Evaluating past and future flood risk reduction in the Rhine river basin

Adrian Schmid-Breton^{1,a} and Nikola Schulte-Kellinghaus^{1,a}

¹ International Commission for the Protection of the Rhine, Kaiserin-Augusta-Anlagen 15, 56068 Koblenz, Germany

Abstract. To evaluate the effects of implemented or planned flood risk management measures on risk and damage reduction, the International Commission for the Protection of the Rhine (ICPR) has developed a method and a specific tool named “ICPR FloRiAn (Flood Risk Analysis)”, running in a geographic information system. The instrument, available on demand, was applied by the ICPR to the Rhine but also by external users to other rivers in Europe. The tool uses flood hazard maps (like the so-called ICPR “Rhine Atlas”) and associated recurrence periods for an overall damage and risk assessment for four receptors: human health, environment, cultural heritage and economic activity. Calculations with FloRiAn by the ICPR show that the flood risk reduction target defined in the Action Plan on Floods in 1998 could be achieved with the measures already taken and those planned until 2030. Furthermore, the ICPR launched a new programme in 2020, entitled “Rhine 2040”, which sets quantified risk reduction objectives until 2040. The focus of the programme is climate resilience. In the future, it is planned to use FloRiAn again to estimate the reduction of damages and risks caused by new measures.

1 Introduction

The Rhine connects the Alps to the North Sea (Figure 1). It is 1232 km long and one of the most important rivers in Europe. The topography of the Rhine catchment is various, from high, middle and low mountain chains to lowlands and includes different climatic zones (alpine, low mountainous, atlantic and semi-continental climate) resulting in different discharge regimes as well as flood runoff patterns: nival regime in the South, pluvial regime in the Central Upland region and combined regime in the North. Furthermore, according to a study undertaken in the Rhine basin, the impact of climate change on the water regime of the Rhine could lead to discharge changes in the winter (increase) and summer period (decrease). Together with urbanisation and man-made water works, these natural conditions have resulted in diverse flood risks and catastrophes in the past.

The two catastrophic flood events of the Rhine in 1993 and 1995, causing respectively approx. 511 million euros and 281 million euros on the Lower Rhine (UNDINE – BfG 2021a & 2021b), were the starting point for the nine countries of the Rhine river basin, within the International Commission for the Protection of the Rhine (ICPR) founded in 1950, to deal with quantitative issues and flood risk (Figure 1) (Schmid-Breton 2016; Schulte-Wülwer-Leidig et al. 2018). The first results of this cooperation were the Action Plan on Floods (APF) in 1998 (included in the programme “Rhine 2020”) (ICPR 1998 & 2020b). Since 2015, there are also the International Flood Risk Management Plans (IFRMP) (ICPR 2020d) according to the European Floods Directive (FD) (EU 2007). In the APF of 1998, one of the four objectives set out by the

Rhine bordering states was to reduce the risk of flood damage by 25 % by 2020, in comparison to the figures of 1995 (ICPR 1998 & 2020b). The most important objective of the FD in force since 2007 is the reduction of the adverse consequences of flooding upon human health, the environment, cultural heritage and economic activity considering - as far as possible - the impacts of climate change.

To evaluate the effects of implemented or future planned flood risk management measures (of the APF and IFRMP) on risk and damage reduction, the ICPR has developed a method and a specific tool named “ICPR FloRiAn (Flood Risk Analysis)” running in a geographic information system (GIS) (Schmid-Breton et al. 2018; ICPR 2021). The instrument which is available for other public organisations on demand was applied by the ICPR to the Rhine but also by external users to other rivers in Europe (Lindqvist 2019; Ditte et al. 2017; Harzendorf, 2017; Buntrock, 2019). The tool uses flood hazard and risk maps (like the so-called “Rhine Atlas” by the ICPR) and associated recurrence periods for an overall damage and risk assessment for four receptors: human health, environment, cultural heritage and economic activity (ICPR, 2020).

In a nutshell, assessment of the APF as part of “Rhine 2020” (ICPR 2020a & 2020b), made by the ICPR amongst other with the help of FloRiAn, shows that since the great flooding of 1995 the risk of damage has been reduced. The states have invested more than 14 billion euro in measures such as the construction of new flood retention areas. In addition, forecasting periods have been doubled and the publication of flood risk maps has increased public awareness.

The responsible ministers and the representative of the European Union met in Amsterdam on 13 February 2020 for the 16th Rhine Ministerial Conference. At this occasion they adopted the “Rhine 2040” programme with ambitious targets for biodiversity and ecology, water quality, flood and low water management (ICPR 2020a). The resilience of the Rhine river basin against negative effects of climate change is at the centre of this programme. The programme represents the working basis of the ICPR for the next 20 years and contains ambitious goals to be achieved together for the further improvement of the states of the Rhine river basin.

In the field of flood risk management, the overarching objective of “Rhine 2040” is to reduce the flood risks on the Rhine and its major tributaries by at least 15 % by 2040 compared to 2020 despite population growth, settlement developments as well as climate change induced modifications. In order to achieve the above-mentioned goal, all actors are supposed to contribute to its implementation and to take the optimal combination of (national) measures. To regularly assess this objective and the effects of implemented and planned measures it is proposed to use the tool FloRiAn.

2. Effects of climate change

In summary, available ICPR studies (ICPR 2011 & 2015a) show that climate change compared to the reference period for the present (1961-1990) with rising temperatures in the Rhine catchment until 2050 (+ 1 to + 2 °C) and until 2100 (+ 2 to + 4 °C) could possibly lead to changes in precipitation and runoff (see Table 1) (remark: all trends should increase by 2100). Indeed, climate change could lead to increased precipitation, mean discharges as well as mean flood runoffs in the winter and a decrease of these parameters in the summer.

Summary of presumed effects of climate change on precipitation and discharge until 2050
a. During the hydrological winter: <ul style="list-style-type: none"> Increased precipitation Increased discharge (up to 20 %) Early melting of snow/ice/permafrost, shift of the line of snowfall
b. During the hydrological summer: <ul style="list-style-type: none"> Less precipitation (but possibly more often heavy rainfall in summer) Reduced discharge (up to 10 %) More periods of low flow.
c. More smaller to medium floods. Increase of peak flows of rare/extreme floods seem to be possible, but their extent cannot be quantified beyond doubt.

Table 1. Presumed effects of climate change by 2050

In 2015, the ICPR published a climate change adaptation strategy for the Rhine river basin (ICPR 2015a). To this end the ICPR states agreed upon different climate scenarios and possible fields of action within flood prevention. As part of the “Rhine 2040” programme, the runoff projections (climate scenarios) for 2050 and 2100 will be updated and the adaptation strategy will be revised by 2025 (ICPR 2020a).

A major part of measures implemented or planned within the IFRMPs can be considered as so-called win-win and no-regret measures for flood prevention, water quality and ecology (ICPR 2020d). They contribute to reducing possible adverse effects of climate change. In particular, this applies to measures as improved water retention and renaturation measures. Thus, assessing the efficiency of these measures through FloRiAn helps to understand how negative climate change effects can be mitigated.

2 FloRiAn: Method and tool

2.1 General

Mathematically, flood risk is defined as a product of probability of occurrence and the potential damage. The ICPR has developed specific methods, some of which are new, for determining the damage potential and the risk for the four receptors human health, environment, cultural heritage, and economic activities (ICPR 2016a & 2016b) (Figure 2).

Furthermore, the effect of various measures can lead to changes in flood risk, which can be affected in two ways: by changing the flood probability and by influencing the potential damage. The modification of flood probability due to water level reduction measures such as retention measures and riverbed enlargement has been calculated by a specific group of the ICPR (ICPR 2012 & 2015b). To do this, hundreds of different types of floods were modelled. Thus, indirectly, altered flood scenarios due to climate change were taken into account.

Figure 2. Overall risk analysis procedure

Figure 3. ICPR FloRiAn as an ArcToolbox with the four receptors and different calculation modules as well as example of outputs (map and table).

The calculations of the flood risk are carried out by using a GIS at the level of raster cells. During the evaluation, the results of individual raster cells are aggregated at the desired level in a table (e.g. riparian municipalities) (Figure 3). Adding together the calculation outputs, information for the whole Rhine is obtained.

The execution of calculations at different time horizons allows to draw conclusions regarding the change or reduction of damage and risk as a result of theoretically or actually implemented measures. Executed measures (from 1995 to 2015) and planned ones (for 2020/2030) were compiled from the Rhine Atlas and included in the calculations.

Figures 2 and 3 give a general overview of the procedure for damage and risk calculation as well as the tool itself.

2.2 Economic risk assessment

This section gives a detailed explanation of the specific calculation method and process for direct economic damage/risks, more quantitative and tangible (monetary results) than the methods for cultural heritage, environment and affected persons (ICPR 2016a & 2016b).

The determination of the potential economic damage is based on the knowledge of the correlation between water depth and the resulting (relative) damage, the so-called damage functions (e.g. the ones of the ICPR Rhine Atlas 2001) (ICPR 2001). Consequently, the damage potential is calculated on the basis of land use maps (the EU Corine Land Cover datasets in the case of the ICPR) and flood risk maps of the Rhine Atlas for the three flood scenarios (frequent - HQ_{high}, medium – HQ_{medium} and extreme floods - HQ_{extreme}) by means of damage functions and specific asset values (updated according to the economic growth) for the 6 following categories of land use (representing economic activities): settlement, industry, transport, agricultural areas and forest (Figure 4). As a result, the potential damage in €/m² per category and the integral/total damage are calculated.

Figure 4. Calculation flow for economic damages and risks

2.3 Effects of measures

Depending on the type of measure or indicator (influence on the damage potential or probability) and the considered receptor (human health, environment, cultural heritage and economic activities), the impact of measures is calculated differently in the tool (ICPR 2016a & 2016b):

- Modification of the damage functions resulting from measures, as shown in Figure 5.
- Changes in the number of people due to evacuation combined with organizational measures.
- Changes in the distance (buffer) of possible pollutions arising from potentially hazardous facilities.
- In the case of various measures, the effect is differentiated if the area is protected/embanked or unprotected/non-embanked. In general, it is assumed that in unprotected areas, which are more frequently flooded, potential victims have more flood experience and thus the reduction effect of potential damage is greater.
- Reduction of inundated area due to improved technical flood protection measures as e.g. planned dike restoration in the Netherlands.
- Change in flood probability due to water level reducing measures (special method of the ICPR) (ICPR 2015b).
- In addition to the effect of individual measures, the summation of the effects of these measures and their interdependencies are also include in the method.

Figure 5. Modification of the damage function for immobile damage (industry) due to the measure "precautionary building" (= measure 1.3.1) for dyked and non-dyked areas

4 The Rhine Atlas

This chapter presents the web-based "Rhine Atlas", one of the main sources of input data on flood hazard and damages for the calculations with FloRiAn as well as a major flood risk awareness tool of the ICPR (Figure 6) (ICPR 2020c).

The Rhine Atlas depicts flood hazard and risk maps for the entire main Rhine river from the Alps to the North Sea including Lake Constance, the IJsselmeer and the Dutch coasts. For the three flood scenarios, the Rhine Atlas consists of a map showing the areas and depths of flooding and the potential consequences in the flood area: people potentially affected, land use and economic activities, polluting industries, water extraction and nature protection areas, cultural heritage. These are all input data for the FloRiAn calculations.

The first version dates back to 2001 and was last updated in 2020 (ICPR 2001 & 2020c). It makes it possible to comprehensively inform the population, planners and decision makers about the flood risks on the Rhine. It enables also the consultation of detailed national maps linked to the atlas.

Figure 6. Extract from the ICPR Rhine Atlas 2020 (example: area of Mainz in Germany, extreme flood scenario).

5 Flood risk reduction

In the following the results of FloRiAn calculations ran by the ICPR within the assessment of the damage and risk reduction objectives of the APF and the IFRMP for the risk receptor “economic activity” from 1995 to 2030 (projections) are presented (ICPR 2016a, 2020b & 2020d).

The assessment with FloRiAn has revealed a flood risk reduction for economic activities by 25 % for 2020 (target stated in the APF) compared to 1995 due to a whole range of national flood prevention and protection measures (Figure 7). This reduction, although lesser, could be prolonged until 2030 (Figure 7). Risk reductions have also been established for the other risk objects “human health”, “cultural heritage” and “environment”. Detailed results and figures can be found in ICPR 2016a and will be updated by the end of 2021.

Figure 7. Evolution of economic risk from 1995 to 2030

Water retention along the Rhine, such as the construction of flood retention areas, the relocation of dykes and measures that give more room to the river are considered very efficient for risk reduction by changing the probability of flooding. In addition, various other measures for protection, prevention and preparedness, including dyke restoration, flood forecasting, early warning systems and crisis management plans have contributed to reduce the increase of damage in floodplain areas since 1995 (Figure 7).

6 Conclusion and outlook

The countries of the Rhine basin have already achieved major successes in recent years in their efforts to reduce the risk of flooding. However, the results of the most recent available calculations, made with the help of FloRiAn, also show that the efforts of the states would have to be continued in the coming years if the risk reduction objective set out in the “Rhine 2040” programme is to be achieved by 2040. They also demonstrate the solidarity between the states in the Rhine basin and the joint efforts to reduce the risk of flooding at Rhine level. Ultimately, it is clear that regular assessments of progress in this area are necessary.

In this respect, FloRiAn and the method underpinning seem appropriate and meet the needs. It is therefore planned to carry out new calculations with this tool on a

regular basis, seeking in the future to take account of flood scenarios linked to climate change.

Finally, the tool has also proved its value outside the Rhine basin. Upon request, the ICPR provides FloRiAn to other river commissions, public authorities, scientific institutes or universities.

7 References

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