Ecological rehabilitation of the river Rhine: a proposal for a Netherlands research programme

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1. INTRODUCTION

The 7th Ministerial Conference on the Pollution of the river Rhine, held in Rotterdam in December 1986, agreed upon a programme for the ecological rehabilitation of the river. For the first time, biological objectives were explicitly formulated: by the year 2000 the Rhine aquatic ecosystem should have recovered from man-made perturbations so that populations of higher species, such as that of the salmon, might develop. The rationale for an integrated ecological rehabilitation of the river Rhine is that a sound, well-functioning river ecosystem is probably the best safeguard for the many functions that the river has or should have.

The Rotterdam conference also asked for research to be done on the short-term and long-term impact of the Sandoz accident. Furthermore, the conference recommended that studies be done on the development of biological methods to characterize the pollution and to record ecological improvement of water and sediments of the river Rhine.

The latest (8th) Ministerial Conference, held in Strasbourg in October 1987, agreed on a "Rhine Action Plan" (IKSR, Strasbourg, Sept. 1987) with the following objectives:

1. to create the conditions for the return of higher species (e.g. the salmon);
2. to safeguard the use of Rhine water for the supply of drinking water;
3. to eliminate the pollution of sediment with hazardous compounds.

It was decided that the policy aiming to reduce the discharge of toxic compounds should be continued. Furthermore, it was recognized that other ecologically important factors deserve action. The increasing discharge of nutrients (phosphate and nitrogen) in the river has led to a significant and potentially hazardous eutrophication of the North Sea and is still an important nutrient source for the eutrophied inland waters in The Netherlands. Furthermore, the hydrological and morphological constraints imposed on the river Rhine are so intense that a "normal" ecological functioning of the river cannot be restored solely by reducing the discharge of waste waters.

Clearly, the actions mentioned above, especially the implementation of the "Rhine Action Plan", should be supported by biological information, and progress should be monitored using biological techniques. Proposals for future measures and evaluations of measures that are already being implemented must be based on a thorough knowledge of the river Rhine.

This knowledge is still far from complete and rather diffuse. The necessary information on the structure and function of the ecosystem must be obtained in a consistent long-term programme. The best way to go about establishing a biological basis for the ecological rehabilitation of the river is for the research institutes of the Rhine states to collaborate. As a first step towards an integrated programme, the three Dutch institutes involved in biological research on the river Rhine have formulated the research programme presented here. The programme is also intended to stimulate international discussions within the framework of IKSR, leading to official research collaboration between the states bordering the river Rhine.

The research programme presented here has short-term as well as long-term objectives, emerging from the decisions taken by the 7th and 8th Ministerial Conferences. It is important to develop and to install bio-alarm systems within a reasonable time-span, to control the river water. Ecological information on the effects of toxic substances and on hydrographical conditions is already needed for the first phase of the "Rhine Action Plan" (1989) and should become available via preliminary studies. Furthermore, it is acknowledged that more definitive ecological studies on the ecological status of the river will be required for subsequent phases of this plan.

This research programme does not deal with all the research needed for the "Rhine Action Plan". The following related fields of research have been ignored: control of waste water discharges, chemical monitoring of river water and modelling the distribution of compounds in the river.

2. OBJECTIVES AND CONCEPTS OF THE NETHERLANDS ECOLOGICAL RESEARCH PROGRAMME

Sensitive parameters for the environmental quality of streams can be obtained from river communities and river organisms by biological methods. The response of biological systems to perturbations can be very rapid, within hours at the physiological level, or very slow e.g. at a time scale of decades when the succession of natural communities is involved. This research programme concentrates on actual problems that have a similar time scale. Short-term pollution control requires a rapid toxicity assessment within hours. However, it is envisaged that the rehabilitation of natural communities in the river Rhine will require at least a decade. The research programme has been subdivided to cope with the variety of these objectives. The short-term registration of

toxic substances (see I) is treated separately from the long-term study of the river ecology. Some of the ecological studies are orientated on systems analysis (see II), others are oriented on impact assessment (see III).

I Bio-alarm systems are designed to immediately registrate toxic materials in river water. Here the objective is mainly technical: to give a rapid and reliable signal when a given level of toxicity in the river is exceeded. Organisms of different taxonomic groups are used in the tests: e.g. bacteria, algae, crustaceans, mussels, and fish, in order to allow comparisons to be made with river communities.

II Basic exploration documents the composition of river communities and gives information on the foodchain and on the interactions between organisms and their environment. Cause and effect relations in biological systems tend to be complicated, because of the web-like interactions. Therefore, this part of the programme is dedicated to a basic ecological description of the communities of bacteria, algae, macrophytes, invertebrates, and fishes that inhabit the river in its present state (i.e. under conditions of water pollution, obstructed migration routes, etc.).
Studies of biomass and species composition of organism groups will be combined with process studies to achieve a more complete ecosystem analysis, supported by mathematical modelling.

III Impact assessment is specifically dedicated to the analysis of perturbations of the river system and to the evaluation of restoration measures. Often, perturbations (such as input of toxic substances, eutrophication, and morphological changes) exert their influence on the biota simultaneously, so that it is difficult to disentangle the effects of measures. Therefore, impact assessment has diverse research needs. Parts of the investigations are directed to experimental studies, e.g. on the toxicity of compounds present in sediments, on the toxic substances accumulating in fish, or on the effects of morphological changes in the river banks. On the other hand, the results of the sections I (Bio-alarm) and II (Basic exploration) of the programme are needed to describe the present-day impact and to develop scenarios for reduced impact. Some of these scenarios will be designed as mathematical models. Finally, the long-term effects of the "Rhine Action Plan" on the ecosystem of the river Rhine will be recorded in a monitoring

programme, covering the essential parameters selected from sections I, II and III of the programme.

Fig.1. Map of the Netherlands part of the river Rhine. Black: reaches of the river studied intensively. Some studies include also Lake IJssel and the river Meuse.

3. OUTLINE OF THE INVESTIGATIONS

The proposed research programme will focus on the ecosystem of the river Rhine, including the main sedimentation basins in the lower reaches of the river in The Netherlands (Fig. 1). For practical reasons the programme will concentrate on the river Rhine, although it is felt that these studies will also be applicable to (and needed for) the river Meuse. Furthermore, the chemistry of the river Rhine and of industrial effluents is being studied in related programmes of the institutes. The impact of polluted riverine sediment on marine organisms will be analysed in a separate programme.

Table I lists the projects currently being carried out by the three participating institutes. Full descriptions of these projects are available on request from the individual institutes. Below, these projects have been summarized under the main themes of the proposed collective programme on the river Rhine.

3.1 Bio-alarm

Bio-alarm systems aim to give an early warning when pollutants are present in the water at concentrations that cause acute toxic effects. The different communities in a river ecosystem all have their own levels of sensitivity for a given substance. In order to achieve a complete bio-alarm scheme, a range of systems will be involved, using species at several trophic levels. The selection of the bio-alarm systems is based on three criteria:

- the most sensitive response of a given species that can be measured within a short period of time;
- the reliability of the system (no false alarms);
- the practical and economic feasibility.

Bio-alarm systems are a supplement to classical chemical monitoring programmes. The bio-alarm systems now available commercially are less sensitive than chemical measurements, but react rapidly.

The initial phase of the bio-alarm project will involve the installation of standardized semi-continuous bio-assays at Lobith (at the German-Netherlands border), such as the Microtox^{R} test with luminescent bacteria and LC_{50} assays with Daphnia (water fleas); these methods will be especially useful in the event of calamities. Early warning systems based on the swimming performance of fish and on activity patterns of Daphnia are commercially available and will be installed at an early stage of the project.

In the second phase, the test systems that could be used to complete the range, will be investigated. Continuous flow systems will be developed into bio-alarm systems. Prototypes of monitors with mussels, algae and bacteria will be tested for their practical performance in surface waters. The sensitivity of a combination of bio-alarm monitors for various pollutants will be examined critically. When progress in enzyme technology offers sufficient perspectives, a new generation of bio-sensors could also be included in the programme. So, in the next few years, the project aims to select a suitable combination of bio-alarm systems that will cover a broad spectrum of toxicants in a sensitive and reliable way at reasonable costs.

Research on bio-alarm is internationally coordinated by a working group of the IKSR.

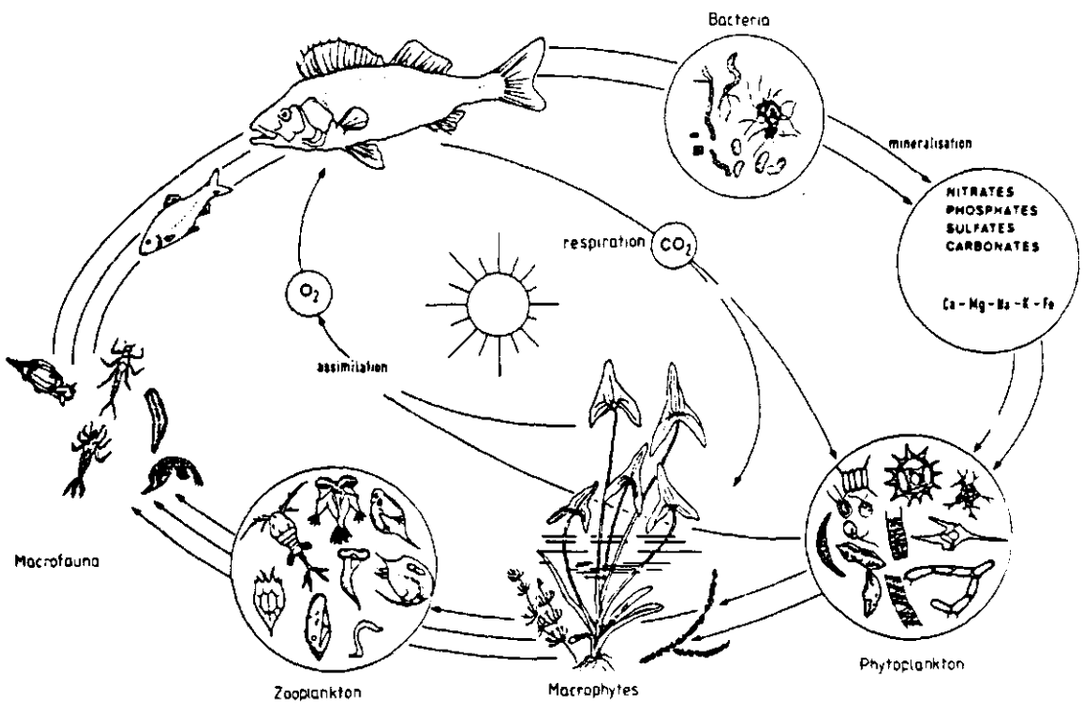

Fig.2 Diagram of an aquatic ecosystem (after Arrignon,J., Bordas, Paris, 1976)

3.2 Basic exploration

Aquatic communities are composed of numerous interacting elements. Fig. 2 depicts the cycling of materials in the foodchain of a water body. River communities are characterized by the steady down-stream transport of detritus and food, and by the migration of larger organisms such as fish. This transport and other differences in river characteristics along the river generally result in a gradient in the communities along the main axis of the river. Fig. 3 illustrates these gradients for an undisturbed river system.

In the programme a series of investigations on populations of riverine organisms are planned, but studies on the regulation of the communities and of the whole ecosystem are also scheduled.

The following projects cover the main biological elements of the river. Planktonic micro-algae, bacteria, rotifers and microcrustaceans are currently being studied (Table 1). Their seasonal densities and, as far as possible, their metabolic activities are measured.

The microbial activities in the river sediments produce vertical gradients in oxygen and in redox potential that are important for the

aquatic life in and the chemistry of deposits. These gradients are described in a pilot study. Bacterial activities e.g. denitrification and nitrification associated with the riverbed are being studied in a project concentrating on large-scale metabolic activities in the river (see Table 1).

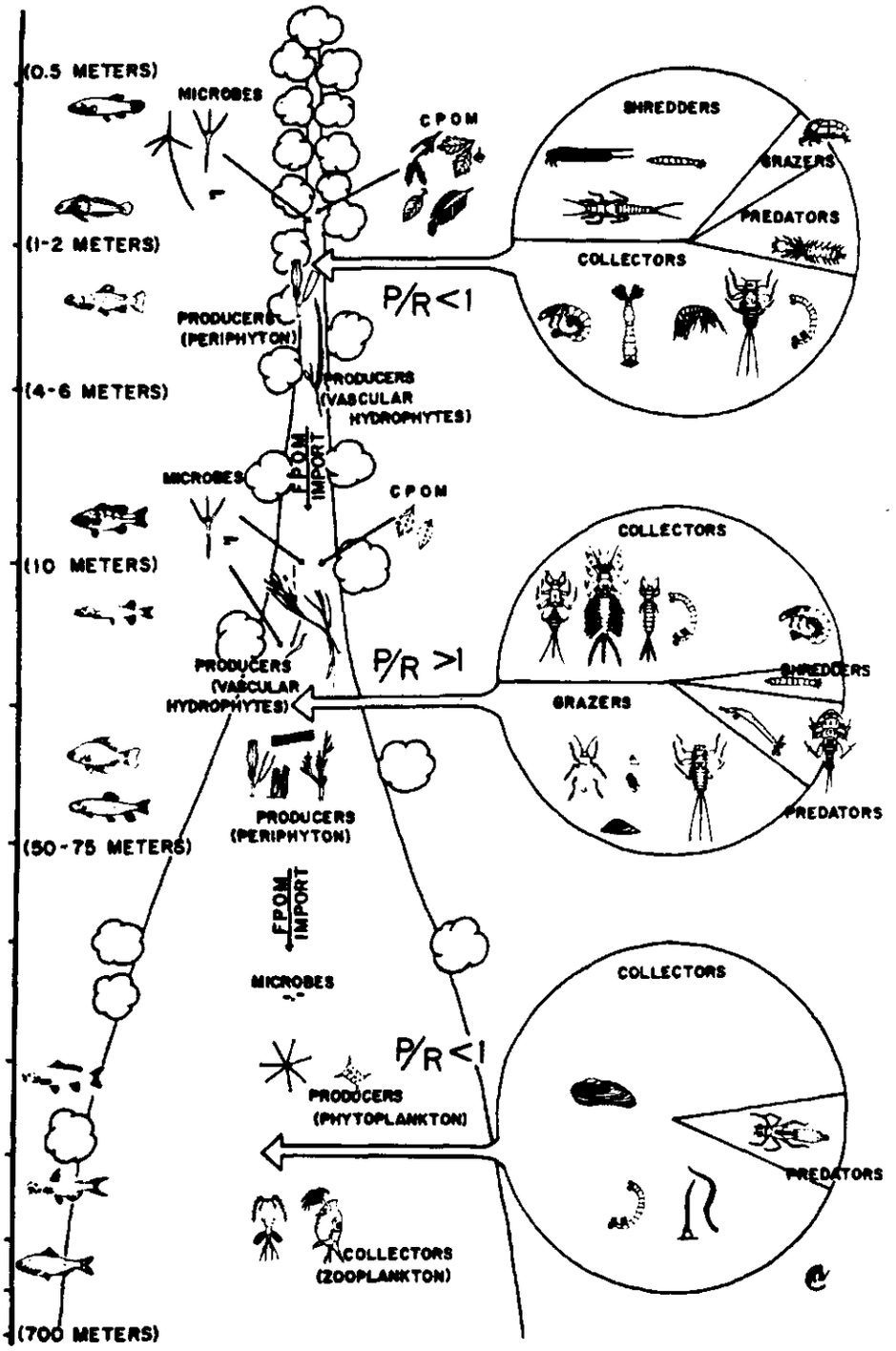

Fig.3 Diagram showing the changes in undisturbed biological communities over the main axis of a hypothetical river according to the river-continuum concept of Cummins (in: The ecology of regulated streams, ed. J.V. Ward and J.A. Stanford, Plenum Press, New York, 1979). P/R: ratio of production to consumption.

The development of the macrofauna of different river habitats has been described for several years and these studies will be continued, emphasizing the relations with sediment characteristics and sediment pollution. The monitoring will be extended to artificial substrates in the river at Lobith. The possibilities of the lower Rhine being recolonized by riverine macro-invertebrates will be investigated; research will be focused on the habitat requirements of selected species, their present distribution and dispersal. Historical trends are being reconstructed on the basis of palaeo-ecological data. The distribution and densities of nematodes in the river bottom are also being measured. The ubiquity of these animals can probably be exploited to make a biological classification or mapping of the river bottom.

The aquatic vegetation of the river banks and floodplain is thought to serve as a refuge for river organisms. The summer channel is now so carefully regulated that the water plants and marsh vegetation are often absent or are separated from the river itself. Different projects are currently describing these vegetation types, their role for the present communities, and the possibilities of restoring vegetation structures bordering the river.

A literature study will give a survey of the riverine fish species that have disappeared or have been reduced in number. This study will also indicate which fish species (other than the salmon) should be rehabilitated in the river. A project on salmonid fishes is being carried out in the German, Dutch and Belgian parts of the rivers Rhine and Meuse. The restrictions caused by hydraulic obstructions between the North Sea and the Dutch part of the river will be studied. The migration routes of juvenile and adult sea trout in the Dutch tributaries will be studied, as well as the effects of weirs and sluices on fish migration. The present status of spawning places and nursery areas for fish species that are now absent in the Rhine and the possibilities for their rehabilitation will be assessed. Also, the present-day food situation for certain fish species will be studied.

The species composition and abundance of riverine fish species will be monitored in the river and in the coastal zone.

The information from the studies on organism groups will be integrated so that it can be used in the case study of the river Rhine. Data and viewpoints on the ecosystem will be synthesized through the following activities.

Planktonic and benthic foodchains will be analysed as parts of the projects mentioned before. The information obtained will be linked and presented as a foodweb for the lower reaches of the river Rhine. A

first step in this direction has already been taken, by constructing a simplified carbon budget of the system. In the project on mathematical modelling it is planned to analyse the system dynamics in terms of carbon transfer in the foodweb.

Finally, changes in functional or structural aspects of the ecosystem over periods of many years are being recorded in several projects. These data collectively document the progress towards the ecological objective chosen for the river Rhine.

3.3 Impact assessment

a. Impact of toxic substances

The continuous loading of the Rhine with toxic substances has resulted in the presence of numerous compounds in relatively low levels of concentration. The toxicological impact of the multitude of compounds on natural communities must be assessed so that priorities for the reduction of effluents in the river can be set, with the final goal being the restoration of a structurally and functionally sound ecosystem.

Attention will be focused on generating additional experimental data on the individual and combined toxicity of specific chemicals to sensitive life stages of various aquatic organisms.

Incorporation of these data in environmental risk assessment studies should give a firm basis for regulatory agencies to set ecotoxicologically relevant discharge limits, thus reducing the emission of the most toxic and persistent chemicals now found in effluents.

From the projects listed in Table 1 three research thrusts can be discerned. First, current knowledge about the ecotoxicological effects of the priority pollutants listed by the IRC will be reviewed. This list, however, only includes a few of the compounds identified in Rhine water; the number of substances still to be identified is probably much larger. The identification of toxicants by means of physico-chemical techniques coupled to toxicological bio-assays will therefore be a continuous research activity. This will enable us to focus on potential, hitherto unknown, toxicants.

Secondly, experimental studies are directed on the effects of priority pollutants on species that are important in river ecosystems. In several projects the susceptibility of populations of bacteria, algae, macrofauna and fish to chemical pollution will be assessed. Special attention will be given to organisms that were once abundant in the Rhine. Toxicity tests with organisms from different trophic

levels will also be carried out to assess the quality of sediments in the Rhine delta.

A monitoring programme will measure the concentrations of priority pollutants that accumulate in fish, both in the field and under more standardized conditions in flow-through systems with river water. Finally, attention will be given to the combined toxic action of chemicals, in studies with heavy metals and/or organic micropollutants. These studies will include research on the effects of mixtures on the dynamics of populations in field enclosures. Later, *in situ* studies will be carried out to validate proposed environmental quality criteria.

In the third line of research, results of these experimental studies will be used for risk-assessment in different developmental scenarios for the Rhine. Models have been developed for the distribution of toxic compounds in the Rhine. In the next few years models that incorporate biological components of the river and their interaction with the toxic compounds will be constructed. This essentially new generation of ecotoxicological models cannot be created unless effective ecological models are developed for all or parts of the riverine ecosystem (see II).

A research programme on effluent characteristics is worked out in detail elsewhere. The combined programmes should lead to guidelines for the regulation of toxic effluents.

b. Morphology and hydrology

The Rhine and its tributaries are subject to intense regulation by weirs, dikes, and sluices, and parts of the river bed have been modified for shipping. Regulated streams with a straight stony embankment impose other, more restricted, habitats for aquatic communities. The research programme will study the role played by stagnant, old branches of the river or marsh zones. New ideas for at least a partial rehabilitation of the hydrological or morphological diversity in the river system will be tested, and pilot studies will be done at suitable locations. Furthermore, the management of sluices (including sea sluices) with regard to fish migration will be analysed.

4. PLANNING

The resources of manpower and finances needed to carry out this ecological research programme are given in Table 2. Collectively, the three ministries will support an amount of ca 20 manyears per year of research activities at the three institutes. In addition, 1.4 to 2.1 million guilders per year are being used to support Rhine-related research at other institutes. Some of these "external" projects have been provisionally included in the programme.

This research programme is intended to support the implementation of the "Rhine Action Plan" in all its stages, including the monitoring of the envisaged ecological rehabilitation. The "Rhine Action Plan" is planned for a period up to the year 2000. Yet the research programme presented here has been designed for the period 1988-1991, in view of the need to readjust the research activities after that period of time. Obviously, parts of the programme will be continued after 1991.

The results of the research programme will be presented in a special series of publications and reports of the project "Ecological Rehabilitation of the River Rhine".

The programme will be carried out under the joint responsibility of the three ministries involved. Therefore, a steering committee of representatives of the ministries and the institutes will be formed under the chairmanship of the ministry of Transport and Public Works. The research coordination is carried out by an inter-institute committee.

Table 1 - Survey of projects included in the research programme "Ecological Rehabilitation of the River Rhine"

	Programme section I: Bio-alarm	Project leader	Institute
1	Operationalization of standardized bioassays and existing early warning systems at Lobith	Van de Guchte	DBW/RIZA
2	Development of alternative early warning systems	Van de Guchte	DBW/RIZA
	Programme section II: Basic exploration		
	Plankton		
1	Composition and seasonal development of plankton and food web analysis under various conditions of the river	De Ruyter/ Admiraal	RIVM
	Benthos		
2	Conditions for the development of waterplant communities and riverbank vegetation in the main channel and directly related standing waters	Smit	DBW/RIZA
3	Hydrobiological characterization of different types of water in the winter channel	By de Vaate	DBW/RIZA
4	Measurements of metabolic activities in the river bottom and analysis of the carbon fluxes in the river ecosystem	Admiraal/ De Ruyter	RIVM
5	Survey of microgradients of O_2, Eh, pH, HS^-, NO_3^- in sediments of the Rivers Waal-Meuse-Haringvliet	Admiraal	RIVM
6	Inventory and classification of nematode populations in soil and sediment of the River Rhine	De Kruijf	RIVM
7	Survey of the macro-invertebrate fauna in the sedimentation area of the lower Rhine	Smit	DBW/RIZA
8	Palaeo-ecology of the lower Rhine: Reconstructions of the former invertebrate fauna and their habitat characteristics	Van Urk	DBW/RIZA
9	Possibilities of the lower Rhine being recolonized by selected riverine macro-invertebrates	Van Urk	DBW/RIZA
10	Ecological monitoring of rivers, using macro-invertebrates	By de Vaate	DBW/RIZA
	Fish		
11	Monitoring of fish populations in the rivers Rhine and Meuse	Cazemier	RIVO
12	Abundance of anadromous fish species in the Dutch coastal zone	Cazemier	RIVO
13	Study of the migration routes of anadromous fish species and restrictions to their migration caused by sea sluices and weirs in the Dutch part of the Rhine and Meuse	Cazemier By de Vaate	RIVO DBW/RIZA

14	Assessment of the food conditions and spawning habitats of riverine fish species in the Dutch part of the Rhine and Meuse	By de Vaate Cazemier	DBW/RIZA RIVO
15	The importance of standing waters in the winterchannel of the river Rhine for riverine fish species	By de Vaate	DBW/RIZA
16	Desk study of the ecological feasibility of the recolonization of the Dutch part of the rivers Rhine and Meuse by rare or extinct fish species	By de Vaate	DBW/RIZA

See also III.3, III.15 and III.17

Programme section III: Impact assessment

General

1	Development of methods for formulating ecological objectives	De Kruijf	RIVM
2	Modelling of ecological, ecotoxicological and chemical processes in the river Rhine	Aldenberg	RIVM
3	Development and implementation of environmental models in risk assessment studies: a) fluxes and fate of waterborne and sediment-related chemicals b) bioaccumulation of selected chemicals in aquatic food chains c) quantitative description of dose-effect relationships	Van de Guchte/ Bruggeman	DBW/RIZA

Toxic substances

4	Toxicological approval of "IMP" quality in Rhine water	Canton Van de Gaag	RIVM DBW/RIZA
5	Identification of toxic fractions of Rhine water and industrial effluents	Van de Gaag	DBW/RIZA
6	Measurements of the toxicity of of Rhine water with Microtox after XAD concentration	De Zwart	RIVM
7	Collection of ecotoxicological effect data on IRC priority pollutants and sumparameters	Van de Gaag	DBW/RIZA
8	Combined effects of mixtures of heavy metals on plankton dynamics in field enclosures	Van de Gaag	DBW/RIZA
9	Effect studies on ecologically relevant species of aquatic organisms to assess the environmental impact of selected chemicals	Van de Guchte	DBW/RIZA
10	Toxicity of sediments from Rhine and Meuse to aquatic organisms from different trophic levels	Van de Guchte Canton	DBW/RIZA RIVM
11	Monitoring of the potential accumulation of IRC-priority pollutants in fish collected from the field and in fish held under standardized flow-through conditions at Lobith	Van de Guchte Van der Valk Wegman	DBW/RIZA RIVO RIVM

12	Biodegradation of organic pollutants in Rhine sediment under natural conditions	Beurskens	DBW/RIZA
13	The influence of toxic compounds on the biodegradation of chlorophenols in Rhine sediment	Van Beelen	RIVM

Morphological and hydrological measures

14	The design of hydrological and morphological changes in the river system to improve its ecological function	De Haas	DBW/RIZA
15	The effects of hydrological measures on the structure and functioning of waterplant communities and riverbank vegetation	Smit	DBW/RIZA
16	The feasibility of using willow roots for shore protection in large rivers	Smit	DBW/RIZA
17	Hydrological aspects of the improvement of fish migration along the Haringvliet sluices, the weirs in the Nederrijn/Lek and the Afsluitdijk	De Haas	DBW/RIZA

See also II.1, II.2, II.3, II.4, II.10, II.13, II.14, II.16

Table 2 - Personnel and financial input of the institutes involved in the research programme "Ecological Rehabilitation of the River Rhine"

Institute			1988	1989-1991
DBW/RIZA	institute personnel	my/y	9.5	9.5
	project personnel	my/y	-	-
	external projects	1000 NLG	1400	2000
RIVM	institute personnel	my/y	4	4
	project personnel	my/y	3.5	3.5
	external projects	1000 NLG	70	100
RIVO	institute personnel	my/y	2.5	2.5
	project personnel*	my/y	3.5	3.5
	external projects	1000 NLG	-	-

* granted by DBW/RIZA