Management of Rivers and Coastal Waters under the Aspect of Ecologically Oriented Engineering

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1. The European Water Framework Directive

In the knowledge that the intensive use of surface- and ground- waters and the discharge of harmful substances into these waters becomes an increasing danger for society the European Community has adopt a directive which has been integrated into the national law systems of all member states. The main objective of this directive (guideline) affects the European water politics and is the basis for the management of rivers, lakes, channels, and ground waters.

Waters in the European Community are under increasing pressure from the continuous growth in demand for sufficient quantities of good quality water for all purposes. It is therefore necessary to develop an integrated Community policy on water. The success of this policy relies on close co-operation and coherent action at Community, Member States and local level as well as on information, consultation and involvement of the public, including users.

A new legislation for the water of all European Member States - the EU water Framework Directive - (WFD) has come into force in December 2000 (Directive 2000/60/EC of 23. October 2000). Those countries sharing river basins with Members of the EU, which are not or not yet Members of the EU, are also integrated in the planning process.

All of Europe’s waters will be subject to protection under the WFD, surface waters and groundwater. Unlike previous water legislation, the framework directive covers surface waters and groundwater together, as well as estuaries and marine waters. Its purpose is:

(1) to prevent further deterioration, and to protect and enhance the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;
(2) to promote sustainable water consumption based on the long term protection of available water resources;
(3) to contribute to the provision of a supply of water in the qualities and quantities needed for its sustainable use, and
(4) to aim at enhanced protection and improvement of aquatic environment, inter alia, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances.
Member States of the EU will have to ensure that “good” ecological status is achieved or kept in all waters at the end of the year 2015. A good ecological status for surface waters is defined as follows: the values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associates with the surface water body type under undisturbed conditions (Directive 2000/60/ECD, Annex V, no. 1.2). Ecological quality and chemical quality are the criteria.

For each river basin district, some of which transcend national frontiers, a “river basin management plan” is needed to be established and updated every six years. This plan will have to include an analysis of the river basin’s characteristics, a view of the impact of human activity on the status of waters in the basin, and an economic analysis of water use in the basin district.

The objective of achieving good water status needs to be pursued for the whole river basin, so that measures in the same ecological, hydrological and hydrogeological system are coordinated. International river basins like the Rhine basin serve as a positive example for this approach to water management, with their co-operation and joint settings of objectives across Member States borders even beyond EU Member States.

2. Ecological Features

2.1 Long-term development in species richness of the rivers Elbe and Rhine

Qualitative and quantitative composition of organisms within streams depends mainly on their degree of organic pollution. These substances will be decomposed by microorganisms and this oxygen consuming process normally results in an oxygen deficiency. In correspondence with the increasing sewage input into our rivers and streams, which were most noticeable since the 50th of the last century, we have noticed, even in our largest rivers, Rhine and Elbe a pronounced decrease in species numbers. This decline reached its maximum in the early 70th. In the River Rhine, for example, in many parts not more than 3 invertebrate species could be found in 1971 and in the River Elbe in 1989 still not more than 7 invertebrate species have been recorded. The few fish caught by professional and sports fishers were not consumable due to high levels of contaminants. However, the construction of new industrial and municipal sewage treatment plants as well as refurbishment of existing plants resulted in a pronounced improvement of water quality since the 70th in the Rhine and the same development was possible in the river Elbe starting in 1990 with the reunification of Germany.

In the Rhine the abundance of species was decreasing from 160 species found in 1900 to less than 40 in 1955. This development is well correlated with the waters oxygen concentration. Therefore, the largest decrease in abundance could be documented for insects with high oxygen requirements. With increasing oxygen concentration past 1971 the number of species increased again, and since the 80th even the sensitive water insects have regained in abundance. Since 1990 we have recorded more than 150 species in the Rhine and since than this number remains constant.

The dramatic decline in diversity in the Elbe is also correlated with the decrease in oxygen concentration. However, in contrast to the Rhine, this conditions continued till the German reunification.
The East German government was not providing the required funds for the industrial and municipal sewage treatment plants. However, since the reunification of both German states the rivers water quality has improved considerably. At the end of the 90th the river Elbe had regained already 80% of the species found in the Rhine after it’s completed regeneration.

The speed of regeneration was much faster in the river Elbe than in the Rhine. In the almost complete regeneration took place in only 10 years, while the same development lasted approximately 25 years in the Rhine.

The reason for this accelerated process are:

1. The reduction in organic pollutants from industrial and municipal sources was much quicker in the Elbe than in the Rhine. The construction of new sewage treatment plants in the Elbe was completed within a very short time period, while in the Rhine this process took much longer.

2. Moreover, in the Elbe the new sewage treatment plants contained techniques which have been developed and implemented over the years along the river Rhine. Therefore, the success story of the fast restoration of the Elbe would not have been possible without the know-how gained during the reconstruction efforts from the Rhine.

3. The River Elbe was preconditioned for a fast recolonization, because this river possesses a much higher structural variety than the Rhine.

During regeneration of both rivers many typical species reappeared. Some of them, which had been formerly considered extinct, often re-emigrated with large numbers in astonishing short time periods. The most spectacular reoccurrence of a typical Rhine species was that of the mayfly Ephoron virgo (August-mayfly), which had been considered extinct in the Rhine for more than 30 years. In the late 80th this species re-appeared with a spectacular event. This species is known to perform mating flights within the very short time period of a few hours in warm August nights, right after sunset. As most insects are attracted by light sources, this species was found in masses around brightly lit areas like bridges. Due to this mass-developments of the August-mayfly in 1990 and 1991 bridges crossing the river Rhine in the cities of Bonn and Cologne had to be closed temporarily for traffic and some newspapers reported about this (“Millions of flies, alert in Bonn; scenes like in a horror movie”). However, for the ecology of the river Rhine, the reoccurrence of Ephoron virgo is not a horror event as this newspaper headlines suggest but a good indicator for the success of the re-cultivation efforts in the past.

2.2 The influence of the current regime on the ecology of animals in large rivers

Beside the contamination with anthropogenic pollutants river ecosystems have to cope with many natural environmental factors such as periodic and spontaneous changes in water level and discharge. It is evident that these factors have a tremendous influence on the distribution of many river-borne invertebrates.

However, regular appearance of discharge fluctuations (including catastrophic events like extreme high water levels) are a characteristic and continuous reoccurring feature of most rivers and streams dating, at least, back to the last ice age. Therefore, the animals found in our rivers and streams should be well adapted to such events and they are, at least to some extend. However, even though many of them show adaptations to
high water levels and high flow speeds they are still influenced by it. For example, every now and then, floods tear breaches into aquatic populations. From these gaps other species can benefit and they can fill them in until they become victims of the next high water event. Therefore these events enhance the temporal diversity of streams.

Beside the increasing water discharge itself, with its acceleration in flow velocity, the animals are highly influenced by changes in the streams bed load. Higher flow velocities result in an increasing transport of sediments which will prevent animal colonization. This influence is most distinct on the bottom of streams.

2.3 Morphological structures

Common structures found along large rivers are groins and parallel structures, so called longitudinal groins. The function of these structures are to maintain the navigation channel or to stabilize the river banks. Along 685 km, between the Czech Republic and the weir at Geesthacht, the riverbanks of the river Elbe in Germany contain about 6900 groins and 330 km of riprap as well as longitudinal groins.

The development of the banks is strongly influenced by these groins. Nevertheless, many banks still have natural conditions. In compliance with the Federal law, the Waterways and Shipping Administration is looking for rehabilitation measurements in the riverbed. The main aim is to increase hydrological and structural dynamics and the associated habitat diversity.

A number of investigations of the Federal Institute of Hydrology were carried out to prove the impact of modifications on traditional groins. Between the groins variety of different habitats exist. For example: habitats exposed to high flow velocities, stony habitats, sandy habitats, and habitats were muddy sediments prevail.

All present fish species and a remarkable number of macrobenthic invertebrates benefit from groins and modifications improve the occurrence of species, especially of indicators species for still waters. The different distribution of four species of crustaceans shows for example different types of habitat utilization. Some species for example are most abundant at the groin heats. Obviously they favor high flow conditions. Other species favor the stony and sandy areas along the groins, while others, can be found at almost all samples sites in-between the groins in similar abundance’s, and other species, seem to be highly specialized. Investigation of fish abundance’s in groin fields have shown similar results. There are fish species, which are specialized, while others can be found without distinct preferences. Interesting is that in some fish species adult and juvenile species show different preferences.

As already mentioned, there are different groin types in use and under investigation along German waterways. The typical inclined groin type, and two modified types. In general, modification seem to enhance the ecological diversity of the groin habitats and more species are likely to be found in higher numbers. In general, groins provide a divers and important habitat for many aquatic organisms.

2.4 Compensation and remedial actions

Considerable expansions of the water body have, according to the national German environmental laws,
to be compensated by installation of compensation areas. This remedial area should, whenever possible, be established as close as possible to the area lost due to the expansion. In most cases, artificial shallow water areas are established, which are separated from the main water body by groins and longitudinal groins. The main objective of this procedure is to increase the structural diversity, thus increasing biodiversity of flora and fauna.

2.5 Fish migration in anthropogenic altered rivers

Today, the majority of rivers, especially in highly populated areas and states, has been altered by man. Structures like dams, navigation locks, and power plants are insurmountable obstacles for most migratory fish.

Fish populations are in general highly dependent upon the characteristics and morphology of the aquatic habitat which supports all their biological functions. This dependence is most marked in migratory fish, which require different environments during their life cycle (reproduction, production of juveniles, growth and sexual maturation). This species have to migrate from one environment to another in order to survive. In Germany we have to consider fish-migration especially for fish species like salmons and trout's whose reproduction takes place in freshwaters, while their adolescence takes place in the oceans. For the survival of these species the passage to their breeding grounds is inevitable. For background information: all around the world approximately 8 000 species of fish live in freshwaters while 12 000 live in the oceans. From these about 120 species migrate regularly between the two environments.

The construction of dams and other obstacles is seldom without effect on fish populations: migrations, as well as other fish movements can be substantially disabled, or in the worst case, some species can be cut off totally from their habitats. It is evident that this can have a tremendous impact on the ecology of migrating fish species. In case of power plants migrating fish can suffer major damage during their transit through hydraulic turbines or over spillways.

The upstream passage for fish species past obstacles can be provided for through several types of fish passages. Fish pass design involves a multidisciplinary approach. Engineers, biologists and managers must work closely together. It should be remembered that the fish pass technique is empirical in the original meaning of the term, i.e. based on feedback from experience. The general principle of upstream fish passes (fish ladders) is to attract migrants to a specified point in the river downstream of the obstruction and to induce them (actively) to pass upstream, by opening a waterway (so called fish pass). Upstream fish pass technologies can be considered as a well-developed technique for.

Are fish passes effective mitigation means? The Effectiveness of a fish pass may be measured through inspections and checks e.g. visual inspection, test trapping, continuous video check. In 1987, the International Commission for the Protection of the Rhine (IKSR) formulated proposals for improving the ecosystem of the river Rhine.

On behalf of the Federal Republic of Germany and the French Republic, and with support of the EU-Government it was planned to build the fish passage structure at Iffezheim. This fish passage system was designed in particular to enable fish species such as salmon and sea trout, to bypass the dams across the
Rhine and reach their spawning grounds in the Rhine tributaries of the Black Forrest and adjacent French mountains. The fish pass at Ifezheim was under way since April 1998 and was in Operation on July 2000. During the investigation period, from June 2000 to December 2001, almost 33 fish species were recorded while using the structure. Some of them in fairly large numbers. The success of this design will help to speed up the implementation of further projects to build fish passage structures in large rivers.

Since April 1998 a new fish bypass was established at the Geestacht tidal weir. In contrast to the situation in Ifezheim, the construction here was much easier because the weir was not used for power supply and during construction no complicated measures had to be taken to support a highway as it was the case in Ifezheim. Consequently, the construction costs for this bypass amounted a fraction of that used for the Ifezheim fish pass. In contrast to the Ifezheim fish pass this bypass was constructed using natural stone material in a riffle-pool sequence. The success of the Geestacht fish bypass has been investigated by the Federal Institute of Hydrology.

3. Bedload Management at the River Rhine

Canalization of the main channel, fixing of embankments, reclamation of floodplains and flood control measures have forced the large navigable rivers into an even smaller channel and have changed the naturally existing hydraulic and morphologic processes. In addition, the sediment flow has been drastically disturbed especially after construction of impounding dams in the upper courses and along the main tributaries. Today the free flowing parts of the rivers are characterized by a general bedload deficit and an non-uniform bedload distribution. This leads in large parts to severe bed degradation whereas other reaches are stable or slightly aggrading. As water levels tend to follow bed level trends (Droege et al., 1992, Brinkten and Goelz, 2001) ecological damages in the flood plain, serious navigation problems in the main channel, and economic disadvantages for water management, agriculture and forestry are well known negative consequences.

Alternatively, the construction of additional impoundment dams would have been possible. However, this would have resulted in drastic and radical negative changes of the ecological conditions of the runoff regime river Rhine. The decision to supply the river instead with a continuous supply of bedload material can therefore be considered as ecologically oriented engineering.

To avoid these disadvantages a strategy has been developed for the river Rhine which allows to stabilize the river bed by combining conventional training measures with measures of bedload management (Goelz, 1994). The latter means to balance the bedload budget of the river by artificial bedload supply as well as by dredging and disposal of bed sediment. Additionally, local river training works and scour prevention measures have to support this sort of dynamic bed stabilization.

3.1 Artificial bedload supply

Artificial supply of bedload material for the dynamic stabilization of river reaches has become an accepted method in river engineering and is being applied increasingly on German Federal waterways. The material to be added is released from hopper barges forming a thin mobile gravel carpet on the river bottom.
The dimension of the amount of material and its grain-size composition is mainly oriented at the transport capacity of the reach to be stabilized and the grain-size of the natural bedload there. Additional stabilizing effects or a reduction of the material to be added is expected from using coarser material, e.g. in an Austrian bed-stabilization project downstream of Vienna (Zottl, 1999). Conversely, also the addition of finer material may be appropriate as well, if the aim is a quick stabilization of reaches further downstream (Goelz, 1990). In order to have a better scientific basis for bedload supply measures field tests with petrographic tracers have been carried out, which give not only information's about sedimentological processes like hydraulic sorting, mixing and abrasion but show also how the material supplied will spread over the reach to be stabilized (Goelz, 2002).

Long term experience has been gained at the Rhine river near Iffezheim. To avoid bed degradation immediately downstream of the Iffezheim barrage the river has been supplied with gravel since 1978 when the weir was put into operation (Kuhl, 1992). Stabilization of the riverbed and of waterstages immediately downstream of the impoundment weir is the primary aim of this measure, as the unhindered access to the ship locks of the impoundment must be ensured.

Moreover, this bedload supply at Iffezheim is the only major source of the free-flowing Upper Rhine since the impoundment weirs upstream and the dam regulation of the main tributary, the river Neckar, inhibit the natural supply of bedload to a high degree. In the long-term average about 180 000 m³ of gravel are dumped each year.

3.2 Bedload withdrawal

Some 170 km downstream of the Iffezheim barrage the hydraulic conditions of the river have drastically changed. Between Mainz and Bingen water-level slope and flow velocity reach a minimum with the consequence that bedload transport slows down. The sandy sediment delivered from the Upper Rhine tends to form large dunes which obstruct shipping traffic especially at low water conditions.

Due to their mobility and limited dimensions, these obstacles are difficult to dredge. Thus other solutions had to be found to cope with the problem. In 1989, a huge bedload trap was implemented near Mainz. A trench 160 m wide and 1.4 m deep was dug widthways into the bed. This structure collects the bedload delivered from the Upper Rhine. The sudden widening of the cross section forces the bedload to settle in the trench. From there it can be easily removed by dredging. On an average, in the bedload trap near Mainz about 100 000 m³ of sand and fine gravel are dredged each year. Due to this measure navigation conditions have been markedly improved within the last decade.

3.3 Overall concept for the river Rhine

Based on the positive experience with the artificial gravel supply at Iffezheim and the bedload withdrawal at Mainz an overall concept for the free flowing section of the river Rhine was established by a working group appointed by the German Federal Ministry of Transport aiming at establishing a dynamic equilibrium of the river bed. To avoid aggregation and erosion sediment transport must be controlled in such a way that transport capacity and bedload are in harmony, both locally and on the large scale. Accordingly, the concept must rely on mutually complementing measures of river training (improving or...
construction of groins, guidewalls, etc) and measures of bedload management (supply and withdrawal of
bedload material). Generally, large scale deficits and excesses of sediment should be compensated by
measures of bedload management, whilst local imbalances should be counteracted by river training measures.
This graph shows the bedload distribution and the individual bedload management measures at the Rhine
between Iffezheim and the German-Dutch border.

3.4 Realization

The implementation of the overall concept based on artificial bedload supply presupposes besides the
financial resources, a series of organizational, logistic, and scientific-technical requirements. The most
important precondition, however, for long term bedload management is the availability of suitable material.
The Upper Rhine, the Elbe river and the Danube downstream of Vienna are fed with a mixture of sand and
gravel from adjacent gravel pits. At the Middle Rhine, where gravel exploitation is very limited, broken
material from quarries has to be supplied. The same applies to the Lower Rhine. Therefore the suitability
of broken material as a substitute for gravel had to be tested by several field tests (Goelz et al., 1995).

Together with the bedload supply at Iffezheim and the bedload withdrawal at Mainz now five
bedload-management measures have reached the operational state whereas two measures at the Lower Rhine
are still in the test phase.

4. Ecological Oriented Guidelines for the Maintenance and Extension of
Fairways to the German Seaports.

The fairways to German seaports have a length of several hundred kilometers and are mostly under tidal
influence. The total amount of dredging material that will be removed in order to maintain the necessary
depth of the fairways is approximately 40 Mio m³ of sand and mud per year. The dredging and disposal of
the material influences heavily the ecological conditions in the estuaries and tidal flats.

For the authorities which are responsible for the dredging activities, our Institute, the Federal Institute of
Hydrology, has developed in order of the Minister for Transport practical guidelines for coastal waters
(HABAK) and inland waters (HABAB).

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