Chapter 8

Transboundary Cooperation and Sustainable Development in the Rhine Basin

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Abstract

The Rhine connects millions of people from the Alps to the North Sea. With a length of 1233 km, its catchment includes nine states, an area of about 200,000 km^2, 60 million inhabitants as well as important cities and fascinating landscapes. Consequently, the Rhine is culturally, historically and economically one of the most important rivers in Europe. The International Commission for the Protection of the Rhine (ICPR) was founded in 1950 with the first common goal in history to reduce water pollution. The whole process got a new impetus with the chemical catastrophe at the Sandoz plant (near Basel) in 1986, which saw aquatic ecosystems being seriously damaged. This disaster led to a better integration of the issue of ecology into the tasks of the ICPR. Depollution and rehabilitation programmes with actions and measures were established. In the 1990s, severe flood events forced the ICPR to add flood prevention to its sustainability goals enabling a better protection of citizens. This chapter presents the common work of the countries aimed at protecting the Rhine basin and the most important environmental outcomes of this special and long-lasting partnership.

Keywords: Rhine, Rhine basin, integrated river basin management, transboundary cooperation, international water management, water quality, ecology, alluvial areas, biotope, ecological continuity, migratory fish, water quantity, flood risk management, low water, low flow, climate change

1. Introduction

The Rhine connects millions of people from the Alps to the North Sea. With a length of 1233 km, its catchment includes nine states, an area of about 200,000 km^2, 60 million inhabitants as well as important cities and fascinating landscapes (**Figure 1**). Consequently, the Rhine is culturally, historically and economically one of the most important rivers in Europe.

Figure 1. States in the Rhine catchment.

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The states and regions in the Rhine basin (Switzerland, France, Germany, Luxemburg, the Netherlands, Austria, Liechtenstein, Wallonia, Italy as well as the European Union) all join forces in the International Commission for the Protection of the Rhine (ICPR) founded in 1950 to improve the sustainable development of the river and its catchment [1]. The first historical common goal of the ICPR was to reduce water pollution. The whole process got a new impetus with the chemical catastrophe at the Sandoz plant (near Basel) in 1986, which saw aquatic ecosystems being seriously damaged. This disaster led to a better integration of the issue of ecology into the tasks of the ICPR. Depollution and rehabilitation programmes with actions and measures were established. In the 1990s severe flood events forced the ICPR to add flood prevention to its sustainability goals to enable a better protection of citizens.

This chapter presents the common work of the countries for the protection of the Rhine basin and the most important environmental outcomes of this special and long-lasting partnership.

2. Integrated Rhine river basin management: the ICPR

2.1. Historical background

For many centuries, the Rhine river has played an important role in the history and the social, political and economic development in Europe. Multiple uses, conflicting interests and particularly environmental and flood problems in and along the river have highlighted the importance of an integrated approach aimed at protecting the Rhine.

The foundation of the ICPR 5 years after the end of World War II was a first political success. On 11 July 1950, the ICPR began its discussions on issues of Rhine protection and monitoring with a view to finding joint solutions. Mutual confidence had to be carefully created in the international working groups of the ICPR. The high pollutant loads and the contamination of the Rhine with salt were of great concern for the downstream users.

Thirteen years after its foundation, the ICPR was given a status under international law. In 29 April 1963, the envoys of the German, French, Luxembourgian, Dutch and Swiss government signed the “Convention on the International Commission for the Protection of the Rhine against Pollution” in Berne [2]. One year later (1964), a permanent international secretariat was established in Koblenz, Germany, to coordinate the cooperation of the contracting parties in the working languages German and French, since 2003 also in Dutch.

2.2. A real step-by-step approach

At the beginning of the activities of the ICPR, between 1950 and 1970, the first challenge was to establish a common Rhine water quality monitoring from Switzerland down to the Netherlands. However, there was no improvement of water quality to measure. On the contrary, by the end of the 1960s, the Rhine water quality was worse than ever. In 1972, the ministers in charge of environmental protection in the Rhine catchment met for their First Conference of Rhine Ministers. In their next meeting in 1973 in Bonn, they charged the ICPR to draft a Chemical

Convention and a Chloride Convention [3]. Both Conventions were signed in 2 December 1976 in Bonn together with an additional protocol to the Berne Convention of 1963 which confirmed the European Economic Community becoming a contracting party to the ICPR.

In the 1970s and 1980s, successful programmes were developed to reduce inputs of polluted municipal and industrial wastewater, with the focus on “end-of-pipe” techniques, that is, wastewater treatment, rather than on preventive measures within the industrial enterprises. As a result of these measures, the concentrations of toxic substances also dropped.

The Sandoz accident in 1986 clearly illustrated the disastrous impact accidental pollution can have on the whole river. Due to a fire in a Swiss factory producing chemical and pharmaceutical products, between 10 and 30 tons of insecticides, fungicides and herbicides flushed into the river with the fire extinction water and killed almost all aquatic life between Basel and Koblenz (approx. 400 km downstream). Citizens from Switzerland downstream to the Netherlands demonstrated solidarity with the Rhine and its protection. The considerable public pressure exercised on the governments of the states in the Rhine catchment contributed to the increasing influence of the ICPR. The riparian states of the Rhine were forced to act. The governments—triggered by two Rhine ministerial meetings after the accident—charged the ICPR to draft a plan aimed at saving the river. One year later the Rhine Action Programme (RAP) was ready for approval [4]. It was designed to thoroughly rehabilitate the Rhine by the year 2000.

When adopting the RAP, the ministers agreed on very challenging and ambitious targets like the return of the salmon by the year 2000 and a 50–70% reduction of inputs of dangerous substances between 1985 and 1995. All along the river, measures were taken to prevent pollution (see Part 3). Since 1970, more than 80 billion Euros have been invested into constructing municipal and industrial wastewater treatment plants; today, about 96% of the population in the Rhine catchment are connected to municipal wastewater treatment plants.

Almost all reduction targets were achieved by 2000. Inputs of most priority substances were reduced by 70–100% or were no longer detectable. The success of the Salmon 2000 and Salmon 2020 programmes is evident [5]. Although completely extinct in the 1950s, by 2016, almost 8900 adult salmon returned to the Rhine basin for spawning (see Part 4.5). Further measures are required to achieve a self-sustaining salmon population in the Rhine catchment. The ongoing reactivation of parts of the former floodplain areas will lead to more room for the river, higher biodiversity and a more natural river system (see Parts 4 and 5).

The concept of further integration of policies received an extra impetus and stronger political commitment after the extreme floods in 1993 and 1995 (see Part 5). Two floods were needed to convince the Rhine states that flood prevention measures had to be taken. In 1998, the ICPR adopted an Action Plan on Floods [6]. By 2010, important action targets were achieved after implementing different measures entailing costs of 10.3 billion Euros [7]. With the aim of reducing extreme flood levels, retention areas for 229 million m^3 of flood water along the main stream have been created.

Since 1998 and in order to integrate the main uses and functions within the Rhine basin in the working process, the ICPR grants an observer status to non-governmental organisations (NGO) and stakeholders, thus giving them the possibility to participate in the plenary assemblies and in working expert groups [2]. The observer status offers public participation to a certain extent and enables information dissemination to a larger public. Further ways of informing the general and specialised public are the website of the ICPR (www.iksr.org), various brochures, reports and workshops.

In addition, the cultural importance of the Rhine river must be highlighted. Landscapes, many old Roman towns as well as preserved floodplains and lakes are attracting tourism and leisure activities. Many examples prove that sustainable recreational uses of the Rhine and its environment are possible. The Upper Middle Rhine Valley between Bingen and Koblenz is classified as UNESCO World Heritage Site, and therefore there is an obligation to find the right balance between landscape conservation and tourism development.

To sum up, integrated river basin management was developed within the ICPR step-by-step: the ICPR has been dealing with the reduction of water pollution since 1950, with ecosystem improvement since 1987, with water quantity issues since 1995 and with groundwater issues since 1999. Now, all topics are integrated into the two European Directives (Water Framework Directive (WFD) 2000, several daughter directives and the Floods Directive (FD) 2007), and the ICPR is coordinating the basin-wide implementation of both directives within the international river basin district Rhine (IRBD Rhine) [8, 9]. The special ICPR programme is called "Rhine 2020 – Programme on the sustainable development of the Rhine" [10].

3. Water quality improvement and challenges

As mentioned in Part 2, water quality improvement has been a main ICPR task since the Commission's establishment in 1950. The Rhine has had to face tremendous pollution. Flowing through densely populated and industrialised areas, it had to cope with huge loads of untreated wastewater in the past. Additionally, there was some accidental pollution as, for example, the severe Sandoz accident in 1986.

Between 1950 and 1970, the ICPR established a uniform monitoring programme from Switzerland down to the Netherlands (**Figure 2**). This required a comparison of the different national monitoring stations and an agreement on an international monitoring programme, the substances to monitor, monitoring frequency, sampling dates and analytic methods. Due to a joint approach of the authorities in charge, the Rhine water quality could and can still be assessed reliably and on a scientific basis.

During the last 40 years and following the many measures taken, the water quality of the Rhine and of many of its tributaries has considerably improved. At an early stage, in the beginning of the 1980s, the ICPR recommended its member states to include a third treatment stage (elimination of phosphates) when planning new wastewater treatment plants. One of the results of this recommendation is that the Rhine water quality steadily improved, in particular with respect to heavy metals, total phosphorus and ammonium nitrogen (**Figure 3**).

The improved water quality is also reflected by the development of oxygen concentrations at the monitoring stations Rekingen (High Rhine, Switzerland), Koblenz (Middle Rhine,

Figure 2. Monitoring stations of the Rhine monitoring programme (2015–2020) [11].

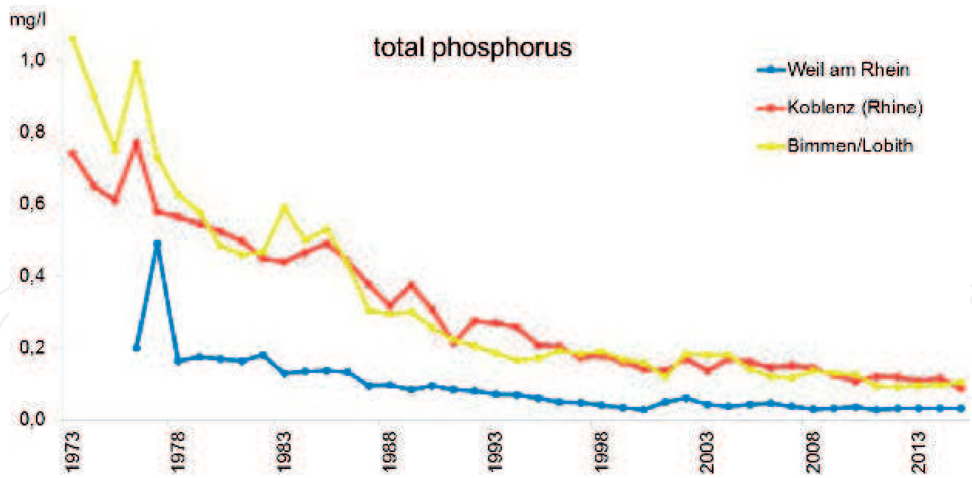

Figure 3. Annual average concentrations of total phosphorus from 1973 to 2015 in Weil am Rhein (near Basel), Koblenz (Middle Rhine) and Bimmen/Lobith (German-Dutch border).

Germany) and Bimmen/Lobith (Lower Rhine, German-Dutch border) between 1954 and 2015 (**Figure 4**).

The political approaches were changed to a long-term ambitious goal setting, and programmes combatting pollution and furthering river restoration were launched shortly after the Sandoz accident. Within short time, three conferences of ministers were staged [12], leading to the adoption of the RAP in 1987 (see Part 2).

After the accident at Sandoz in 1986, the ICPR also improved its international Warning and Alarm Plan (WAP) [13]. If, in spite of all preventive measures, an accident occurs or great amounts of hazardous substances flow into the Rhine, the WAP is activated, which above all

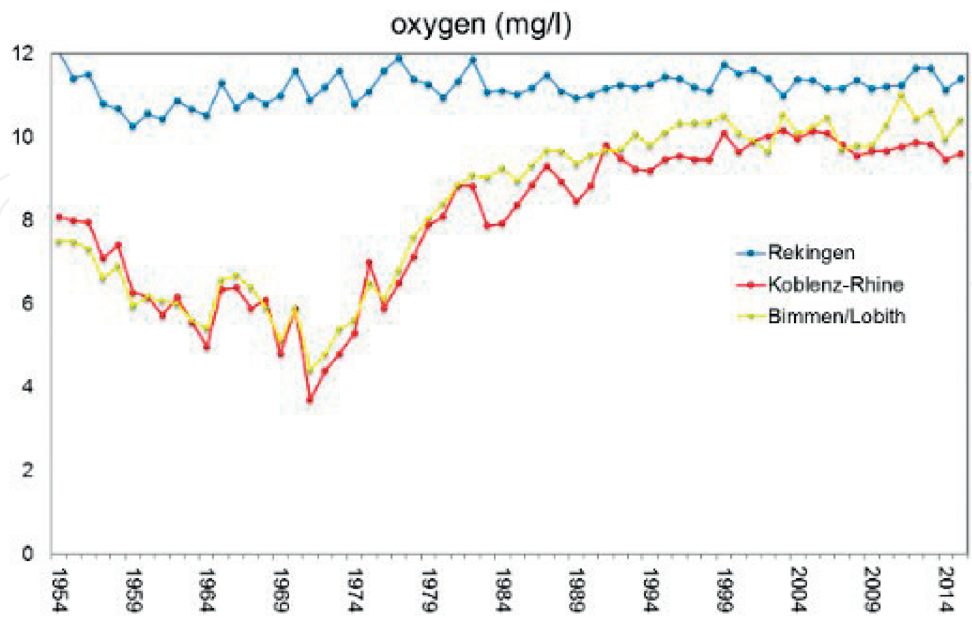

Figure 4. Annual average concentrations of oxygen from 1954 to 2015 in Rekingen, Koblenz and Bimmen/Lobith.

warns all users downstream (**Figure 5**). Apart from warnings, which are only issued during huge and serious water pollution events, the WAP is more and more also used as an instrument for exchanging reliable information on sudden water pollution measured by monitoring stations along the Rhine rivers, Neckar and Main and smaller tributaries.

Another consequence of the Rhine Action Programme was that requirements concerning municipal and industrial wastewater treatment plants became distinctly stricter.

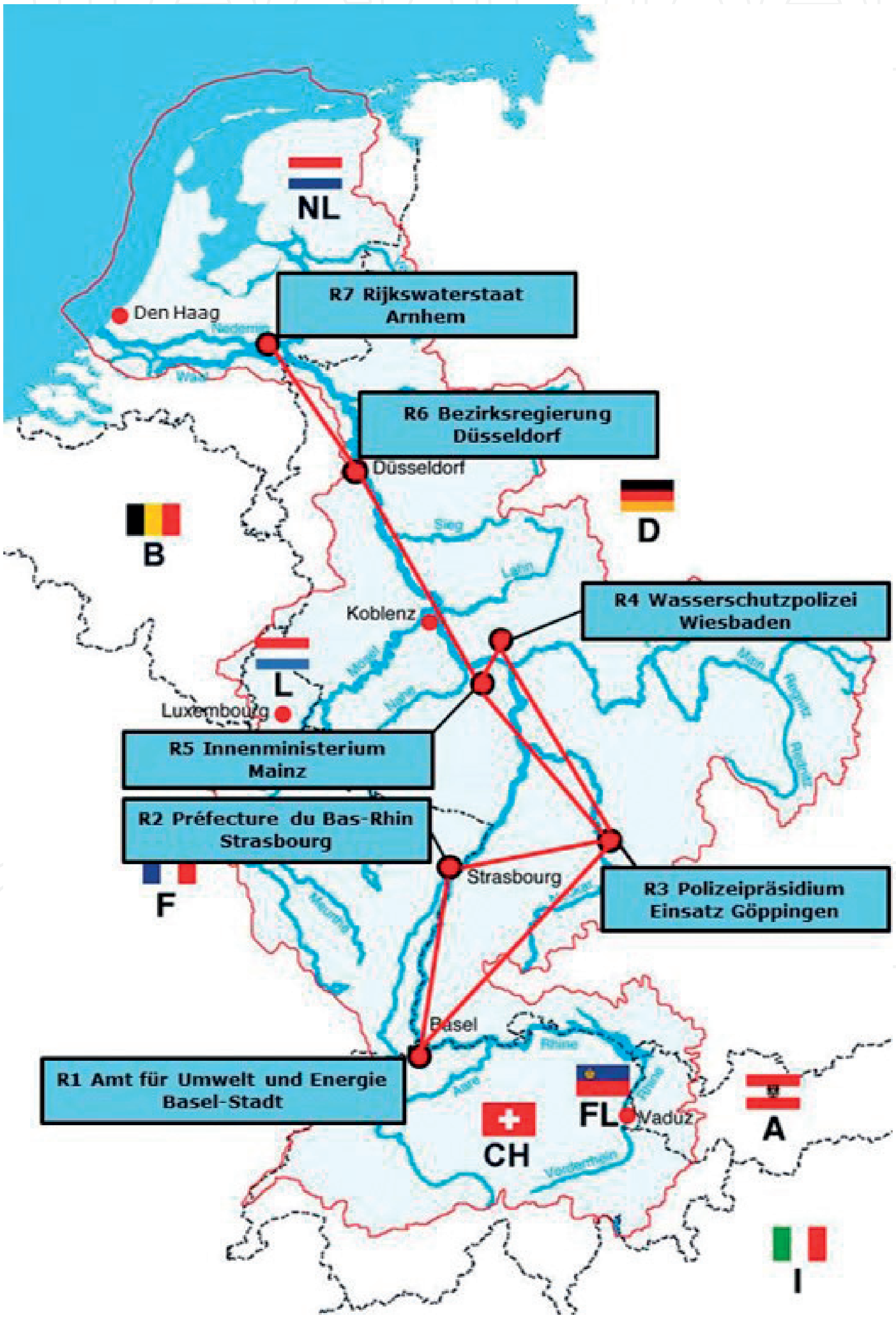

Figure 5. The international main alert centres and the exchange of information.

Following this most successful Rhine Action Programme, the ministers in charge of the Rhine adopted "Rhine 2020" [10]. In this new programme, the ICPR recommended goals regarding the water quality for environmental quality standards; the phased reduction of emissions; the guarantee to produce drinking water using simple and near to nature treatment procedures; the further reduction of the accumulation of hazardous substances in organisms; the uncritical consumption of fish, mussels and crustaceans; the disposal of dredged material, bathing and the depollution of the North Sea.

The pollution of the Rhine with heavy metals and other pollutants has been reduced (**Figure 6**). Additionally, the amount of polluted Rhine sludge has decreased. For instance, the quantity of polluted harbour sludge that the city of Rotterdam had to dispose sunk from 10 million cubic metres in 1987 to about 1 million cubic metres per year in 2016.

Today, water bodies in the Rhine watershed are used for many, partly concurrent purposes which almost always modify water bodies and impact on water quality. In order to reach a sustainable situation, uses and protection of the Rhine and its tributaries must be brought into an acceptable balance.

Worldwide, the Rhine figures among the most important shipping lanes and is the most important one in Europe. Compared to other means of transportation, inland navigation is rather environmentally friendly. Nevertheless, it still directly and indirectly contributes to deteriorating the ecological state and water quality of the Rhine. The ICPR and the Central Commission for the Navigation of the Rhine (CCNR) are closely cooperating on different environmental issues. Examples of actions helping to achieve environmental objectives are information and recording losses of pollutants from navigation and the "Convention on the collection, deposit and reception of waste produced during navigation on the Rhine and inland waterways" (CDNI).

The impact of the different uses is regularly monitored within international and national monitoring programmes, in order to be able to assess the impact of their stress. The results

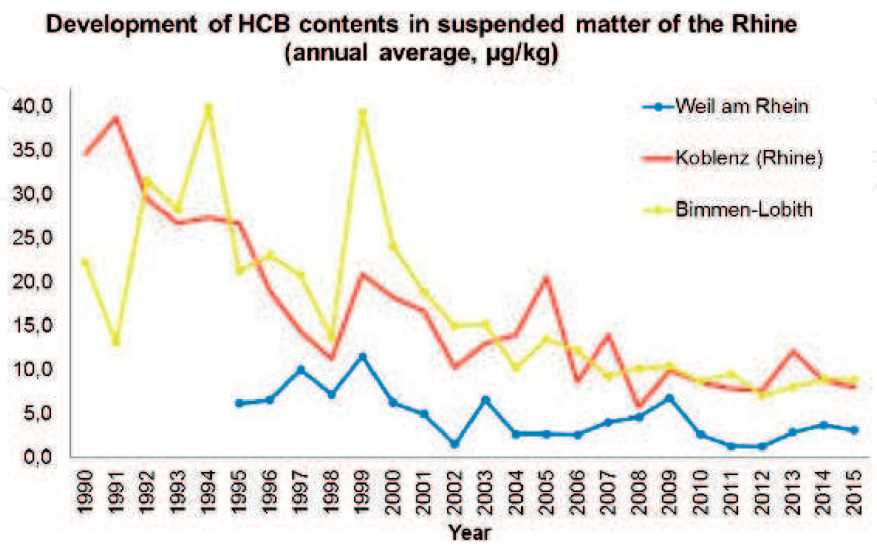

Figure 6. Annual average concentrations of HCB (hexachlorobenzene) in suspended matter from 1990 to 2015 in Weil am Rhein (yellow), Koblenz (red) and Bimmen/Lobith (purple).

and an assessment of the water quality are summarised and published by the ICPR, from 1956 to 1999 as books and since 2000 on the Internet [14]. In addition to the regular monitoring programmes, the ICPR established a platform for new and upcoming techniques. Since 2015, laboratories in the Rhine catchment using nontarget analysis meet on a regular basis in an expert group. In 2017, the ICPR organised a special monitoring programme including nontarget analysis. This will help to get a better overview over potential pollutants in the Rhine and its tributaries.

In spite of improvements in water quality, a few substances are still detected in too high concentrations. This particularly concerns ubiquitous substances (e.g. mercury), which are persistent and occur almost everywhere in the Rhine catchment [15]. Unfortunately, there are few measures capable of reducing the pollution with these substances on the short run.

Additionally, micro-pollutants are of concern for water quality. There is a diverse group of micro-pollutants, like medicinal products (e.g. carbamazepine) (**Figure 7**) or odoriferous substances, which are partly not eliminated in the wastewater treatment plants. Very low quantities of these pollutants are detectable in waters and may detrimentally affect life in the Rhine and drinking water production.

The active pharmaceutical agents of medicinal products are detected in the Rhine catchment area. The highest concentrations are measured in the Lower Rhine and in tributaries with a high share of municipal wastewater. Wastewater treatment plants have been identified to be a main pathway of input for all therapeutic products for human use and their transformation products. One example of an active pharmaceutical agent in the Rhine catchment area is carbamazepine which is used for the treatment of seizure disorders and neuropathic pain (**Figure 7**).

The Conference of Rhine Ministers (2007) [12] assigned the ICPR to develop a joint and comprehensive strategy for reducing and avoiding micro-pollutant inputs from urban wastewater and diffuse sources into the Rhine and its tributaries by improving knowledge on

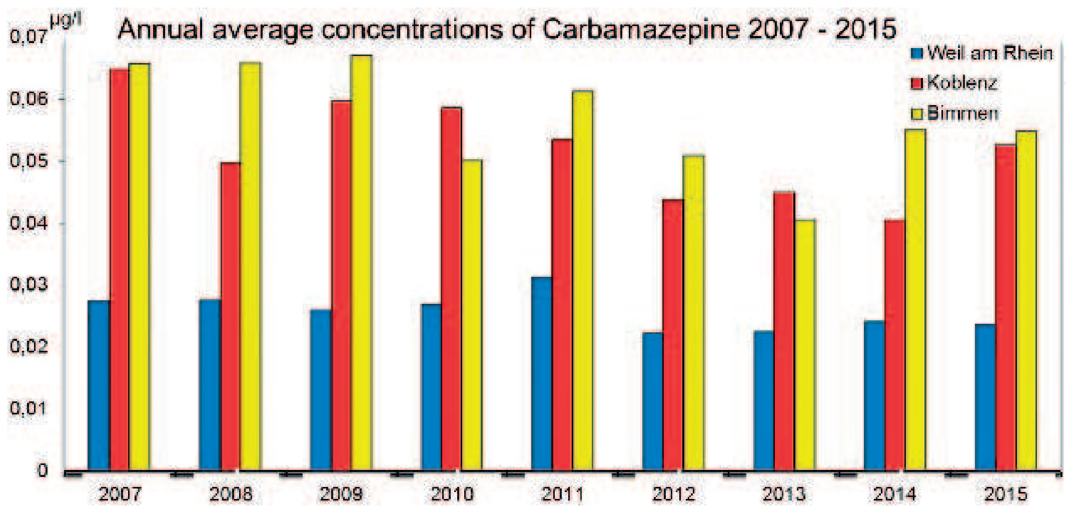

Figure 7. Annual average concentrations of carbamazepine from 2007 to 2015 in Weil am Rhein, Koblenz and Bimmen.

emissions and ecotoxicological reactions in nature and to draft suitable treatment methods. The knowledge collected since 2008 has been published in several ICPR reports [16, 17].

The ICPR will continue its efforts towards reducing point source inputs, inputs of diffuse origin (e.g. nutrients and plant protection agents) and the inputs of micro-pollutants.

Although we are still facing challenges to improve the water quality, the Rhine, one of the largest rivers in Europe, has undergone an impressive restoration. The ICPR programmes are a success story, as pollution could be reduced so that the salmon is coming back to the Rhine (see Part 4).

4. Conservation and rehabilitation of aquatic ecosystems

4.1. Ecological balance and ICPR programme "Rhine 2020"

Due to the cooperation of the Rhine-bordering countries within the ICPR, not only the water quality of the Rhine but also its ecological state has further improved. Many intermediate aims for the ecological revalorisation of the Rhine river stated in the "Programme for the Sustainable Development of the Rhine – Rhine 2020" have already been achieved [7, 10, 18]. Besides, the common implementation of the Internationally Coordinated Management Plan 2015 for the IRBD Rhine is currently going on [15].

Alluvial plains of the Rhine are again flooded, oxbow lakes are reconnected to the river and along short stretches the river structures have been ecologically improved. The number of animal and plant species has increased. Since 2006, salmon and other migratory fish may again reach Strasbourg on their way upstream from the North Sea (**Figure 8**).

The connection of the different habitats along the Rhine from Lake Constance to the sea in order to achieve habitat patch connectivity is successful. In this connection, the ICPR sets definite targets and spatial focal points aimed at linking water protection with nature and

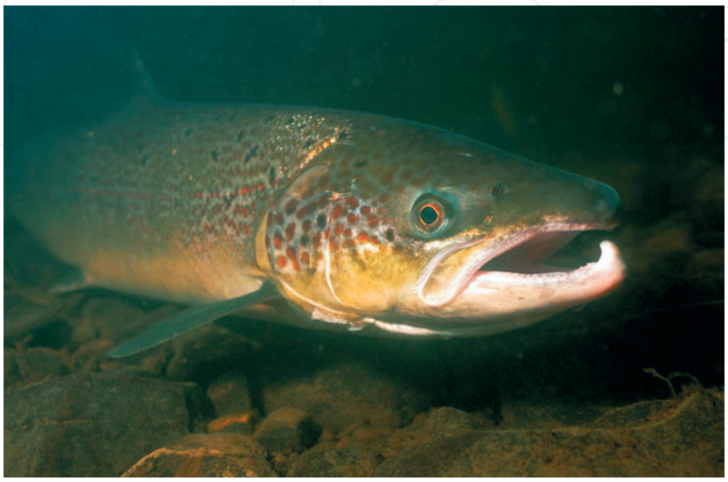

Figure 8. Atlantic salmon (source: Ulrich Haufe, AugenBlick Naturfilm).

flood protection. In spite of the success achieved, the ecological functionality of the comprehensive Rhine system is not yet satisfactory.

Above all, the ecological continuity of the Rhine from Lake Constance to the sea and of its tributaries must be further improved. Further targets are to increase the structural diversity of the banks of the Rhine and its arms and the extension of alluvial areas [7, 10]. With a view to restoring the ecological continuity of the Rhine and its tributaries, the ICPR has drafted a "Master Plan Migratory Fish Rhine" [19].

4.2. Fauna and flora

Many hundreds of animal and plant species live in the innumerable different habitats along the Rhine and its tributaries (**Figure 8**). The presence of a particular species permits conclusions regarding the ecological state of the habitat. Therefore, some fish typical of a specific habitat and other water organisms serve as indicators for the ecological state. Plankton and water fowl also play an important role.

The ICPR regularly publishes summary reports on all biological analysis results of the 6-year monitoring cycle [18]. The last biological inventories showed that with a number of 64 species in the Rhine, the range of fish species is almost complete again [18]. Apart from fish, the Rhine fauna consists of worms, mussels, snails, crustaceans, insects, birds and mammals. From the Alpine Rhine until the North Sea, more than 500 invertebrate species—called macrozoobenthos—were detected on the bed of the Rhine. Many water plant species have also returned to the Rhine. Thus, the ecological network is in a distinctly better state than in the 1980s.

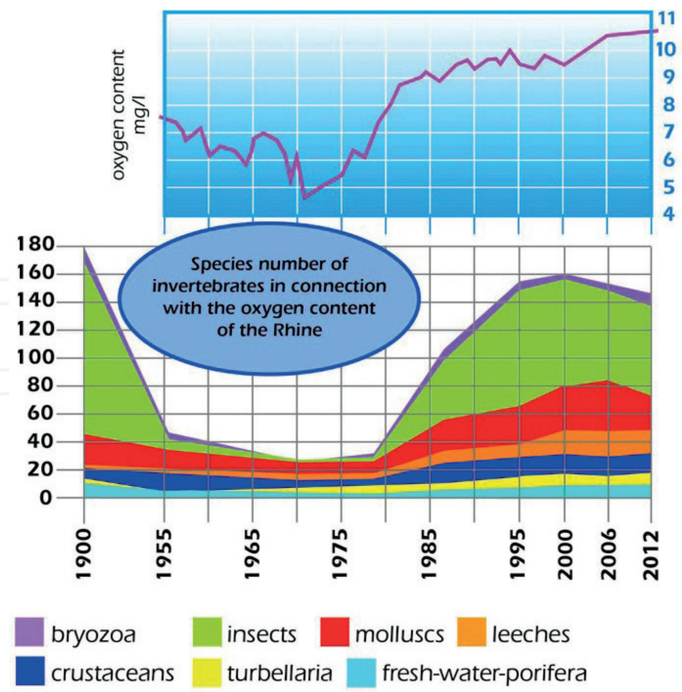

Figure 9. Development of the invertebrate communities of the Rhine and average oxygen content of the Rhine at Emmerich (Lower Rhine).

This result was achieved by improved wastewater treatment (as mentioned in Part 3) and more river continuity. **Figure 9** shows the development of the average oxygen content and of the invertebrate communities in the Rhine at the German-Dutch border.

However, today's biological diversity in the Rhine is different from that in former times, as many new species have settled, which will remain part of the future water system. Measures aimed at restoring waters and removing obstacles to migration will favour indigenous species and strengthen the ecosystem.

4.3. Alluvial areas

Alluvial areas are essential for the Rhine ecosystem as they represent valuable nature resources and act as natural flood buffers. They increase water retention and are thus important means of flood prevention (see also Part 5). Reactivating floodplains along the Rhine and reconnecting alluvial waters are two important measures aimed at ecologically upgrading the Rhine [18]. Such ecological support is required, as numerous river training measures along the Rhine and almost all tributaries have basically modified the hydrological and morphological conditions. For example, cutting off more than 85% of the alluvial areas along the Upper and Lower Rhine has led to great losses of habitats and of animal and plant species typical for the Rhine.

The ICPR programme "Rhine 2020" for a sustainable development of the Rhine includes targets to reactivate 160 km^2 of floodplain along the Rhine and in the lowlands of the Rhine

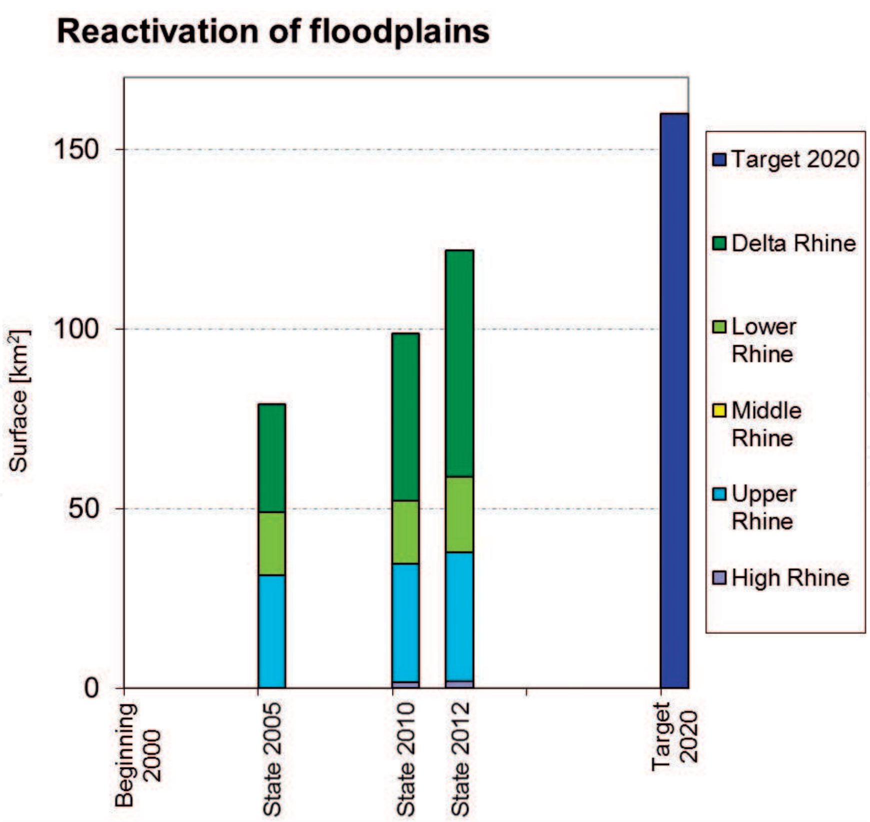

Figure 10. Reactivation of floodplains between 2000 and 2012.

and 1000 km^2 in the entire Rhine watershed as well as to renature 11,000 km of flowing waters by 2020. Furthermore, 100 old water courses of the Rhine and backwaters are to be reconnected by 2020. A first balance revealed that the intermediate targets set for 2005 had been achieved and that progress continues. By 2012, about 122 km^2 of alluvial areas along the Rhine had been reactivated and 80 old water courses of the Rhine and backwaters had been reconnected (**Figure 10**) [7, 10, 18].

4.4. Habitat patch connectivity

In order to maintain an ecological continuity, biotopes along the Rhine must again be interconnected. Once the connected habitats of the Rhine and its tributaries present an ecological continuity, animals may move up- and downstream (see also Section 4.5 on migratory fish), and plants may be carried away by the currents. After eventual extreme situations, such as floods and low water periods, they may recolonise up- or downstream sections from lateral waters. Therefore, habitat patch connectivity is a very important functional characteristic of the Rhine ecosystem which will serve water protection, nature protection as well as flood protection. The sum of all measures will also support the increase of biodiversity in the ecosystems of the Rhine. For these reasons the re-establishment of the habitat patch connectivity along the Rhine from Lake Constance to the North Sea is one of the targets set by "Rhine 2020" and is also part of the report and the atlas of the ICPR for achieving a habitat patch connectivity along the Rhine [20–22].

4.5. Importance of ecological continuity for migratory fish

Restoring the ecological continuity of the Rhine from Lake Constance to the North Sea and that of priority tributaries for recolonisation is also a distinct target of the ICPR "Master Plan Migratory Fish Rhine" [19]. The Master Plan is supposed to indicate how self-sustaining, stable migratory fish populations can again be settled in the Rhine watershed as far as the Basel area within both reasonable time and at reasonable costs.

During their life cycle, anadromous long-distance migratory fish like salmon (spawning in fresh water) and the catadromous eel (spawning in marine waters) migrate from the sea into fresh water or from fresh water into the sea for the purpose of reproduction (**Figure 11**).

Formerly, the Rhine catchment used to be an important habitat for migratory fish. However, since the nineteenth century, systematic river training, e.g. for navigation and hydropower uses, on the Upper and High Rhine and along many tributaries has heavily interfered with ecological continuity in the Rhine system (see Part 4.3). Transverse structures, such as weirs or barrages, may seriously interfere with or completely obstruct migration in a water body. Spawning grounds and juvenile fish habitats of migratory fish have partly been destroyed and are no longer accessible, or their accessibility is considerably reduced.

Due to the implementation of the Master Plan Migratory Fish Rhine, ecological continuity has been improved at more than hundreds of barrages, e.g. by constructing fish passes (**Figure 12**), and in 2015, 21% of the salmon spawning grounds were again accessible. Since about the year 2000, annually several hundreds of salmon again migrate upstream to the Upper Rhine and reproduce naturally in the accessible salmon waters [23].

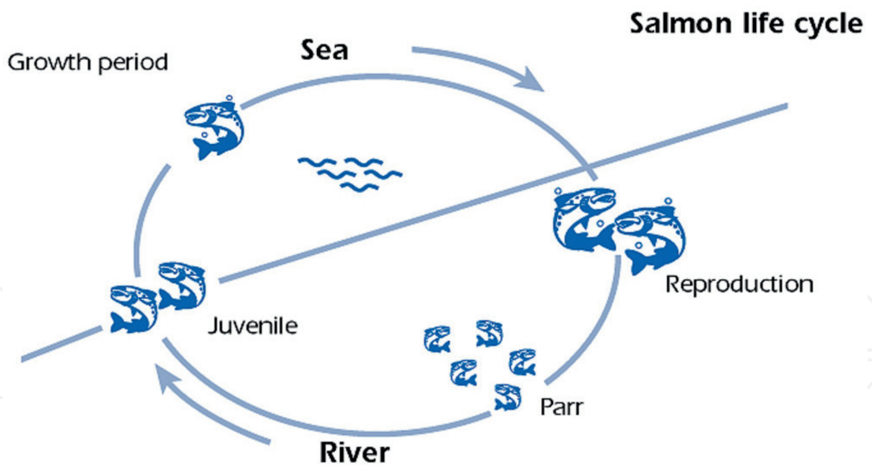

Figure 11. Life cycle of migratory fish Atlantic salmon.

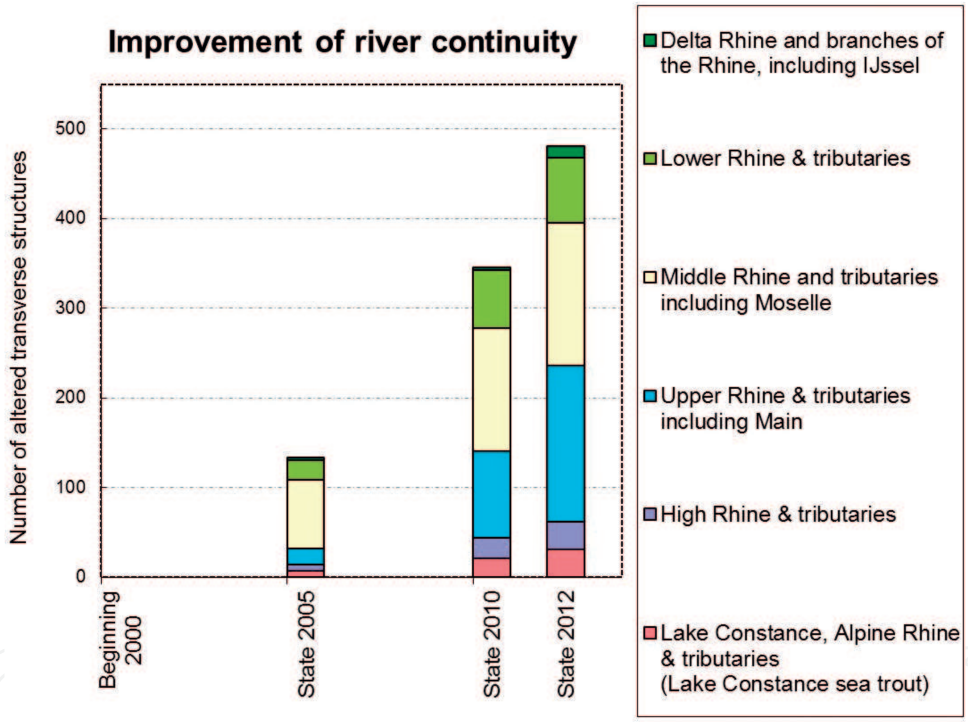

Figure 12. Improvement of river continuity between 2000 and 2012.

5. Reducing the impacts of water quantity issues (floods, low flows)

The topography of the Rhine catchment varies and includes different climatic zones (alpine, low mountainous, Atlantic, semi-continental climate). Different discharge regimes are overlapping: a "snow regime" in the southern part near the Alps with flood events mainly occurring in summer (snow melt) and low water periods mainly in winter. Waters draining the Central Upland region (Neckar, Main, Nahe, Lahn, Moselle, etc.) are characterised by a "pluvial regime" with prevailing winter floods and low flows in summer. Since these two regimes overlap, the downstream discharge distribution over the year is uniform ("combined regime") [24, 25].

Furthermore, climate change consequences for the discharge lead to more homogenous runoff in the south, while the seasonal distribution becomes more marked in the north. These tendencies continue during the twenty-first century, and, due to reduced runoff in summer, they might even be intensified (**Figure 13**) [25, 26]. Together with land settlement and man-made water works, this is already now resulting in diverse flood and low flow patterns.

As stated in Part 2, the two catastrophic flood events on the Rhine in 1993 and 1995, causing, respectively, 1.4 and 2.6 billion euros damages, were the starting point for the ICPR to deal with quantitative issues and flood risk (**Figure 14**) [6, 7]. Because of several low flow events since the 2000s and their negative impacts, the Rhine Ministers decided in 2013 to address this issue and undertake an in-depth analysis of low flows and their consequences (**Figure 15**) [12]. Apart from that, the ICPR is working on the topic of climate change effects on the water regime and the water quality and environment (**Figure 13**). Since 2015, the ICPR has published a first Climate Change Adaptation Strategy for the Rhine Basin based on hydro-climatic observations and measurements from the twentieth century and scenarios for the twenty-first century [25, 27]. The different working groups of the ICPR (dealing with water quality, ecology, flood and low water) have made a thematic assessment of the respective consequences and proposed actions which have been integrated into the strategy.

The focus in this subchapter will be on flood risk management, as low water has just begun to be treated within the ICPR. Interesting results about low water change, repercussions, etc. will be available in the upcoming years.

5.1. Transboundary flood risk management

Since 1998, the ICPR has implemented the Action Plan on Floods [6, 7] which set out four action targets: reduce damage, water levels, improve flood forecast and risk awareness. Since 2007 it has established a framework for the exchange of information and coordinated implementation of the European Floods Directive (FD) within the IRBD Rhine [28].

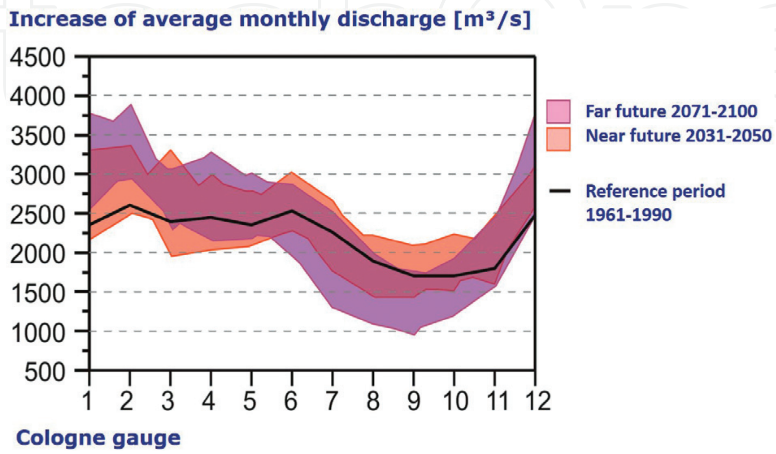

Figure 13. Possible effects of climate change on discharges in the near and far future (Cologne).

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Figure 14. 1995 Flood in Cologne, Germany (source: Stadtentwässerungsbetriebe Köln).

Figure 15. 2015 Low water in Koblenz, Germany.

The objectives of the FD concern the management of flood risk in order to reduce potential adverse consequences of floods for human health, the environment, cultural heritage and economic activities. The Directive stipulates extensive cooperation in the field of flood management in international river basin districts. Based on the principle of solidarity, the states should avoid taking measures which, due to their extent and their effect, increase the flood risk in other countries upstream or downstream in the same river catchment as long as these measures are not coordinated between the member states concerned and no common solution has been found.

In accordance with the FD, different common products (reports, maps) have been drafted and published on the ICPR homepage, among others, the first overriding Flood Risk Management Plan (FRMP) (2016–2021) for the Rhine basin (see measures of the FRMP in Part 5.1.2) [28]. The measures of the FRMP Rhine are currently being implemented by the states themselves, and discussions have started to prepare the second FRMP (2022–2027).

5.1.1. Principles and targets of the FRMP

Consistent with the APF [6] and the FD, the Rhine states have determined common principles for the FRMP:

- Responsibility, solidarity, proportionality and clear task distribution (between the states when it comes to flood risk management).
- Synergy with other EU environmental politics (specially the WFD; see Parts 3 and 4).
- Sustainable and integral flood risk management.
- The security level has to be ecologically, economically and socially compliant.
- No 100% security, always residual risks.

These principles are translated into four overriding, general targets representing the whole flood risk management cycle (prevention, protection, preparedness, crisis management and recovery) (**Figure 16**). Relying on these targets, the states have decided joint measures presented in Section 5.1.2.

5.1.2. Presentation of joint measures of the FRMP

The FRMP for the Rhine basin describes measures with transboundary effects and measures, for which an exchange of information and an international coordination between the states in the Rhine catchment are important. The FRMP Rhine also includes information and links to the national and regional FRMPs.

5.1.2.1. International coordination of measures

The EU member states in the Rhine catchment are in charge of implementing the FD and apply the principles of subsidiarity and solidarity. In order to respect these provisions, the states, Länder and regions within the IRBD Rhine have agreed not to increase flood risks outside their respective territories. To this end, they will effectively coordinate measures with transboundary

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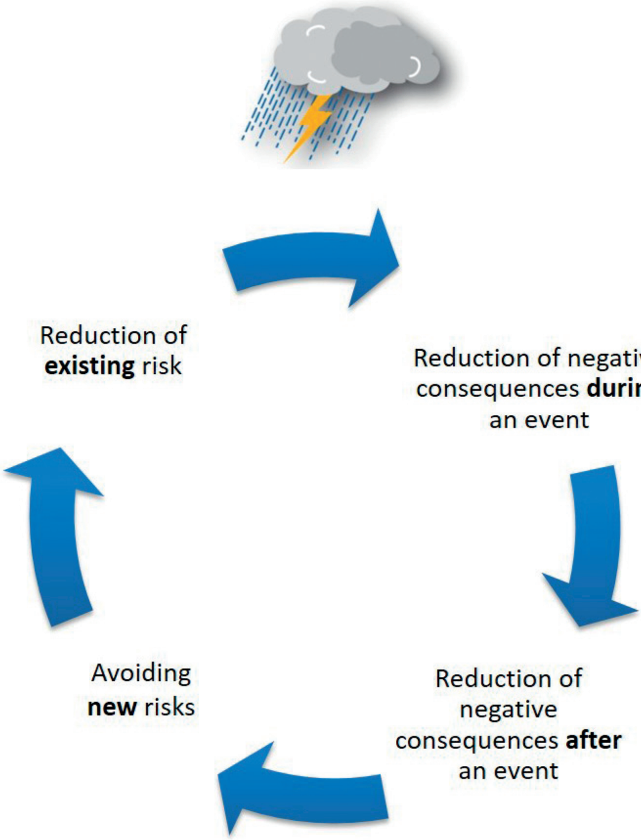

Figure 16. Overarching targets and simplified risk management cycle.

effects. Furthermore, according to the WFD and FD, some measures, e.g. retention areas, have to be coordinated or present synergies between the goals of the FD and the WFD.

5.1.2.2. Implementation of measures aimed at lowering the water levels

As stated in the Conference of Rhine Ministers (2013), and due to the effects of climate change and the expected increase of the number of flood events, supra-regional flood risk management measures such as keeping flood-prone areas free from further uses or creating more flood retention areas and more room for the river are increasingly important. Therefore, the Ministers decided the further and consequent implementation of all measures aimed at lowering water levels or of retention measures along the Rhine planned until 2020 within the framework of the APF (**Figure 17**).

The following measures aiming at lowering water levels are related to the latter and are included in the FRMP (**Figure 17**): future retention areas, dike relocation, renaturing (**Figure 10**) and keeping discharge corridors free (see Part 4). For the further measures, the securing of the surfaces under aspects of spatial planning is being determined in the FRMP.

According to an ICPR study [7, 29], a reduction of flood peaks will be achieved once all planned measures will have been implemented (**Figure 18**). The results permit a substantiated evaluation of the effectiveness of measures implemented and of their contribution to achieving the objectives of the FRMP.

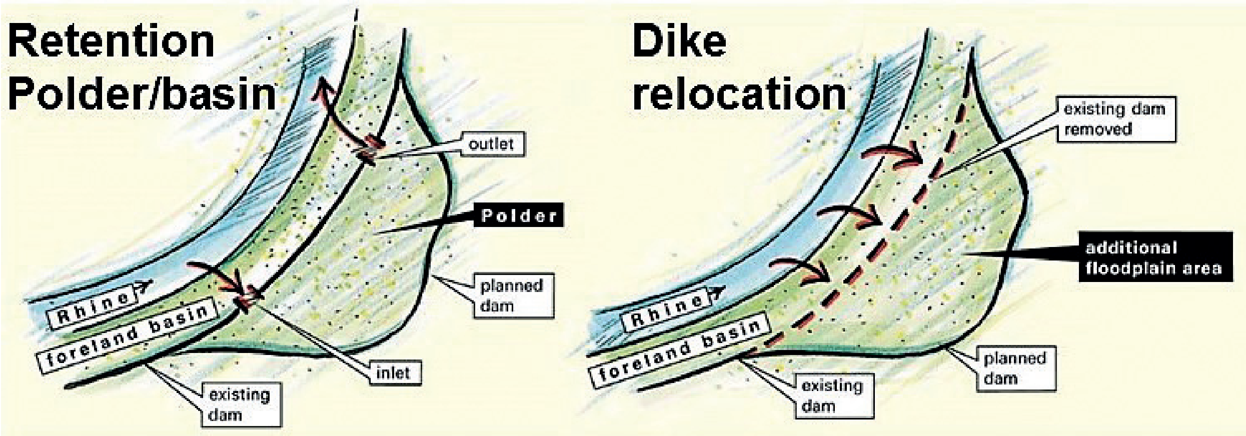

Figure 17. Example of measures aimed at lowering water levels: retention basin and dike relocation (source: Regierungspräsidium Freiburg—Integrated Rhine Programme (2011)).

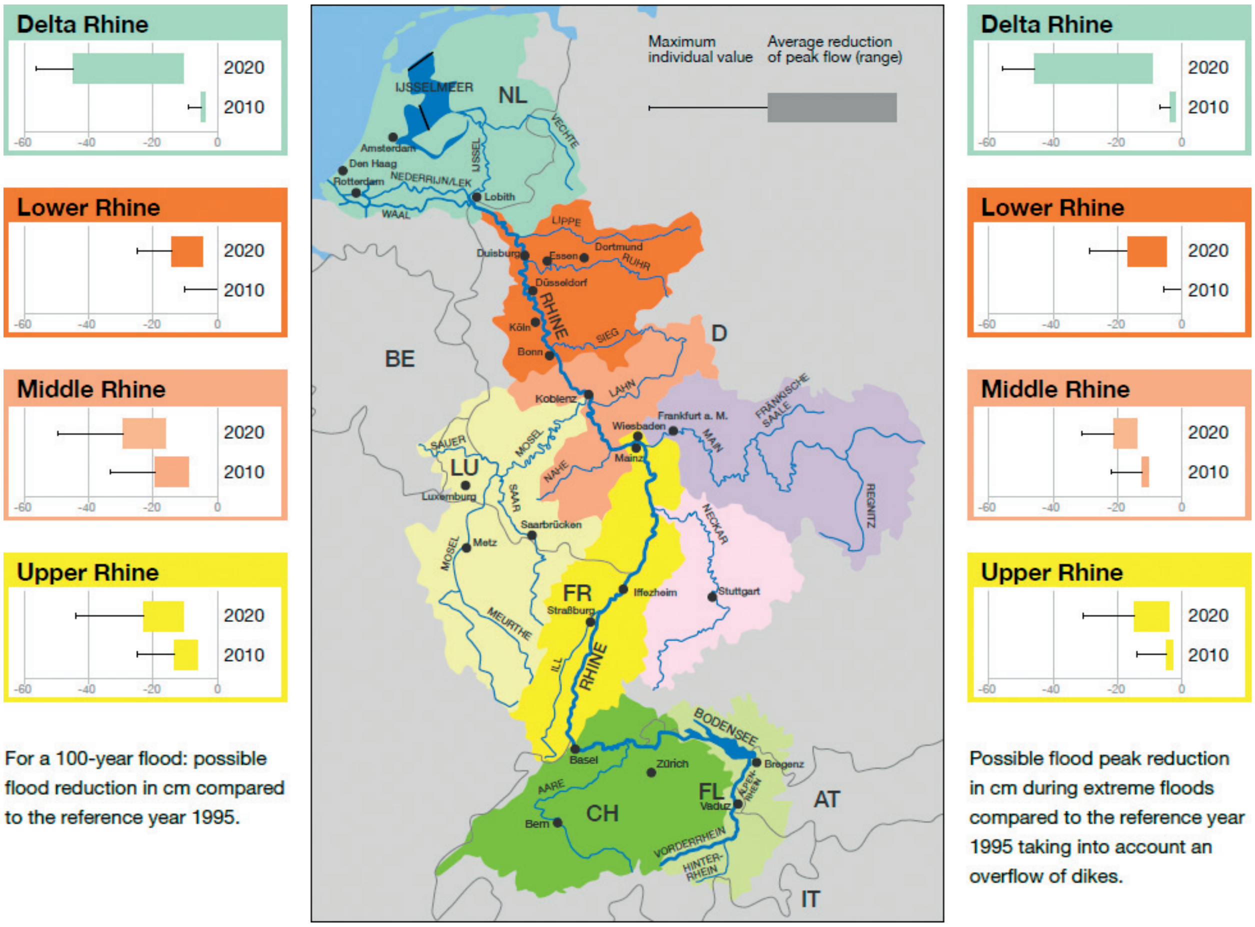

Figure 18. Possible reduction of flood peaks due to measures lowering the water level (State 2010 and 2020).

The reduction of water levels by different corresponding measures along the Rhine (**Figure 18**) may equally lead to reduced flood probability [29, 30]. This also results in a reduction of flood risks. The results of this study [30] were used for calculating the modification of flood risk with the GIS instrument [31, 32].

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5.1.2.3. Improved exchange of information and access to information

The mutual exchange of information on flood risk management is done at the ICPR level. The population is also being well informed on a national, regional or local scale, so that regional specifics may be taken into account. The "Rhine Atlas" [33] is a supranational sensitisation tool comprising aggregated flood hazard and risk maps (**Figure 19**). For the main stream of the Rhine, flood depth and areas as well as objects at risk are shown for three scenarios (high, medium and low flood probability). Additional information and more detailed national maps are available by clicking on any area of the atlas. Together with uses adapted to floods, it also supports the implementation of preventive measures in flood-prone areas.

5.1.2.4. Instrument for the assessment of the impact of flood risk management measures on risk evolution

The ICPR, supported by the engineering consultant HKV, developed the instrument "ICPR FloRiAn (Flood Risk Analysis)" aimed at evaluating the effect of measures to reduce flood risk and at estimating the future evolution of flood risk. The instrument, working in a consistent, reproducible and transparent manner, is available on demand at the ICPR and is applicable to other river basins [31, 32]. ICPR FloRiAn is GIS based and in the case of the ICPR covers the main stream of the Rhine. Flood maps (e.g. developed under the FD) are the basis for the tool. In addition to the quantification of economic flood risk, modules are developed for quantifying the consequences of risk for human health, to the environment and to culture heritage. In short, the main instrument consists of three interacting calculation modules (Model Builders) resulting in an overall damage or risk assessment.

The ICPR uses this tool to assess risk reduction and evolution along the Rhine from 1995 up to now as well as to carry out regular reviews of the impacts of measures on flood risk reduction for the FRMP. Calculations made with the help of ICPR FloRiAn proved—among other results—the reduction of flood risks by 25% between 1995 and 2020 for economic activities. Under a supra-regional aspect, measures increasing water retention in the direct vicinity of the Rhine river prove to be most efficient (**Figures 17** and **18**) [31, 32].

Figure 19. Rhine Atlas (flood hazard and flood risk maps).

5.1.2.5. Improve flood forecasting and warning systems as well as crisis management

Flood forecasting and flood announcement contribute to reducing damage in case of a flood event [7, 31, 32]. Therefore, the states, Länder and regions in the IRBD Rhine—through national centres along the Rhine (**Figure 20**)—cooperate at an international level when exchanging data

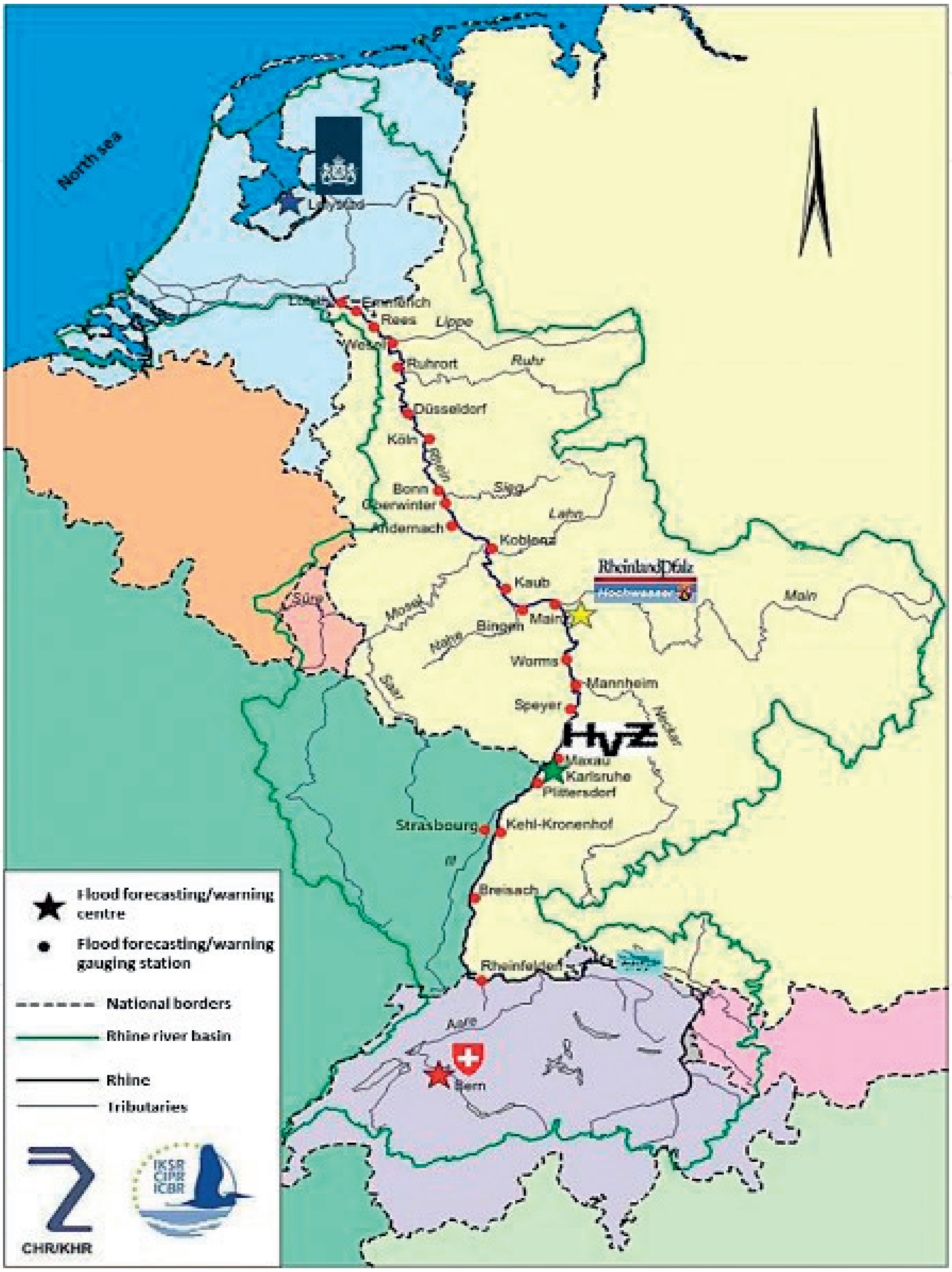

Figure 20. Flood forecasting centres along the Rhine.

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on discharge and precipitation and using them for flood forecasting [34]. The quality of information and forecasting is continuously being improved. Today, national mobile applications like "Meine Pegel" or "KATWARN" disseminate information and warn on water levels or storms (**Figure 21**) [35, 36].

Good crisis management planning for flood events is important in order to be able to reduce risks during the event. The ICPR has begun to compile existing multilateral crisis management systems and the understanding of national disaster risk reduction. If necessary, this exchange of information will enable improvements in this domain. This also applies to recovery measures.

5.2. The issue of low flows

Just as floods, low flows are natural, evident events that cannot be avoided. However, low water may considerably restrict navigation on the Rhine. The performance of hydropower plants may equally be reduced in times of low discharge. Besides, low flows can go hand in hand with high temperatures, leading to reduced oxygen content which may detrimentally impact the ecosystem. The Rhine states are therefore paying increased attention to the topic of low flows. In 2017, the ICPR (Expert group "Low water") has begun to analyse the trend of low water since the beginning of the twentieth century, to examine past low flow events and classify them in return periods. The ICPR is investigating the various consequences of low water for different uses of the Rhine. It is furthermore working on the inventory of national low water management measures as well as on low water monitoring.

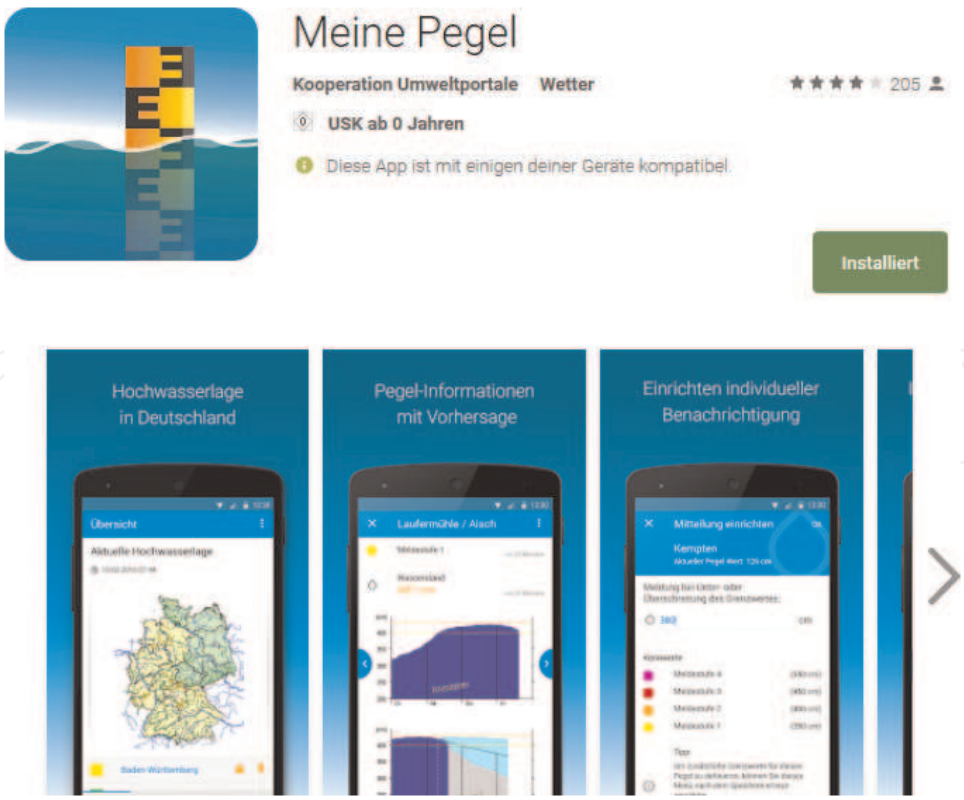

Figure 21. Mobile application "Meine Pegel" [35].

6. Conclusion

From being the sewer of Europe in the 1960s and 1970s, the Rhine has now become one of the cleanest international rivers in Europe. The Rhine and its densely populated catchment area have experienced heavy pollution and impressive restauration.

What started with the development of a joint monitoring strategy in the 1950s and 1960s has developed into a comprehensive integrated management strategy of the Rhine, comprising aspects of water quality, emission reduction, ecological restoration and flood prevention.

This development was guided by a process of "learning by doing" which was triggered by some major disasters (Sandoz accident 1986, floods in 1993 and 1995). These disasters have dramatically changed the political will in all states in the Rhine watershed. Public pressure after the disasters has been key to find common solutions towards restoring the Rhine river.

Since the beginning of the 1990s, the work of the ICPR has triggered the integrated water policy in the European Union. Today, basin-wide and transboundary approaches in water management and the required cooperation between all countries in a catchment are a European obligation.

The functions of the Rhine river, drinking water, water for agriculture and industries, water transportation, water power plants, recreational fishery, recreation and tourism, must be harmonised with ecosystem protection. The ICPR can look back upon a long tradition of cooperating with stakeholders like nature protection and different user associations.

This good transboundary cooperation was based on political willingness and the conscience of common interest, developed on strong pressure from public participation, good multilevel governance, the respect and solidarity of the countries within the basin and a high-level permanent secretariat.

Strong international coordination and cross-border cooperation have set the basis for the future development of the Rhine catchment and its related socio-economic and climate change challenges.

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