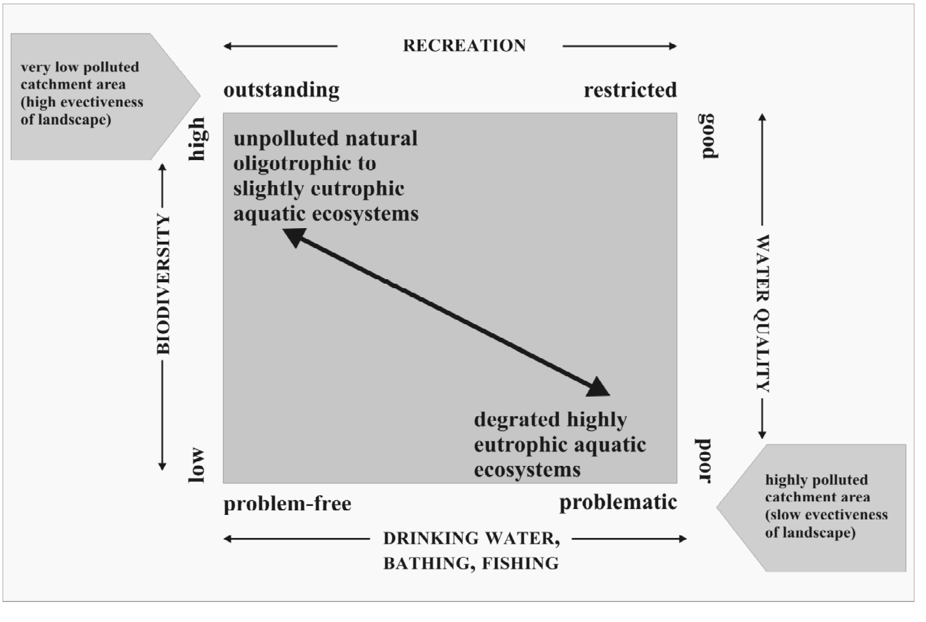

Fig. 2.1-1: The influence of the terrestrial surroundings on water use and water quality (Koschel et al. 1998).

cause acid rain, which in turn promotes acidification of surface waters and soils in regions with low chalk and low buffering capacity. This happens even at great distances from the points of emissions. Acidified surface waters are often clear and thus, apparently are of high water quality. However, the decrease in pH is a reason for the extreme changes of their biocoenoses. Fish and other animals cannot survive or reproduce. As a further consequence, toxic metal ions (especially aluminium, copper, zinc, and lead) are increasingly released from soils and sediments. Especially the north-east of North America and Scandinavia are suffering from acidification. In Germany, the acidification via atmospheric deposition is limited to some regions, such as in the Bavarian Forest and the Black Forest. In addition, exploitation of natural resources can render surface waters prone to extreme acidification. In Germany, there are approximately 500 lakes created by coal mining on a medium-term scale of 10 to 50 years. Most of these lakes are geogenically strongly acidified during their generation. Coal mining leads to the oxidation of minerals rich in sulphur (pyrite, marcasite), causing the release of acids.

Eutrophication

Eutrophication is the most common problem in surface waters (see Chapter 1.7). Eutrophication is defined as the increasing intensity of primary production (trophic state) of a surface water, which is due to increased availability and uptake of nutrients. Since the middle of the last century, the extent of eutrophication has been markedly increased by insufficiently treated waste water, artificial use of nutrients in households (phosphorus in detergents), and by run-off from agricultural areas. Thereby, the deterioration of lakes has been significantly accelerated. As a consequence of eutrophication, blooms of phytoplankton and macrophytes have undesired impacts and severely restrict water uses. The water becomes turbid and changes its colour, blooms of toxic cyanobacteria, loss of diversity, oxygen depletion, generation of sulphide, high fish mortality, and nuisance by smell occur. Thereby, several types of water uses, such as water supply, fishing, and recreation become restricted. Additionally, in eutrophicated surface waters, the effects of toxins can be synergistically reinforced, because these ecosystems are partly destabilised.

In Germany, there are significant regional differences in the trophic state of lakes. In Brandenburg and Mecklenburg-Vorpommern, 90% of 1,500 lakes were classified as mesotrophic or eutrophic, whereas in Bavaria and Baden-Württemberg, less than 50% were of high trophic state. The reasons for this difference are partly natural. The present and former loading from agriculture are reflected by a high portion of eutrophicated lakes. A major problem due to eutrophication of inland waters results from the proximity of intensely used agricultural areas to surface waters, and the intensification of this, coupled with drainage and irrigation measures. Agriculture targets at maximum plant production, however, high biomass production in surface waters should be avoided because of its negative consequences.

The phosphorus (P) acts as a limiting factor and controls the degree of eutrophication in most inland waters. Since the mid 1980´s, the existing dominant point emissions of P, were reduced by as much as 80% with the introduction of P-free detergents. However, the diffuse emissions of P were only slightly decreased. Small losses of P from the terrestrial catchment usually mean a considerable charge of water ecosystems by P. For many inland waters, loadings related to events such as rainfall the result in short-term erosion. The slow P export via leaching, is a long-term problem difficult to predict. At sites with a low sorption capacity near the groundwater table, the long-term fertilisation of agricultural areas, especially by manure, may cause complete saturation with P in the entire soil layer. Scoumans et al. (1988) found that already at the end of the 1980's, more than 10,000 ha of soils were saturated with P in the Netherlands. Similar phenomena can be found also in other regions with low groundwater tables, soils with low sorption capacity and extreme livestock densities (Behrendt & Beockhold 1993). Also in rivers in the north-west of Germany, those catchments which drain agriculturally farmed peat soils with extreme low sorption capacity are very vulnerable to P leaching. The consequence of both cases is that P-concentrations in small rivers can reach the order of magnitude of municipal waste water.

Many running waters are suffering from eutrophication. For example, during the last decades, a considerable increase in algal biomasses could be detected in the low courses of the large German rivers. This was due to waste water treatment strategies which primarily aimed to reduce organic loadings, and neglected the elimination of mineral nutrients; thereby, nutrients were emitted directly in available forms to surface waters (Behrendt et al. 2003). Eutrophication sources of shallow coastal waters, such as lagoons, show that the sources of eutrophication can be several 100 kilometres distant from the location where the eutrophication occurs. For example, the River Oder contributes 15% of the total nutrient emissions to the Baltic Sea, yet it forms a low portion (7%) of the catchment of the Baltic Sea, it has however a high population density which contributes to the sources of eutrophication (Behrendt & Dannowski 2005).

The change in nutrient loads of rivers could be reconstructed by the modelling of emissions to, and the turnover within, surface waters, including periods without measurements. *Fig. 2.1-2* represents the changes of P loads in the River Oder during the last 50 years. Although a

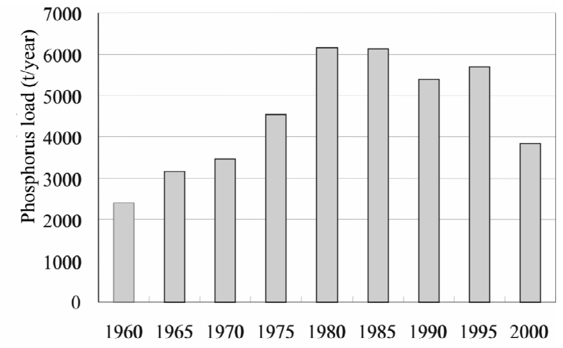

Fig. 2.1-2: Phosphorus loads of River Odra to the Baltic Sea (1960–2000) (BEHRENDT & DANNOWSKI 2003).

decrease in P load due to the introduction of P-free detergents has already started, the present level of P loading to the Baltic Sea by the River Oder exceeds the emissions in the 1960's.

Management goals for surface water ecosystems

Problems with surface waters are usually first perceived when there are restrictions in water uses. Remedial actions aim to improve the state of surface waters, while keeping costs reasonably low. Concerning the planning and execution of measures, the practical question arises as to the degree to which the development of the problem should be reversed.

The aim of the remediation is often the return to the natural or original state. However, definition of this state is difficult. It should not mean the state directly after generation of the surface water. What should be defined as the original state? When humans did not yet decisively influence the ecosystem, which usually means before the Neolithicum, at the end of the Atlanticum, approximately 5,000 years ago? In those times, climate was warmer than today, and in Central Europe, the catchments of the inland waters were covered by a dense canopy of mixed oak tree forests (oak tree, lime tree, elm tree). It is impossible to redevelop the climate of a landscape and its surface waters, and it is almost impossible to change the cultivated landscape of today into a non-cultivated forest landscape. Therefore, the maximum aim of natural remediation measures should be the potential natural state of surface waters. This reference state, the named ideal state, is characterised by a state, which is close to that of pre-industrial times. The ideal state can be individually estimated for each water body by guidelines and by palaeolimnological investigations , and is to be compared with the actual state. The need for action is great if the actual state significantly differs from the ideal state.

In contrast, the formulation of the aim of development for a lake or river is arbitrary, but should be adapted to present and future human exploitation and settling of the landscape, to ecological knowledge, technical progress and financial capacities (STEINBERG et al. 2002). The definition of the aim of development is an iterative process that should be carried out in concert by users, owners, experts, and politicians.

Strategies to control water ecosystems

The charge limits of a water ecosystem are determined by its structure and the structure of its environment. For example, the potential decomposition of organic substances is much lower in regulated river systems than in naturally structured water courses. Critical load models are helpful for achieving qualitative aims of aquatic ecosystem management. These models enable the user to describe qualitative states of an ecosystem, depending on the charge and characteristics of the surface waters. This means that a potential control strategy may include the optimisation of the structure and processes within a lake, so that symptoms of excessive charge can be minimised. The response to changes of charges often follows a sort of hysteresis, in which eutrophicated lakes can persist in their state, despite reductions of external loadings. Furthermore, sufficient decreases in external loadings cannot always be achieved at suitable low costs, and remaining loadings can be compensated for by internal measures. Modern protection of surface waters should therefore consider a combination of external and internal measures (see Chapter 2.9). Which external and internal methods and control opportunities are available at present? There are many examples for a slow reduction of diffuse nutrient emissions by »best management practice« and by extensifying agricultural land use.

Optimisation of external and internal sinks

Beside the reduction of nutrient emissions at their source, the restoration of original nutrient retentions structures within the landscape, such as bogs, ponds, and floodplains, represents the opportunity to reduce diffuse nutrient emissions by internal links in terrestrial and aquatic ecosystems. Thereby, a sustainable management of matter and water circulation is accomplished (see Chapter 3.1, 4.3 and 4.5). Intact ecosystems minimise losses of matter by short-circuiting cycles of water, nutrients, and mineral substances (RIPL & WOLTER 2001). Intact ecosystems are sustainable. However, the consequent application of the concept mentioned above would result in severe restrictions, or even losses, of existing uses. External loading can and must also be reduced close to surface waters by the construction of phosphorus elimination plant for the purification of river water, or by the creation of buffer systems, such as barriers and retention areas planted with *Phragmites australis*, if it is not possible to create retention structures within the catchment.

Restoration and ecotechnology

Technical procedures can influence the physical, chemical, and biological structure of surface waters. Reduction of available nutrients can be used to reduce primary production within the water body, and hence improve its trophic state. The desired improvement can be accelerated, and at the same time external loadings can be decreased, if the P retention within the sediments of lakes is increased by the use of substances for chemical precipitation. Thereby, remaining loading could be compensated for or a level of P concentration could be attained which allows positive feedback and the efficient application of further measures. Biomanipulation is a reasonable example for such measures. By biomanipulation, fish populations are optimised. As a consequence of the resulting decline of the food web, feeding pressure on undesired phytoplankton is increased, and the water becomes clearer. However, global evaluation of such applications has revealed that a certain level of P loading has to be accomplished in order to achieve efficient biomanipulation. In conclusion, high efficiency of measures in surface waters can be achieved by a combination of measures.

Need for action and research

Using the ecological potential

Recent investigations showed that restoration measures oriented only towards the reduction of emissions is questionable, especially considering the limited financial resources in water protection. The vision that any loading reduction has always a positive effects is no longer valid. Instead, the capacities of ecosystems to withstand charges dependent upon their structures has to be explored, and the manifold ecological functions and services have to be used optimally. At present, detailed knowledge of the functioning of surface water ecosystems and their reactions to anthropogenic influences is insufficient. In particular, our understanding is lacking considering that the state of aquatic ecosystems is a function of biological, chemical, hydraulic, hydrological, meteorological, and physical influencing factors, including their temporal and spatial changes. There is a need for an efficient and integrated scientific instrument, which will enable us to analyse the behaviour of ecosystems on a functional, process-oriented, and reproducible basis. In addition, the trends in development of ecosystems need to be calculable with a high degree of certainty (*Fig. 2.1-3*).

The comprehensive and harmonised integration of applied external measures (within the catchment), and internal measures (within the water ecosystem), should be increasingly efficient, if the existing lack of knowledge is minimised. Both the principles of emissions and imissions have to be considered within integrated surface water protection.

Strengthening our knowledge base by case studies

Further reduction of emissions from point sources does not lead to a remarkable decrease of external nutrient loading with acceptable costs. It seems that mainly diffuse loading is an unsolved long-term problem, difficult to identify, and to predict by existing methods.

Case studies from diverse geographical regions could help to analyse the effects, and the course of nutrient loading, by changing land use. Little knowledge exists on the locations and capacities of retention mechanisms in relation to the total loading from catchment areas. For example, the risk of rewetting bogs, which thereby might become P sources, is controversial, because bog systems apparently react in different ways. Restoration of P retention areas may lead to a restriction or decline of existing human uses, which however, decreases public acceptance. The socio-economic problems related to these consequences also have to be solved by related scientific approaches. Holistic pilot studies could

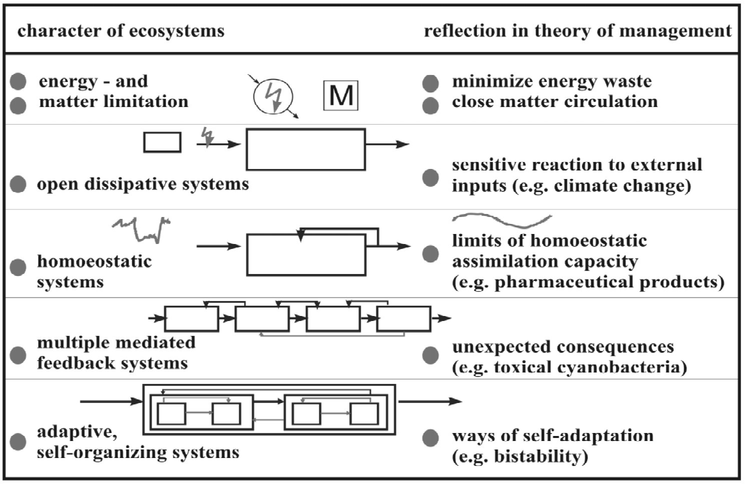

Fig. 2.1-3: Theoretical principles of aquatic ecosystems, their reflection in the theory of aquatic ecosystem management and the illustration of knowledge deficits (modified after STRASKRABA 1993).

contribute to solving these problems (»whole ecosystem experiments« as scientific method).

Acceleration of knowledge transfer in the water economy

LEWANDOWSKI et al. (2002) have revealed that the actual effects of lake-internal measures were often far below those expected. In some instances the applied scientific measures were useless. The research task should be to improve and evaluate the scientific basis of lake-internal measures. In turn, this knowledge should feed applicable decision support systems (SCHAUSER et al. 2003). The better the scientific basis, the more difficult it is to ignore the state of the art. The slow publication of research results limits knowledge transfer, and our knowledge of the environment needs to be more publicly accessible.

Development of cost benefits analysis

There are great gaps in our knowledge of the economic evaluation of ecological functions of surface water systems. In addition, by practical applications it was shown that even sound scientifically-based management measures are not always accepted and financially supported. Therefore, there is a need for further supporting arguments. The inclusion of financial efficiency should be considered as an important element of future strategies for surface water protection. However, the scientific basis is incomplete. These requirements become increasingly important, especially concerning the implementation of the Water Framework Directive of the EU (WFD), which aims to accomplish and evaluate a »good ecological state« for all surface waters.

Policy recommendations and reinforcement of basic research

Conversion of integrated protection of surface waters and the sustainable development of the environment entails many new tasks and challenges for surface water research. Therefore, we need scientifically well based and defined ideals, which are oriented towards the main ecological and hydrological functions of surface waters. The main function can be defined as, the complexity of the food web extending from bacteria to fish (information is stored in structures and genetic codes), the discharge rate of water bodies, the matter circulation, the self-purification potential and the close interrelationship between air (climate), land, and water. We need highly developed instruments (models) for determining and predicting the integrative impacts of anthropogenic and natural factors on the quality and quantity of surface water ecosystems, which in turn should include both socio-economic and global climate changes. We need an extended basis for the economic evaluation of water as a resource. Modern integrated protection of surface waters requires an efficient combination of the principles of reconstruction, redevelopment, restoration, and ecologically useful and sustainable water use. In advance, these requirements demand a high degree of knowledge of the manifold and highly complex processes in surface water ecosystems. Equally, there is a high need for basic research, which should cover improved knowledge of biological, chemical, and physical structures and their functions within surface water ecosystems, and of the regulation of the manifold transport and transformation processes extending from the catchment to the water bodies.

Increase social acceptance

Integral surface water protection inevitably causes conflicts between inhabitants, users of water and land, and owners. These conflicts can only be solved on a long-term basis if environmental education is reinforced, and new forms of public discussion are developed. There have to be opportunities created for politicians, employees of districts and communities, and pressure groups to gain knowledge about the field of surface water protection. Dissemination of information to the media can contribute to making water problems perceivable and to highlight possible actions. Conflicts should increasingly be solved in panels with the participation of inhabitants and the public in the decision process.

Public interest and political pressure have sometimes meant that internal measures in polluted lakes were carried out without the necessary preliminary investigations. Often, these measures were not successful, and at the same time, they exploited the scarce financial resources, which could have been used for more efficient measures.

Combine the principles of emissions and imissions

Surface waters are closely connected to their terrestrial environment, and therefore, preventive protection of surface waters begins in the catchment. Limited financial resources for surface water protection demand an optimal combination of the principles of emissions and imissions (BENNDORF et al. 2003). Many ecological and technical standards are oriented towards the principle of zero emissions (such as those for toxic substances), the state of the art of technology (for example four purification steps in waste water treatments), or they are apparently arbitrary. In some cases, imissions of non-toxic substances could be tolerated, which are higher than the concentrations permitted by directives and laws, if the ecosystem structure is created and optimised accordingly. The latter can be accomplished by eco-technological procedures. Therefore, the principle of zero emissions of any costs is not recommended. Efficient protection of surface waters requires procedures which are adapted to individual cases and regions ♦

[1](extended version after KOSCHEL et al. 2005)