Publications and reports of the project
"Ecological Rehabilitation of the river Rhine", 1989 - 10

Summary of results and conclusions from the first phase (1988-1989) of the Netherlands research programme "Ecological Rehabilitation Rhine"

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1. Introduction

In 1988 a research program for the ecological rehabilitation of the river Rhine was started. In this research program three Dutch governmental institutes are working together: the Institute for Inland Water Management and Waste Water Treatment (D.B.W./RIZA), the National Institute for Public Health and Environmental Protection (RIVM) and the Netherlands Institute for Fishery Investigations (RIVO).

The research program covers the period 1988-1991 and amounts to 20 manyears per year of research effort. Additionally 1,5 million guilders per year is available for projects.

The goals and planning phases of the "Rhine Action Program" offer the main guidelines for the research carried out. The monitoring of the ecological developments, consequently is harmonized on international level by the International Commission for protection of the Rhine against pollution (IRC).

In this report the results of the first 1,5 years of research are summarized. Although short, this initial phase of the project led to an identification of the ecological problems that should be taken in consideration in the further implementation of the Rhine Action Program.

2. First signs of ecological rehabilitation

In the course of this century the biological communities of the river Rhine were degraded by massive emissions of polluted water and other environmental changes. The long-term alterations of the communities have been documented by observations on the bottom fauna and the fish fauna. The most adverse conditions to these organisms were reached in the sixties and seventies. Since then programs of wastewater purification were implemented, resulting in improved oxygen conditions and in a reduced acute toxicity of the Rhine water.

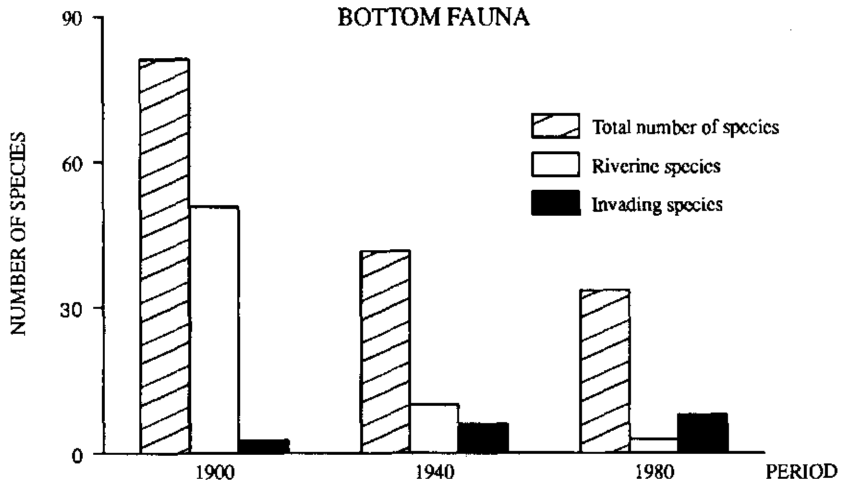

Fig. 1: Changes in species-richness of macrofauna in the branches of the river Rhine in the Netherlands.

The measures taken between 1970-1985 were clearly effective and led to a partial recovery of the ecosystem: species that had disappeared returned and in some cases even animal species, new for the Rhine, inhabited the river. The observations show that remedial actions were effective over periods of 5-10 years.

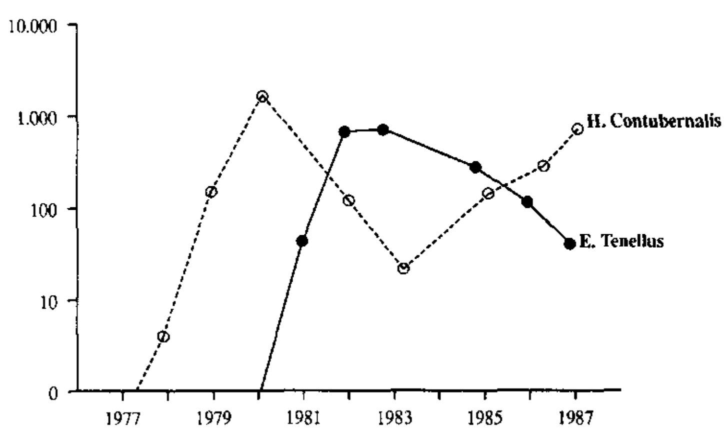

Fig. 2: Numbers of two Caddis fly species in the river IJssel increased due to improvement of water quality.

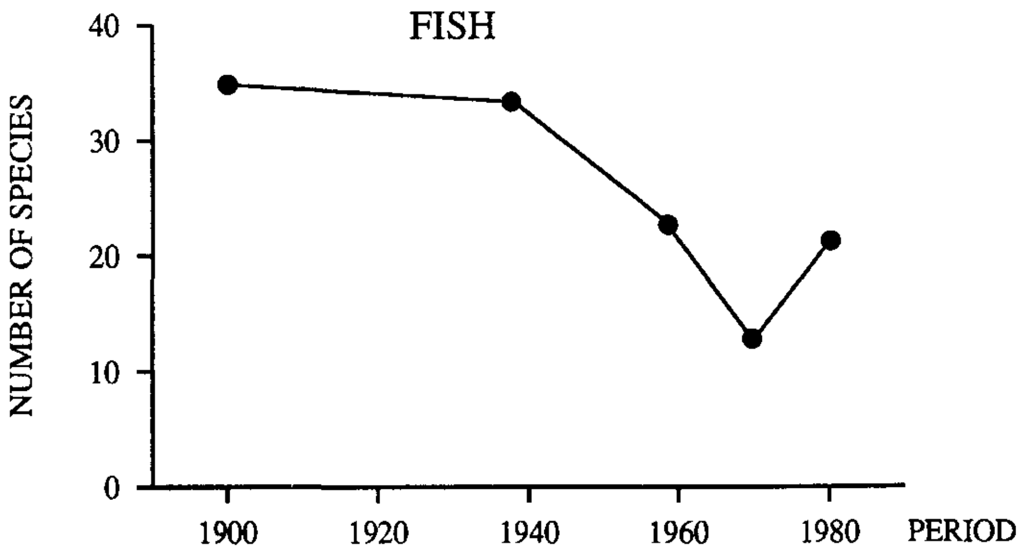

Fig. 3: Change in species richness for anadromous fish groups of the river Rhine in the Netherlands.

Even within a shorter period of time the river communities recovered from temporarily degradation. After the Sandoz accident severely affected reaches of the river were recolonized within one year by bottom fauna and fish species. The observations on river communities indicate that these are very responsive. Therefore it seems that new measures, such as those agreed upon in the Rhine Action Program, will lead to a further ecological recovery of the river communities. However, the character of the necessary measures is more complicated now than in earlier stages of the sanitation.

3. Elaboration of ecological objectives for the Dutch part of the river

In the "Rhine Action Program" a long term ecological objective is formulated. This objective is in general terms and needs further specification.

An attempt is made to give concrete form to this ecological objective by means of a set of indicative organisms or otherwise characteristic features of the river system. A presentation model is developed to show and compare the different states of the river ecosystem depending on the measures taken. This is called the AMOEBE presentation.

To compare the ecological status of the river system a reference situation was chosen: the period 1850-1930. We have quantitative information about the river ecosystem in this period, while the influence of man, at least pollution, was limited.
The selection of the organisms or features to be used was carried out by the following criteria:
- they are characteristic for parts of the river system or certain types of ecosystems;
- they belong to different trophic levels;
- there is quantitative information about past en present situations.

The ecological status of the river is presented as the difference with the reference situation.

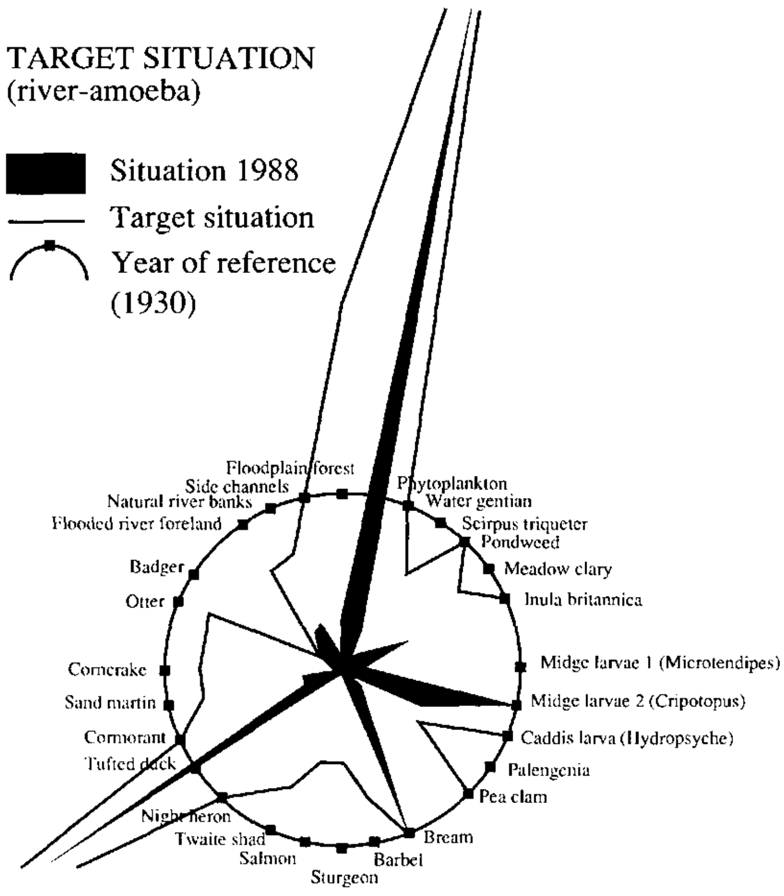

Fig. 4: The ecological target situation and the present situation compared to a chosen reference: a long way to go.

For different sets of measures in the field of water quality or hydrology/morphology, quantitative estimates were made of the expected changes for the indicative organisms or features chosen. One provisional conclusion is that in addition to a 50% reduction in pollution, morfological measures are vital for a rehabilitation of the river ecosystem.

Important for a rehabilitation of the macrofauna species composition of the Rhine are a further improvement of waterquality, the restoration of the interaction between river and floodplain and the rehabilitation of aquatic and shoreline vegetation. For a sustainble rehabilitation it is necessary to create refugia along the river.

For the spatial distribution of the -biologically important- vegetations of submersed water plants and the number of plant species, both the flood regime and the shape of the river banks is unfavourable now. The high nutrient input and chloride concentrations impose further restrictions. For the rehabilitation of water plant vegetations it seems essential that physical improvements of the river banks are combined with a reduced input of nitrogen compounds, phosphate, and chloride.

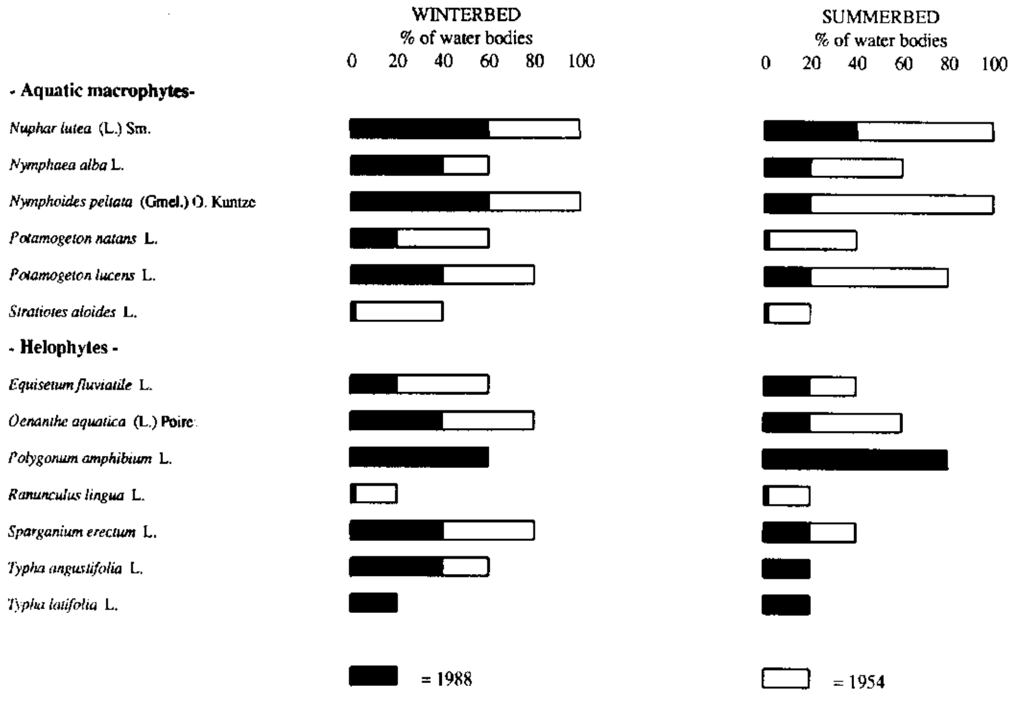

Fig. 5: Changes in the presence of macrophytes in oxbow lakes along the rivers Rhine and Meuse.

Restoration and accessibility of spawning and nursery grounds are of vital importance for the return of anadromous and riverbound migratory fish.

Important measures in the Netherlands are the improvement of the water quality in the downstream region, the improvement of fishpass opportunities at spill sluices in the river mouth, the creation of shallow places for fish to rest, a restoration of the tidal movement at the Haringvliet (necessary for the reproduction of twaite shad) and a limitation on fish catches during the restoration.

4. Return of salmon and other migratory fish species

A literature survey into the possibility of restocking the Rhine tributaries with the atlantic salmon has been carried out. The salmon catches in Germany and the Netherlands have steadily decreased since the turn of this century, despite large restocking measures with several millions of juvenile salmon every year.

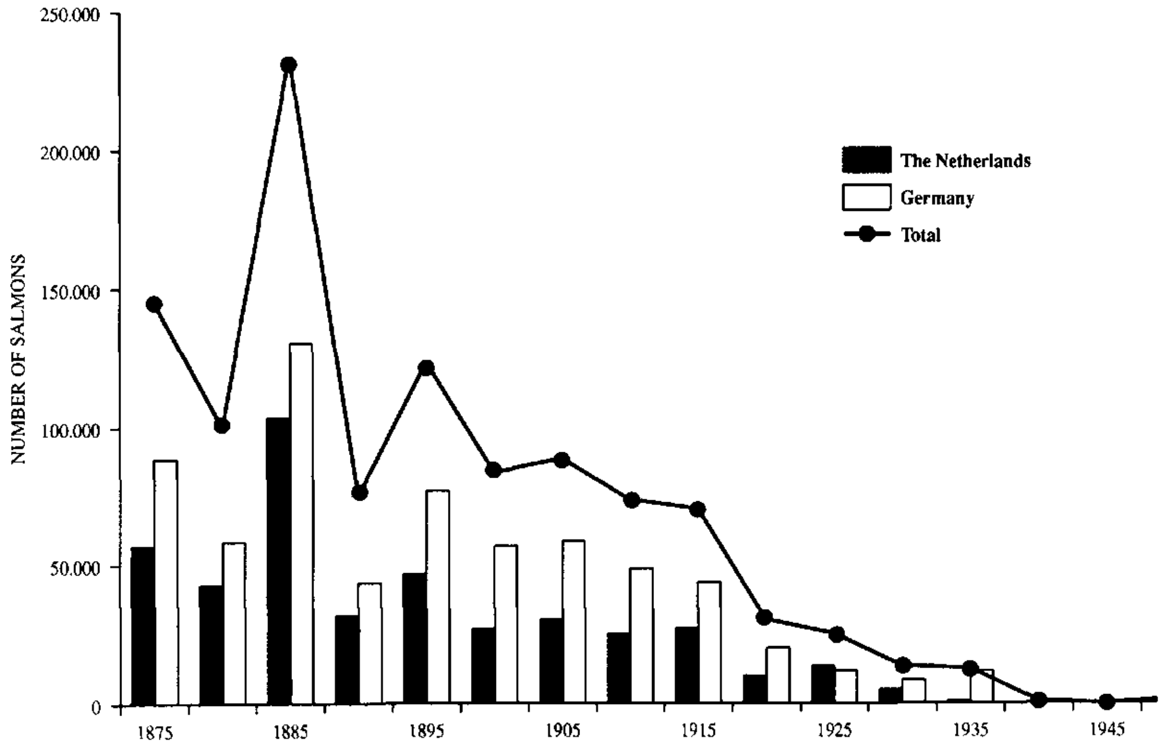

Fig. 6: Dutch and German salmon catches steadily decreased in the period 1875-1950.

An estimation was made concerning the survival rate of salmon. Although the degree of scatter in the data and uncertainties in the assumptions preclude the possibility of drawing firm conclusions, it seems difficult to maintain a stable salmon population in the Rhine, at least for a long time. Provided minimal conditions for the return of the salmon are fullfilled, it will be necessary to restock with large numbers of salmon during 10 years or more.

At present the following anadromous fish species are regularly caught in the Dutch coastal zone: sea lamprey, river lamprey, sea trout, smelt and twaite shad.Riverine fish species present in limited numbers are sea lamprey, river lamprey, sea trout, dace, ide, chub, sneep (Dutch name), barbel and gudgeon.

As appears from catches a certain part of the adult sea trout and the lamprey's as well as elvers and juvenile flounder succeed in entering the rivers from the sea and reaching higher stretches. The number of fish passing through the discharge sluices to the sea (Haringvliet) is not yet known. These sluices seem a serious bottleneck for fish migration. A study on the actual status of the seatrout population will be essential to gather more information about its life cycle in the Rhine and Meuse, and is necessary to appraise the possibilities for the return of salmon in particular.

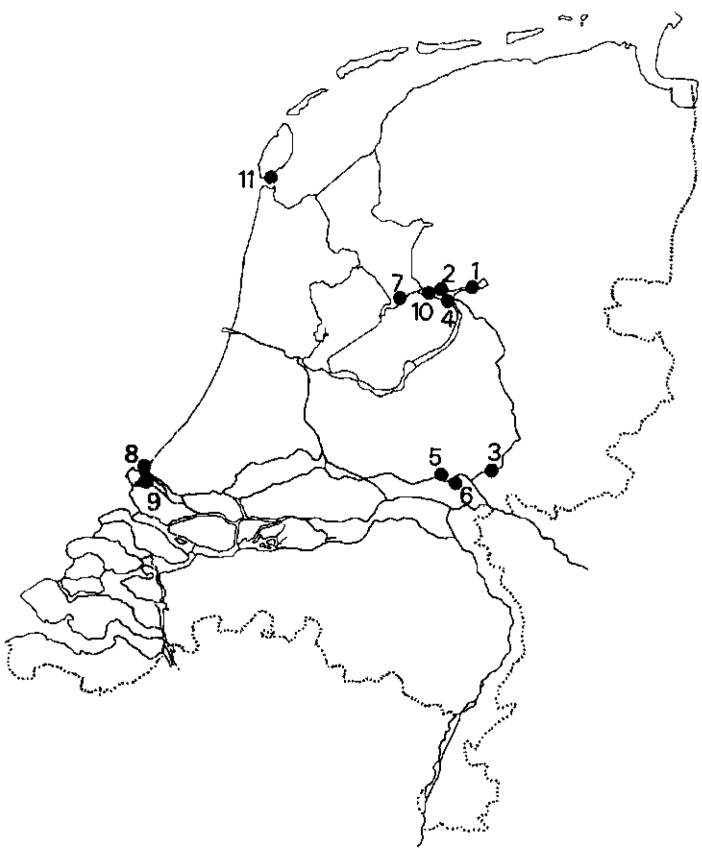

Fig. 7: Recaptures of marked sea trout and salmon smolts in the Netherlands, which were released in the lower regions of the river Sieg in Germany.

From about 1975 onwards a descending migration of seatrout smolts has been detected in every spring along the rivers Rhine and Meuse towards the North Sea. Eight marked sea trout smolts and three marked salmon smolts from recent stockings into the river Sieg in Germany (tributary of the Rhine) have been recorded at places in the Dutch parts of the Rhine. These smolt migrations of more than 300 km can be understood as an important sign of the improvement of water quality in the last decade.

5. High nutrient levels affect the river ecosystem

The concentrations of phosphate and nitrogen compounds in the Rhine are excessively high. The phosphate level seems to decrease in recent years. The total concentration of nitrogen compounds remained at very high levels, but since ca. 1975 ammonium is oxidized in purification plants and in the river to such an extent that nitrate is now the prominent compound. However, the concentrations of ammonium still exceed 1 mg of nitrogen per liter, a value which is extremely high for surface waters and is likely to prevent the settling of sensitive life-forms.

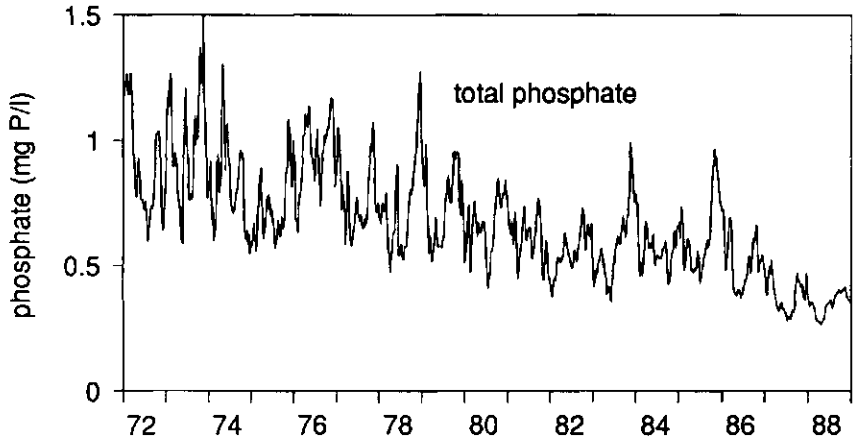

Fig. 8: The phosphate concentration at Lobith steadily decreases.

The (microbial) oxidation of ammonium to nitrate in the river requires substantial amounts of oxygen. This oxidation, which should in fact be completed in wastewater treatment plants, is nowadays the main oxygenconsuming process in the river, most likely responsible for the ca. 20% undersaturation of oxygen in Rhine water at Lobith. This undersaturation is assumed to be inhibitory for sensitive life-forms, e.g. insect larvae.

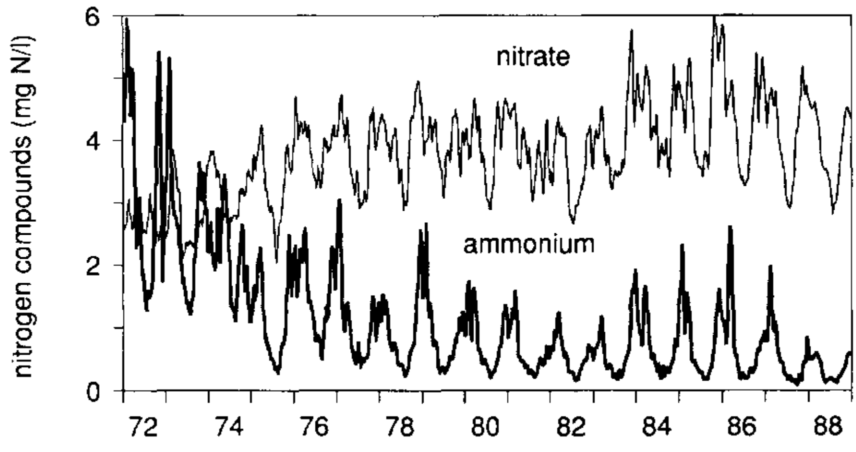

Fig. 9: Nitrogenen levels at Lobith are high. The ammonium concentration decreased but is still responsible for a large part of the oxygen consumption.

Eutrophication not only has consequences for stagnant waters but also for rivers. In the Rhine a dense plankton develops nowadays. In the beginning of this century micro algae occurred in low concentrations. The construction of weirs in the Rhine tributaries, together with eutrophication is most likely responsible for the incidence of dense algal blooms in the lower Rhine.

Sofar algal blooms did not have catastrophic consequences, but the ample supply of edible material probably stimulates the abundance of opportunistic herbivores, such as the zebra-mussel, that now occurs massively in the Rhine. These opportunistic species are typical for disturbed water systems.

Reduction of the algal blooms in the Rhine may therefore be a prerequisite for establishing more natural river communities.

6. Toxicological parameters indicate positive trends in water quality

In former years the water of the river Rhine was contaminated to such an extent that sensitive organisms like daphnids could not survive.Also salmonid fish showed, in the mid seventies, retardations in their larval development when experimentally exposed to the raw river water.

Tumors found in liver and thyroid of bream and roach respectively were considered to be caused by the high amounts of chemicals present in the Rhine.

Over the last ten years the acute toxic properties of Rhine water steadily decreased. Nowadays even daphnids can be used in biological early-warning systems which monitor continuously the actual surface-water quality.

Probably this improvement in water quality in terms of acute toxicity is mainly attributable to the reduction in heavy-metal pollution load. Organic toxicants present in Rhine water have to be concentrated (55-330 times) before they elicit short-term in toxication effects in the Microtox bioassay. This concentration factor remained at the same level over the last ten years, when tests with guppies and het microtox are compared.

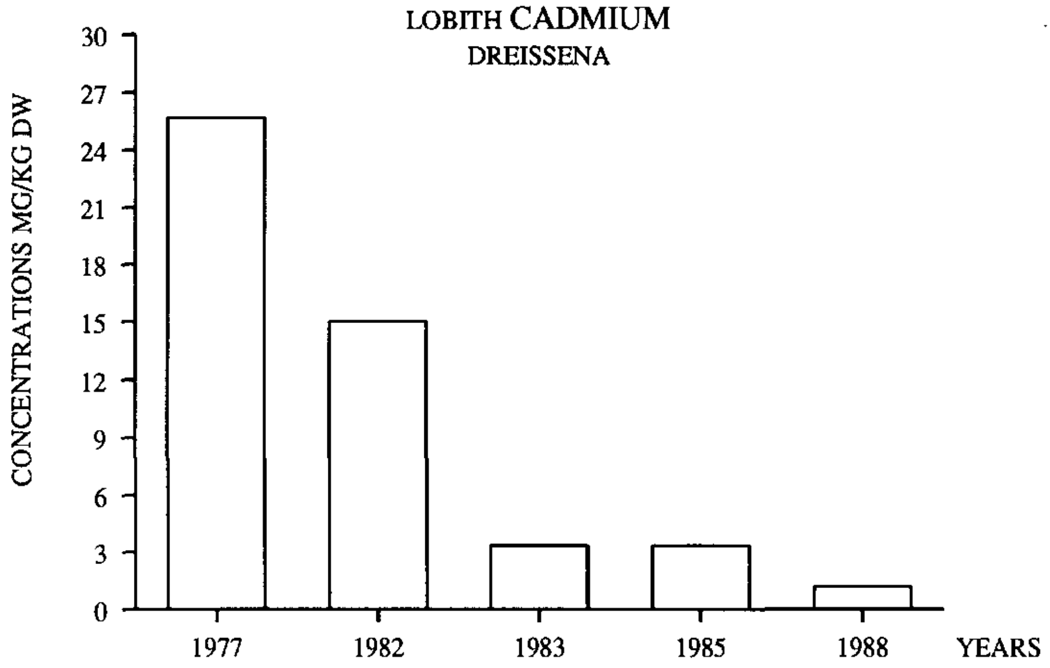

Fig. 10: Decreasing trend of Cadmium in zebra-mussels from the Rhine at Lobith.

Declining trends in the bioaccumulation of heavy metals and persistent chlorinated hydrocarbons in mussels and fish are evident. However, this development apparently is only of limited importance with regard to the reductions in acute toxicity of the river water.

Accidental spills of toxic chemicals, still occur quite frequently -in 1989 over 50 times- and are a constant threat to developing aquatic communities. Locally acutely toxic conditions are not imaginary. This needs more systematic analysis.

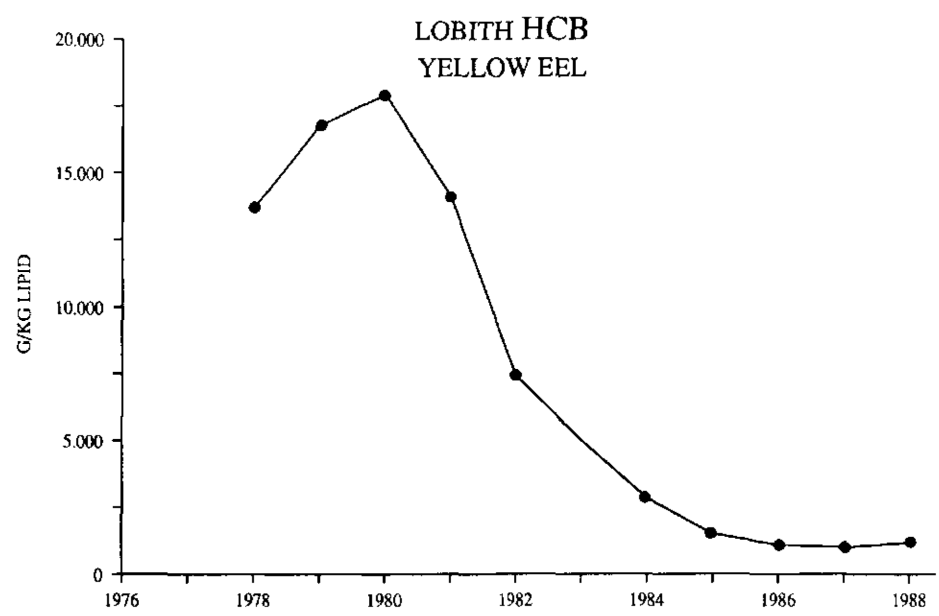

Fig. 11: Over the last decade the bioaccumulation of Hexachlorobenzene in yellow eel from the Rhine at Lobith diminished substantially.

In addition to routine chemical monitoring biological early-warning systems, using organisms like fish and daphnids, are useful instruments to point out sudden changes in the surface-water quality. Because of the large amount of different chemicals present, these changes cannot always be detected by routine chemical analyses.

A more promising approach is the implementation of these continuously operating bioalarm systems in controlling the quality of complex industrial effluents. Adequate operation of such systems can prevent unintended emissions of toxic compounds immediately at source.

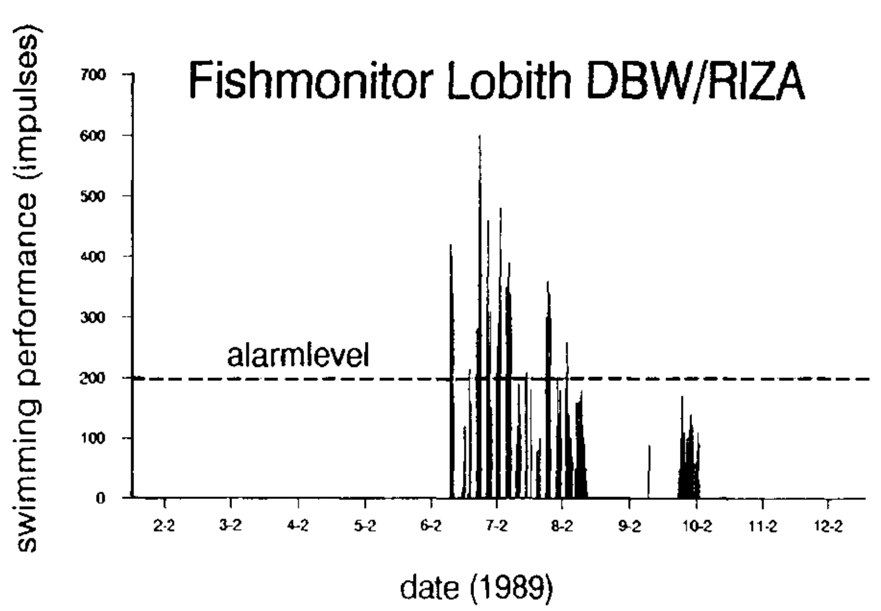

Fig. 12: Although the overall waterquality of the Rhine has improved, toxic conditions frequently develop due to accidental spills of industrial wastewater. These are registered by biological early-warning systems.

7. Available waterquality objectives based on exotoxicology

A compound specific approach to deriving quality objectives for receiving waters is a powerful tool in the abatement of water pollution. For about 300 chemicals, ecotoxicological data have recently been evaluated in order to derive these quality criteria. The additive toxicity of heavy metals and structurally related chemicals is now taken into account, and, for bioaccumulating compounds, data on predatory species like the otter formed the basis for the derivation of consumption standards.

For some chemicals of the IRC-priority pollutants, however, it can be foreseen that, using these quality criteria, the objectives of the Rhine Action Program based on ecotoxicology cannot be realized by a 50% reduced emission. Apart from that, one should bear in mind that ecotoxicological phenomena are not related only to the yearly averages of concentrations at one station (e.g. Lobith). Maximum concentrations of contaminants along the whole river are of interest.

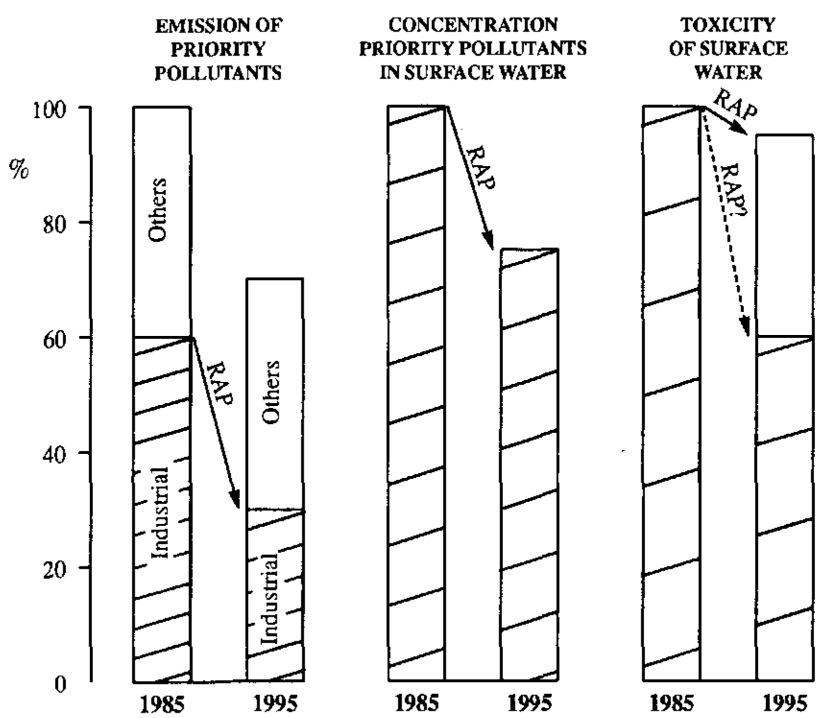

Fig. 13: 50% reduction of emmissions of priority pollutants does not necessarily lead to 50% reduction in toxicity. It is likely to be less.

Furthermore, the 27 toxic chemicals of the first IRC-priority list represent at the most only 20% of the total toxic potency of the river water.

Therefore a 50% reduction of emissions will not necessarily result in a 50% reduction in toxicity. Other contaminants should be taken into consideration as well, e.g. chlordanes, lower chlorinated PCB-congeners, pesticides, dioxins, polycyclic aromatic hydrocarbons.

Special attention should be given to compounds that elicit specific sublethal effects, such as copper, tetrachloroethylene and detergents (LAS). Even at very low concentrations some of these compounds can seriously hamper or even completely block the upstream migration of salmonid fish. The current identification of thus far unknown toxic fractions possibly also reveals other chemicals to focus on.

A recommendation to increase the number of IRC-priority pollutants is being prepared.

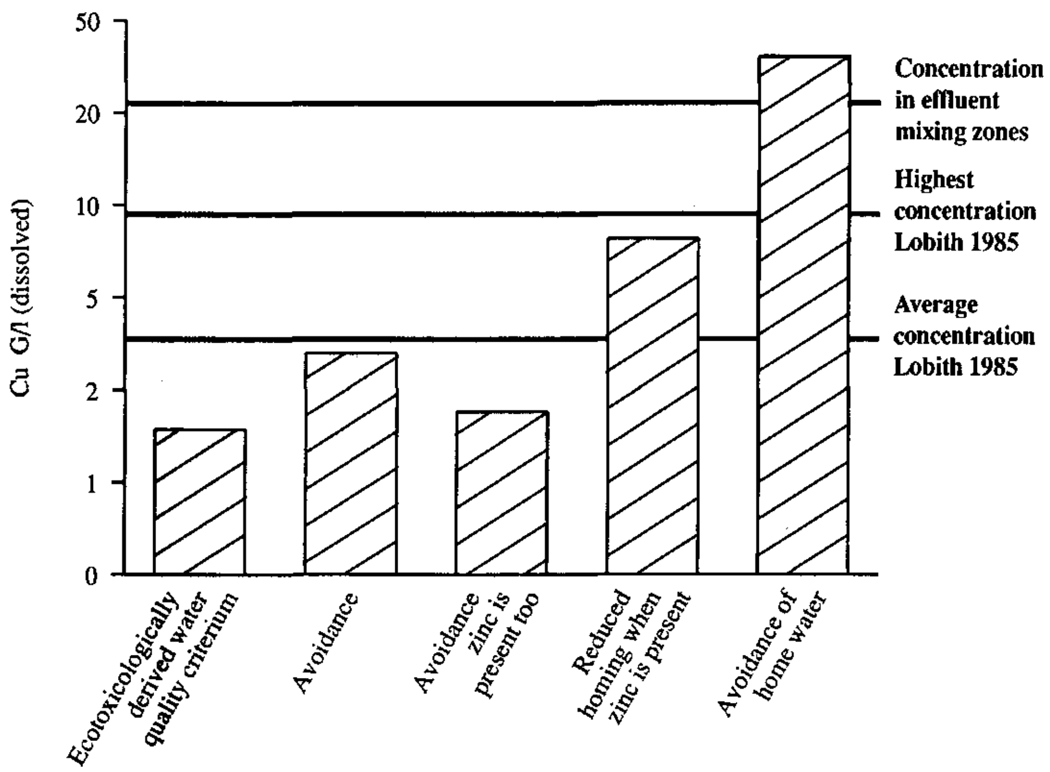

Fig. 14: Effect levels of dissolved Copper upon the homing ability of the salmon (Salmo salar) are well below actual surface-water concentrations.

8. Ecological effects in sedimentation areas caused by pollution

The sedimentation basins in the Rhine delta add to the problems of the rehabilitation of the Rhine. Contaminated silt from the Rhine has been deposited for decades. The estimated amounts of some of the contaminants thus accumulated are high. The freshwater basins that now replace the natural river mouths offer -in ecological terms- unattractive conditions. The IJsselmeer/Ketelmeer is subject to the consequences of excessive blue green algal blooms. The Hollandsch Diep/Haringvliet show a very high rate of sediment accretion. The instability of the bottoms together with the restricted oxygenation of sediments poses limitations on the fauna that exploits this habitat.

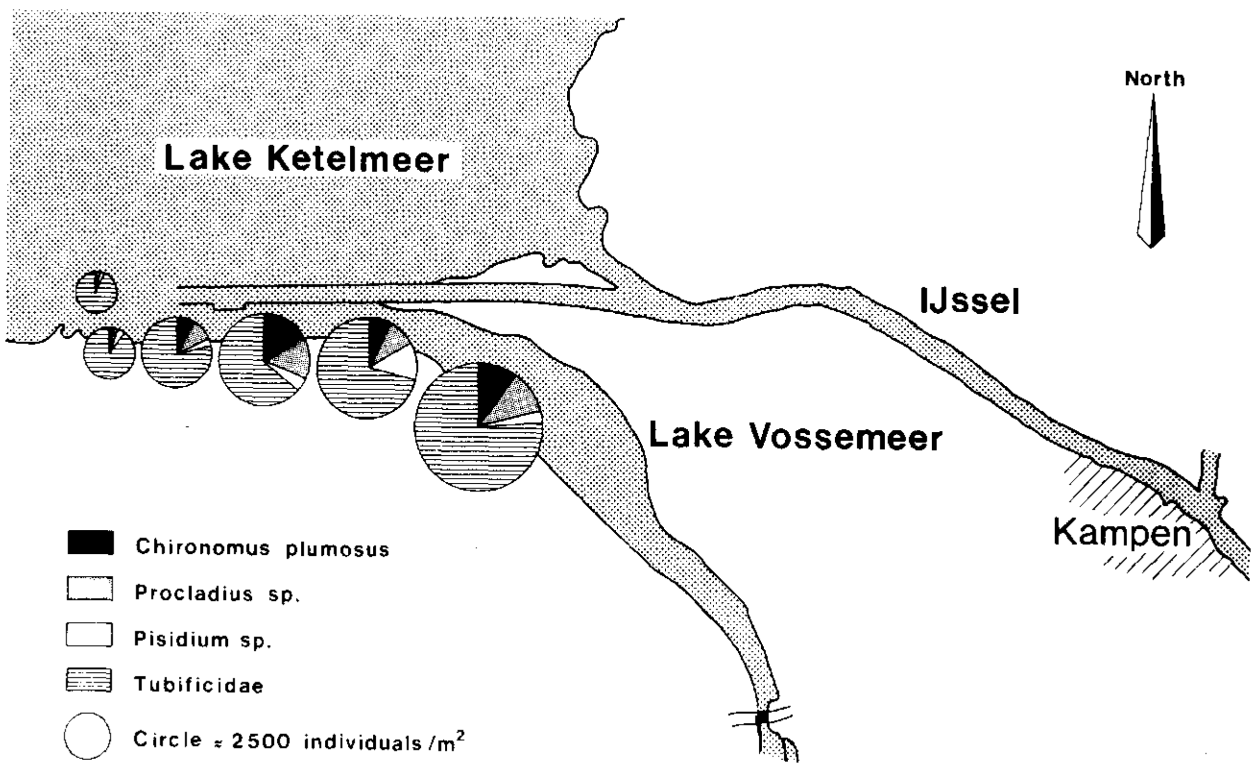

Fig. 15: Biomass and diversity of benthic macrofauna in the polluted Lake Ketelmeer compared to the less polluted Lake Vossemeer.

In the lake Ketelmeer e.g. suspended matter from the river Rhine, transported via the river IJssel, settles down. Here the quality of the sediment is considered to be responsible for reductions observed in total biomass and diversity of the benthic macrofauna, as compared to the less polluted lake Vossemeer.

Also the community structure of sediment-inhabiting nematodes is affected. Laboratory experiments confirm these indications of the suboptimal quality of the sediment of lake Ketelmeer. Exposure of crustaceans and midge larvae to sampled sediments and pore water resulted in reduced reproduction and survival, while the development of trout eggs into larvae was retarded as well.

Mercury	500
Cadnium	1.000
Copper	12.000
Lead	22.000
Chrome	16.000
Zinc	68.000
Chlorinated hydrocarbons	800
Polycyclic aromatic carbons	500
Mineral oil	150.000

Fig. 16: Accumulation of pollutants in sedimentation areas in the Netherlands (tons).

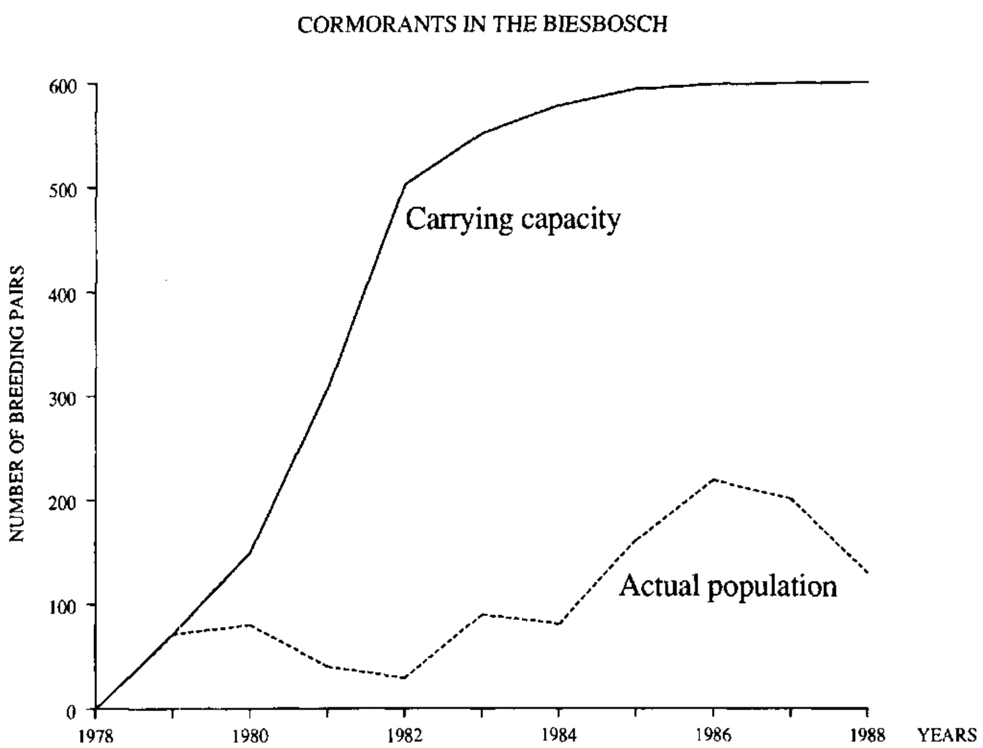

Fig. 17: Due to reduced breeding succes caused by polluted food the number of cormorants in the Biesbosch is much lower than the estimated carrying capacity of this area.

It is likely that populations of birds, fouraging in the sedimentation basins, are prone to intoxication via their food. Diving ducks fed with zebra mussels from the Haringvliet showed a reduced fecundity. Natural cormorant populations in the Hollandsch Diep/Biesbosch area also showed a reduced breeding success. Modelling the environmental fate of persistent chemicals, for example, demonstrates the importance of contaminated food in the bioaccumulation of several compounds (Hg, PCB) in predatory fish.

These observations on the sedimentation basins indicate how vitally important the execution of the Rhine Action Program is. On the other hand, a Netherlands policy for a redevelopment of the sedimentation basins seems to be required as a complement to the Rhine Action Program.

9. Necessary measures for ecological rehabilitation

Summing up the indications derived from the preliminary ecological study of the river Rhine a number of measures is recommended.

* **Restoration of the interaction between river and floodplain**

* **Improvements of riverbanks to create suitable habitats for vegetation**

* **Stimulation of the reconstruction of natural reserves to act as refugia and stepping stones of recovery**

* **Restoration of spawning and nursery grounds for fish and its assessibility in the lower and middle reaches as well as the tributeries**

* **Improvement of fish pass opportunities at spill sluices, and preferably also restoration of the tidal exchanges at the Haringvliet sluices**

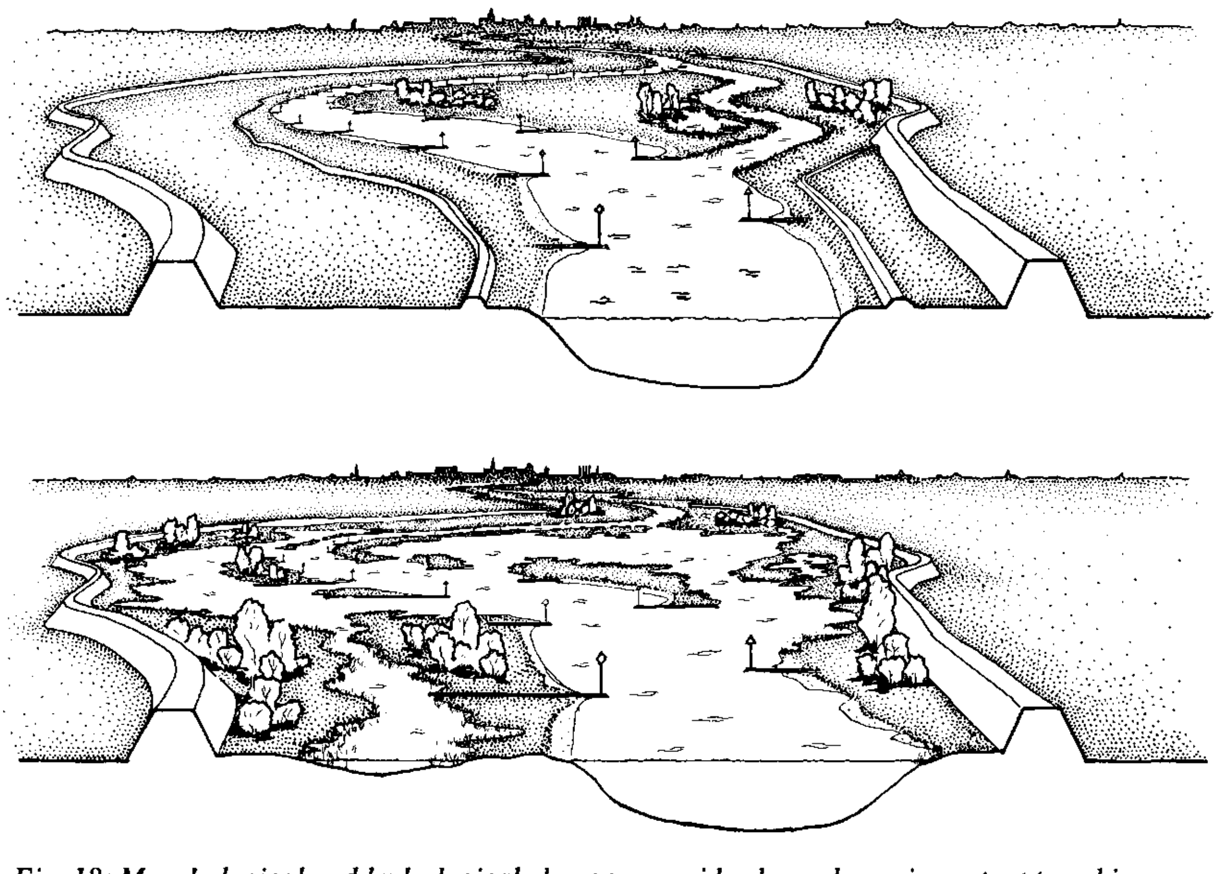

Fig. 18: Morphological and hydrological changes e.g. side channels are important to achieve ecological rehabilitation.

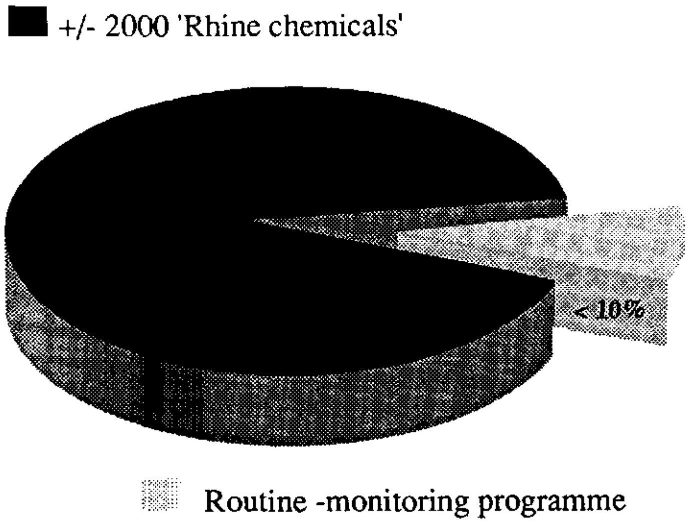

Fig. 19: Only a limited amount of the contaminants present in the river Rhine can be detected by routinely operated analytical procedures.

* **Restocking with large numbers of salmon during ten or more years, provided minimal conditions for the return of salmon are fullfilled**

* **Reduction of the total nitrogen input to the river by at least 50%**

* **Reduction of the chlorid load**

* **Implementation of continuously operating bioalarm systems, controlling the quality of complex industrial effluents**

* **Adaption of the emission reductions of micropollutants to the ecotoxicologically based waterquality objectives**

* **Extension of the IRC-priority list with other micropollutants of ecotoxicological interest**

* **Development of strategies to isolate or to sanitize old and contaminated deposits of river sediment**

Figures

fig. 1.	F.W.B. van den Brink, KU Nijmegen
fig. 2.	G. van Urk, D.B.W./RIZA
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fig. 4.	J. Vanhemelrijk, D.B.W./RIZA
fig. 5.	after F.W.B. van den Brink, KU Nijmegen
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