Assessment of Flood Risk Reduction (Action Plan on Floods, Action Target 1) with Due Regard to Types of Measures and Receptors of the Directive 2007/60/EC (FD)

- Synthesis Report -

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Document status

*The **ICPR** has developed a **method** to provide evidence of the effects of measures upon the risk of flooding, which is integrated into a **Geo-Information System (GIS)**.*

*This **Synthesis Report** (ICPR Technical Report No. 236, 2016) contains a summary of this method and the results of calculations undertaken using the GIS tool to demonstrate the change or reduction in the flood risk along the main stream of the Rhine, due to measures undertaken.*
In addition, the report contains an evaluation of the effect of measures and indicators, as well as recommendations for the further use of the tool by the ICPR and by third parties, and stipulations for the wider use of the tool.

*The **Technical Report** (ICPR Technical Report No. 237, 2016) contains a detailed description of the method and the calculation process, as well as of the tool and the associated data, indicators and assumptions for the documentation of the procedure. This report also serves as an instruction manual for third party users of the instrument.*

The development of the methodology, the GIS tool and the calculations performed by the tool was undertaken between 2013 and 2016 by the ICPR in collaboration with the consortium HKV Hydrokontor and HKV Lijn in Water. The ICPR Expert Group "Flood risk analysis" of the Working Group "Floods" supported the ICPR commissioning of the consortium, and continued the work after the completion of the contract.

Note regarding transfer of the tool to a third party:
The transfer of the instrument and its user guide is feasible, and is undertaken in principle free of cost, with the necessary expenses reimbursed where applicable.
Future users may work with the tool autonomously. In return, users will be asked to notify the ICPR of how the instrument is used (and potentially the results), as well as of any further developments relating to the tool
If further developments are made to the instrument, the ICPR shall receive a free copy.
The transfer of the data used for the calculations and the baseline data (calculation results) shall take place where the owner of the data has provided consent.

Summary and conclusions

In 1998, one of the four objectives set by the states bordering the Rhine in the Action Plan on Floods (APF, 1998) was to reduce the risk of flood damage by 10% by 2005, and by 25% by 2020, in comparison to the 1995 figures. The ICPR has conducted regular evaluations for the APF. In order to provide evidence of the reduction of the risk of flood damage, a more qualitative method has been used for the years 2000 and 2005 (see ICPR Report No. 157).

The most important objective of the Flood Risk Management Directive (FD; directive 2007/60/EC), valid since 2007, is the reduction of the adverse consequences of flooding upon human health, the environment, cultural heritage and economic activity. An evaluation is also planned within the framework of the regular review of the Flood Risk Management Plan for the International River Basin District of the Rhine (FRMP) and the implementation of the FD in 6-year cycles. Similarly to the APF, in the future, flood risk evolution should be assessed within the ICPR for the entire main stream of the Rhine, taking into account flood risk management measures that have been implemented.

The ICPR has developed an evaluation tool for evaluating both the APF and the FRMP. The aim of the calculations under the ICPR was to arrive at a quantitative conclusion.

In contrast to the evaluation of the effectiveness of flood measures for 2005 within the framework of the APF, the areas on the Rhine upstream of Iffezheim, the High Rhine, Lake Constance and the Alpine Rhine have been included here. The results presented in this report relate to input data, resolution and spatial references at the level of the entire main stream of the Rhine (viewed in large-scale) and enable an assessment of the effects of measures within the framework of flood risk management.

The calculations to **demonstrate the evolution of the flood risk** have revealed the following with regard to the Rhine:

In considering the risks to **human health**, it is apparent that safety/evacuation from flooding plays a particularly important role. Measures such as safeguarding/evacuation of those potentially affected, raising awareness, flood forecasting and warning and alarm plans as well as the modification of the probability of flooding all help to mitigate the flood risk. Where all of these measures are implemented, and across the three flood scenarios, a reduction in the risk for human health of approx. 20% to 40% (1995-2005), approx. 70% to 80% (1995-2020) and 70% to 90% (2015-2030 period) is determined. The impact of the "land use control" and "precautionary building/flood proofing property" measures on the existing risk is relatively low in comparison. The measures for controlling land use serve in particular to avoid new risk.

In assessing **cultural heritage** and the **environment**, based on the results of new, experimental – not proven – methods, it is ascertained that over time, damage to cultural heritage and the environment is reduced across all damage categories defined according to importance and vulnerability, and in all scenarios, due to the measures undertaken. The same applies to the risk of flooding with regard to cultural heritage and the environment.
Across all flood scenarios, a reduction in damage and risk of approx. 10% for cultural heritage and approx. 5% for the environment is ascertained for the period 1995-2005, approx. 40% to 70% for cultural heritage and the environment for the period 1995-2020 and approx. 50% to 70 for cultural heritage and the environment for the period 2015-2030.
However, in particular with regard to the environment, it must be emphasised that due to limited details with regard to measures, precise estimates are difficult at present. As with the other receptors, the change in risk is mainly evoked by the change in flood risk probability since 1995, but particularly from 2020 onwards.

In terms of the <u>**economy**</u>, it has been determined that the **APF target – a reduction by 10% of the flood risk by 2005 – can be proven, and that the reduction by 25% before 2020 in contrast to 1995 can be achieved.** These findings confirm the earlier analysis by the ICPR regarding the situation in 2005 (see ICPR Report No. 157). The results also show a reduction in risk of approx. 20% to 45% across all flood scenarios for the future, i.e. for the period 2015-2030.

The calculations carried out for the different time periods show that over time, the implementation of measures has been or shall be expedited, which is reflected in the results. This means that the implementation of various measures since 1995 in terms of both prevention and preparedness, including flood forecasts and early warning systems as well as (the preparation of) crisis management, is leading over time to the weakening of damage growth in the flood plain in comparison to the situation without such measures. This applies to measures relating to protection, such as retention measures, which help to reduce the risk. The retention measures undertaken in the main stream of the Rhine and the Dutch measures within the framework of "Room for the River" which have been realised upstream of Iffezheim since 1995 and planned for the period up to 2020 or 2030, are contributing in particular to the reduction of the flood risk by reducing the water levels and the resulting modification of probability.

Based on the criteria of **effectiveness** and **effort** in terms of data collection and the **relevance** of the information at the level of the main stream of the Rhine, there are key **indicators** that enable the effects and development of flood risk management measures to be proven globally. These, in particular, are:

- Keeping flood prone areas clear/open (prevent the location of new or additional receptors) and establishing building regulations (*indicators: change in the land use data and building regulations and codes/building development plans)*
- Implementation of measures to lower water levels *(indicator: change in flooding probability)*
- Flood protection *(indicator: flood probability/a protection level and an evolution/modification over time)*
- Raising public awareness by, inter alia, provision of flood hazard and risk maps *(indicator: frequency/ update intervals with regard to information campaigns)*
- Flood forecasting and warning *(indicator: improvement in flood forecasting)*
- Crisis management *(indicators: presence and update frequency of alarm and emergency response plans; number of warning systems; specifying civil protection exercises, specifying a minimum and maximum safeguarding rate for those affected in a certain area)*

Based on the experiences attained, for an effective evaluation of the measures regarding the main stream of the Rhine, the aforementioned indicators provide sufficient grounds for continued work.

The ICPR plans in the future to use the assessment tool developed in the period 2014-2016 to **regularly review the FRMP for the IRBD Rhine** and to further refine the methodology.

The ICPR supports the **distribution and use of the instrument, including its underlying methods**, not only **to all states in the Rhine catchment**, but also to regional and national authorities in the Rhine catchment (states/regions/German federal states or even smaller areas).
The same applies for the use of the instrument by **other international and national commissions for river basins or interested states**, i.e. the ICPR offers the instrument for utilisation by other river basin districts or river basin commissions, research institutes, universities, inter-governmental commissions and non-governmental organisations.
It should be noted that when using the instrument in other river basins or sub-basins, the appropriate data sources for calculations, which need to be prepared specifically for the application of the instrument, must be available.

Introduction

In 1998, one of the four objectives set by the states bordering the Rhine in the Action Plan on Floods (APF, 1998) was to reduce the risk of flood damage by 10% by 2005, and by 25% by 2020, in comparison to the 1995 figures. The ICPR has conducted regular evaluations for the APF. In order to provide evidence of the reduction of the risk of flood damage, a more qualitative method has been used for the years 2000 and 2005 (see ICPR Report No. 157).

The most important objective of the Flood Risk Management Directive (FD; directive 2007/60/EC), valid since 2007, is the reduction of the adverse consequences of flooding for human health, the environment, cultural heritage and economic activity. An evaluation is also planned within the framework of the regular review of the Flood Risk Management Plan for the International River Basin District of the Rhine (FRMP) and the implementation of the FD in 6-year cycles. Similarly to the APF, in the future, flood risk evolution should be assessed within the ICPR for the entire main stream of the Rhine, taking into account flood risk management measures that have been implemented.

The ICPR has developed an evaluation tool for reviewing both the APF and the FRMP Rhine Part A. The aim of the calculations under the ICPR was to arrive at a quantitative conclusion.

The flood risk is the product of the damage potential and flood probability. In accordance with the FD, a distinction is made between human health, the environment, cultural heritage and economic activity. In terms of all four receptors, the focus lies upon the direct consequences of, or damage from, flooding[1].

In order to determine the flood risk for the four receptors, the national details taken from the flood risk maps for the Rhine in accordance with the FD (see Rhine Atlas 2015) are used in the calculations. In addition, theoretical, planned or implemented measures according to the categorisation of the FD (see "Guidance for Reporting under the Floods Directive (2007/60/EC)") are reviewed, and their impact on the evolution of the risk is assessed.

In terms of human health, the number of people affected in the event of a flood is used as a parameter.

In terms of environment and cultural heritage, a different approach is taken, whereby a classification based on the combination of water depth categories and categories relating to the vulnerability of potentially affected protection areas as well as the significance of cultural heritage, is used. This provides a matrix, through which the potential damage can be assessed.

In determining the risk with regard to economic activity, Corine Land Cover (CLC) - land usage maps are used together with flood hazard maps in accordance with the FD (see Rhine Atlas 2015), which are available for the entire main stream of the Rhine, although the individual states usually use detailed, domestically available land usage data. As regards economic activity, a monetary risk is determined based on the flood level corresponding with a certain flood probability/return period and existing economical value.

Measures which have an impact on flood risk can be divided into measures that have an impact on flood probability[2] and those which have an impact on the potential adverse consequences/damage.

Within the framework of the FD, categories of measures have been established at EU level. For the categories of measures utilised here, the following main classifications apply: "Prevention",

[1] Estimations of consequential losses e.g. due to interruptions to production are thus not undertaken.

[2] For determining the (modification of the) flood probability level, reference is made to the ICPR Report No. 229.

"Protection" and "Preparedness". Both categories "Prevention" and "Preparedness" comprise measures that above all limit the potential impact. For example these involve non-structural measures, awareness, the preparation of forecasts, communication and crisis management. The measures under "Protection" primarily serve to alter the flood probability level, by lowering the water level, for example, through measures such as retention areas, dike relocations, etc.

In order to monitor the status of the implementation of planned measures, so-called 'indicators' have been defined. These should

- be representative of larger groups of measures, and
- also be measurable using the existing data basis.

The relationship between the degree of implementation of the measure and the consequences has been defined for each indicator. Where possible, this is undertaken on the basis of quantified data, but also on the basis of expert judgement. The effectiveness of a measure is the result of the combination of its maximum effect and the degree of its implementation over the time period and per area.

Geographic Information Systems (GIS) offer excellent opportunities to combine different types of information and data in order to conduct a risk analysis. The ICPR therefore commissioned the consortium HKV Hydrokontor and HKV Lijn in Water to develop such an instrument for GIS applications.

1. Method for evaluating the effects of measures on the flood risk

In Section 1, the method and results of the calculations for the time periods leading up to 1995, 2005, 2015, 2020 and 2020plus[3] (~2030) are presented for the four receptors: human health, the environment, cultural heritage and economic activity.

1.1 Calculation method

The ICPR has developed a quantitative **method for determining the flood risks and the effects of risk mitigation measures**. This was used for the evaluation of the evolution of flood risks with regard to the Rhine in the period 1995-2015 and/or to 2020 as part of the implementation of the Action Plan on Floods and for the regular review of the effects of measures on flood risks within the FRMP Part A for the Rhine. With the appropriate data basis, the method can also be used in other (sub)catchments, however. This method has been implemented as a GIS application.

[3] Measures of the APF/FRMP, which will be implemented after 2020. Referred to in document as state of development 2030.

The FD together with the flood hazard maps (FHM) at low, medium and high probability (hereinafter referred to as HQextreme, HQmedium, HQhigh) with the respective flood depths and for different types of measures, form the basis of this method. Furthermore, the data from the flood risk maps (FRM) for the four receptors (human health, environment, cultural heritage, economic activity) is used in the calculations. The basic procedure is shown in Figure 1. Here, the flood risk is the product of the potential damage and the flood probability.

The HKV consortium and the ICPR have performed calculations regarding the damage and risk for the four receptors: human health, the environment, cultural heritage and economic activity, for the periods leading up to 1995, 2005, 2015, 2020 and 2030. In addition, the effects of various measures were calculated.

In order to quantify the impact of measures on the evolution of flood risk for the different receptors, indicators were defined. These indicators should be representative for a group of measures and be quantifiable.
The relevant states have collected data for the realisation or the planned implementation of these measures/indicators for different time periods (up to 1995, 2005, 2015, 2020, 2030). This data was gathered together by the ICPR.

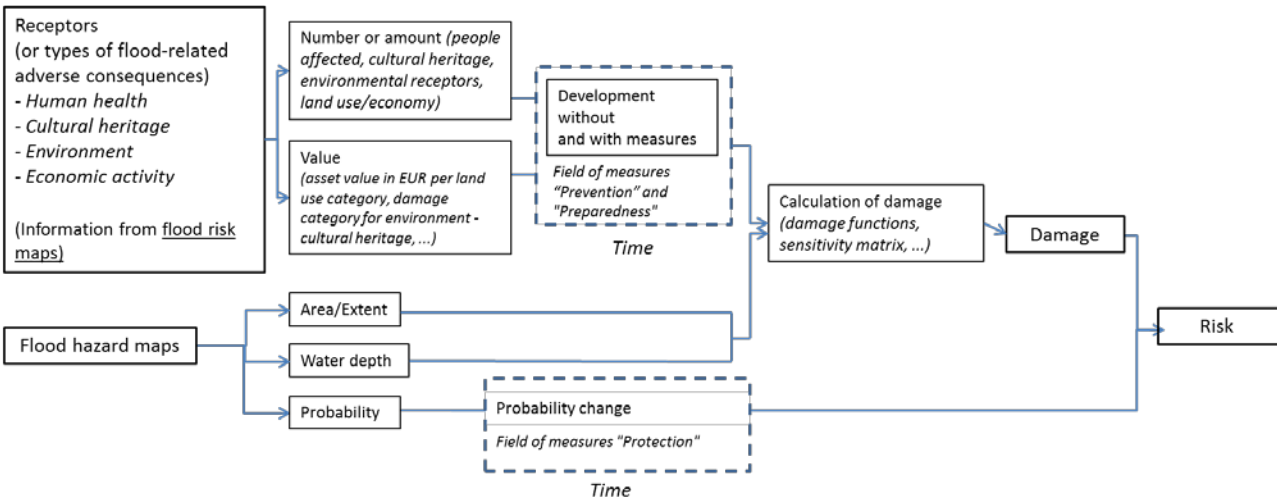

Figure 1: Risk analysis procedure

When considering the effects of measures on the reduction of the general flood risk, it is important to distinguish between the potential damage and the flood probability. The overall effect of measures on the evolution of damage, flood probability and flood risk can be seen in Figure 2 (as well as in Annexe 1).

In general, it should be noted that the non-structural measures in the spheres of "Prevention" and "Preparedness" serve to decrease damage, i.e. subdue the growth in damage usually incurred in the period. Measures that fall under the sphere "Protection" may also have the effect of reducing damage, by reducing the extent of flooding through the reduction of water levels. However, in the present investigation the protection measures were only considered in terms of the change/reduction in the flood probabilities due to implemented or planned measures to lower the water level/retention measures (cf. Section 1.6). This has an impact on the risk and not on the damage. The reduction of damage and thus the reduction of the flood risks in the present study may therefore be an underestimation. The reason for this is that data on the extent of flooding is only available on the basis of the 2015 situation and not for other time periods. The future evolution of flood probability without any measures undertaken is dependent on the influence of climate change. The possible effects of climate change on discharges have not been considered in this study.

If damage, flood probability and measures are combined, this results in a change in the flood risk.

This observation applies to **all four receptors**.

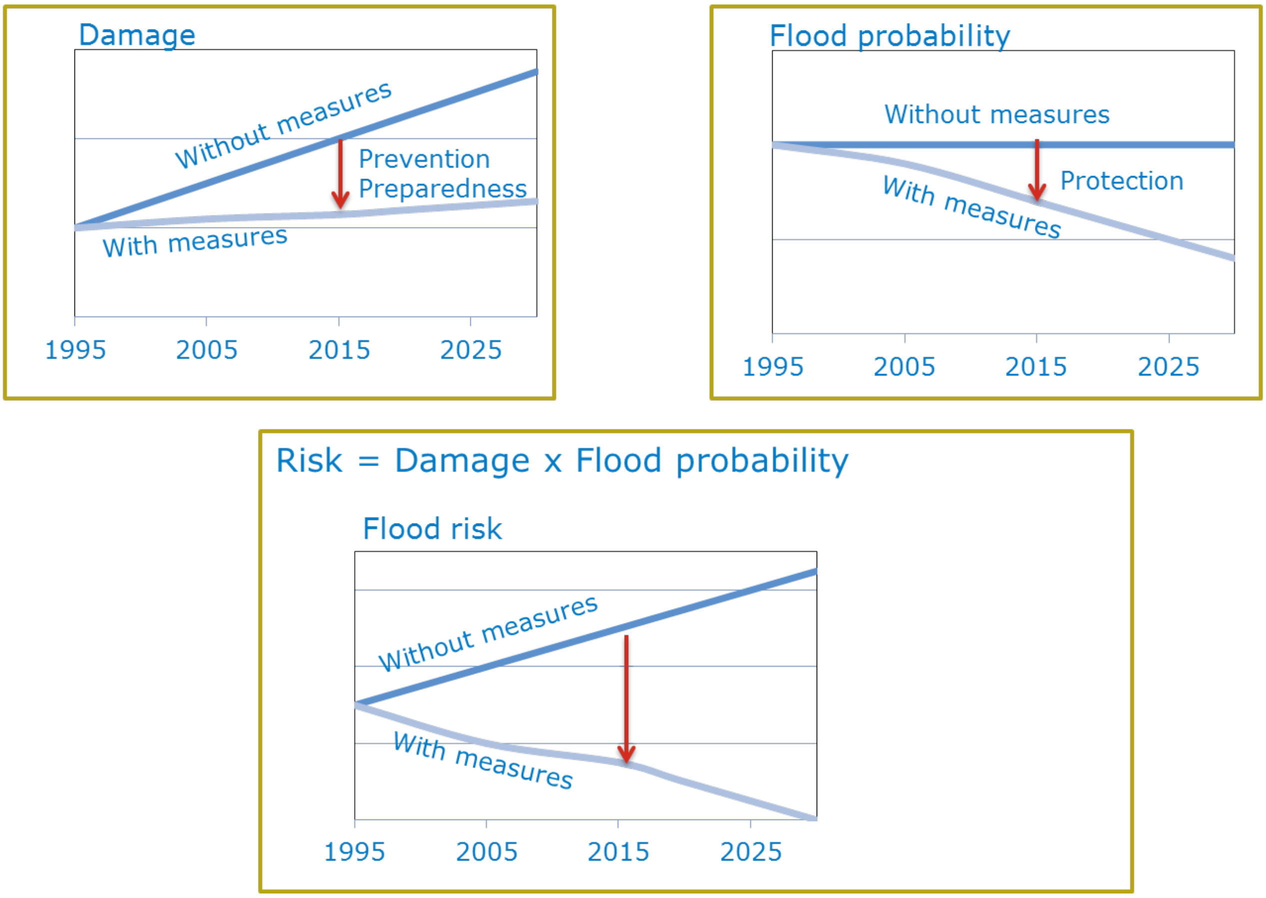

Figure 2: Definition of flood risk and impact of different measures

The specific methodology for estimating flood risks and the impact of measures on the evolution of these risks, and the large-scale communally available databases used for the Rhine catchment may deviate from national calculation methods and results which are based on a more accurate data basis (e.g. within the context of flood risk management planning). The method calculates absolute values for the risks, however more reliable relative changes are represented.

1.2 Human health

The methodology for the review of the receptor "human health" is shown in Figure 3.

In the first stage, the relevant affected population density is separately determined for each flood scenario in accordance with water depth categories.

For these calculations, human health is defined as the number of people potentially affected by flooding in the corresponding flooded area. In this way, measures such as land use control or precautionary building, which have a varying effect on the number of people affected for different time periods, can also be taken into account.

In the second stage, this information determines the number of people per region who can be evacuated in advance of potential flooding (= "safeguarding rate") and therefore are no longer in danger. This "safeguarding rate" can be improved through measures such as raising awareness, forecasts, warnings and crisis management.

The risk is calculated as follows:
Risk for human health = number of people affected x (1 - safeguarding rate) x probability [frequency/year]

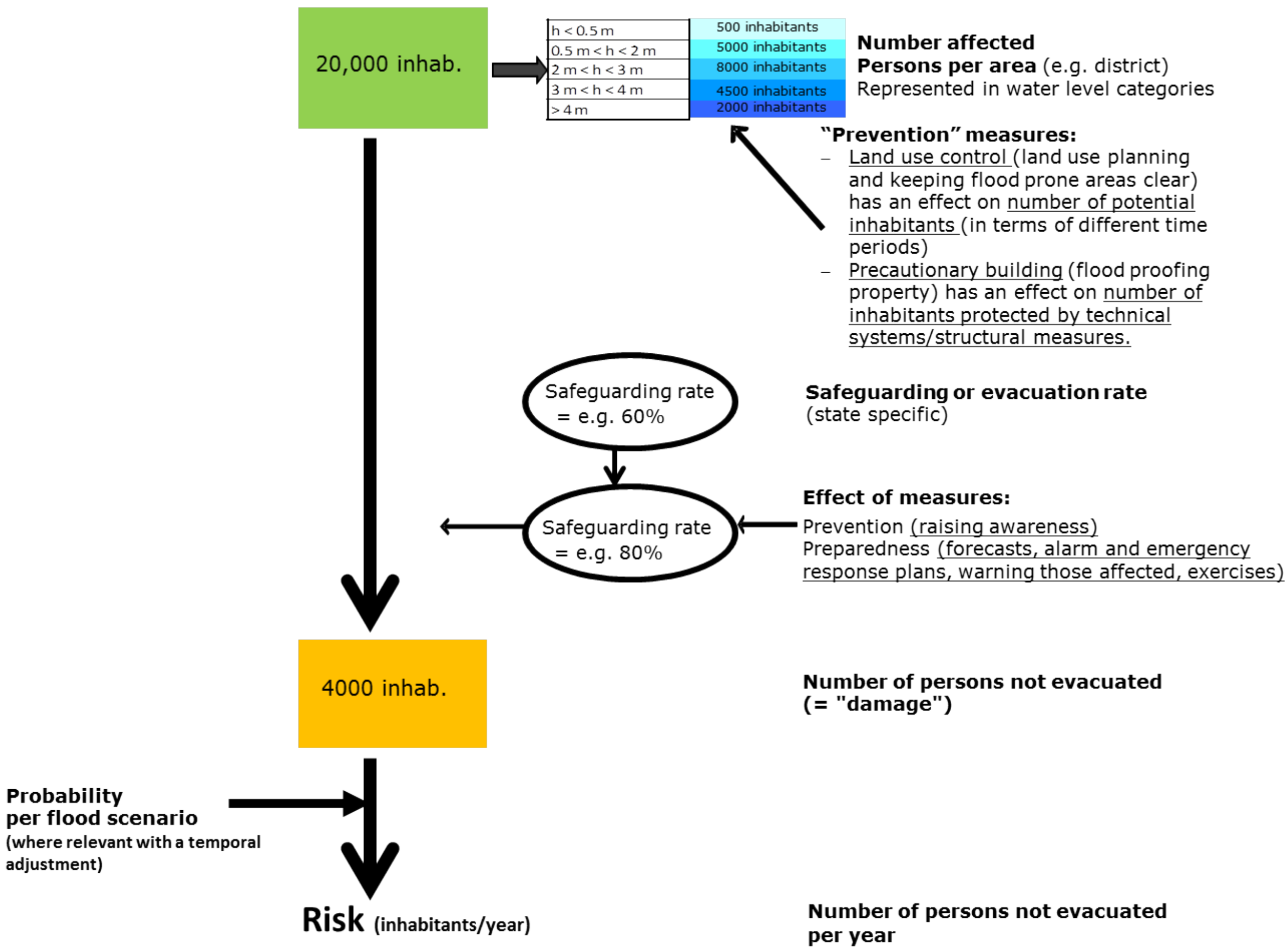

Figure 3: Flood risk analysis and impact of measures for "human health"

1.3 Environment

This new method for assessing flood-related risks to the environment[4] assumes that it is not the flood itself, but rather the flooding of installations and facilities triggered by the occurrence of flooding, that causes damage to surface water bodies with a good or very good ecological status and to areas protected under the WFD[5]. Negative consequences are understood to be the contamination of bodies of water and of flooded areas from installations that have the potential to contaminate (IPPC plants[6], SEVESO operation areas[7] and water treatment plants), due to flooding. Possible damages caused by the direct effect of flooding on the environment are not included in the study.
The assessment of the damage to the environment takes place in 2 stages (cf. Figure 4):

- In the first stage, the pollution potential of the facility is combined with the water depth. The highest pollution potential and the greatest water depth constitute the highest threat. For each facility and each flood scenario, the respective threat is determined and a qualitative scale (1 to 5) assigned.
- In the second stage, the ecological significance of a protected area is combined with this threat.

This assessment produces three damage categories: "low", "medium" and "high", as well as an index for each protected area. For the present study, the damage indices for each flood scenario and time period are added together (= cumulated damage index)
The multiplication of the cumulated damage index with the flood probability produces the risk (= cumulated damage index per year).

For the receptor "environment", the measures "precautionary building/flood proofing property" and "flood-proof storage of water-polluting/hazardous substances" are taken into account (cf. Annexe).
The better a facility is protected against flooding, the smaller the potentially affected downstream area and the lower the risk that a discharge point for drinking water and/or a protected area is affected.

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[4] *This simplistic approach to the large-scale assessment of flood risks differs in part significantly from the analyses of flood risk for such facilities undertaken within the context of flood risk management.*

[5] Annexe IV, Point 1 Paragraphs i and v of the Directive 2000/60/EC: Drinking water and water source protected areas, water-dependent flora & fauna habitat protected areas, water-dependent bird protected areas *(the last two are also called "Water-dependent Natura 2000 sites").*

[6] Facilities as per directive 96/61/EC concerning integrated pollution prevention and control (IPPC directive; now directive on industrial emissions - IE). In the further development of the instrument, IE plants should be considered in the future.

[7] Operating areas as per directive 96/82/EC on the control of major accident hazards involving dangerous substances (also colloquially termed Seveso II directive). Since 1st June this has been replaced by directive 2012/18/EU (Seveso III directive or Accidents Directive).

Contamination potential	Plants
1 (low)	
2	IPPC, water treatment plants
3	SEVESO1
4	SEVESO2
5 (high)	

Water level categories	
1	h < 0.5 m
2	0.5 m < h < 2 m
3	2 m < h < 3 m
4	3 m < h < 4 m
5	> 4 m

Ecological significance scale		Threat*				
		Low → High				
Ecol. sensitivity	Type of protected area	1	2	3	4	5
Low	Water-dependent bird protected areas, Other (various other undefined environmental protection assets)	1	1.5	2	2.5	3
Intermediate	Water-dependent flora & fauna habitat protected areas, Surface water bodies (WFD)	1.5	2	2.5	3	3.5
High	Drinking water and water source protected areas	2	2.5	3	3.5	4
	Damage category (DC)	low	Intermed.	high		

** Threat = (contamination potential + water level category)/2*

Figure 4: Method of assessing the damage to the environment

1.4 Cultural heritage

Damage to cultural heritage receptors can be quantitatively estimated by combining the significance of the relevant cultural heritage[8] (depending on diverse cultural heritage types: UNESCO World Heritage Sites, sites of historical significance, monuments) and the water depth. The matrix developed here enables a relative, not a monetary valuation.

If data for a defined significance/value of a cultural heritage object is combined with the water depth, a specific matrix is created for the assessment of the damage to cultural heritage receptors (cf. Table 1). Cultural heritage receptors with low significance in water levels of less than 2m can expect a low level of damage, whereas water levels of 2m or more lead to high or medium levels of damage.

The matrix evaluation provides a damage index for each cultural heritage object, falling into one of the three damage categories: "low", "medium" or "high". For this study, all of the

[8] A simplified method was developed based on the aggregated data base in this project for the large-scale assessment of flood risks. The selection of cultural heritage receptors and their classification in terms of "significance" therefore deviates from the approach within the framework of flood risk management planning – in places considerably.

damage indices for an object are added together across all damage categories (= cumulated damage index). The multiplication of the cumulated damage index with the flood probability produces the risk (= cumulated damage index per year).

Here, the same measures have an impact as is the case for the receptor "economic activity" (cf. Section 1.5), as presented in detail in the Annexe.

Table 1: Matrix for assessment of damage to cultural heritage receptors

Cultural significance scale	Physical impact scale (water level)				
	1 h < 0.5 m	2 0.5 m < h < 2 m	3 2 m < h < 3 m	4 3 m < h < 4 m	5 >4 m
1 local significance (monuments, other)	1	1.5	2	2.5	3
2 national significance (protected urban areas/sites)	1.5	2	2.5	3	3.5
3 international significance (UNESCO world heritage site)	2	2.5	3	3.5	4

Damage category (DC)	low	intermediate	high

1.5 Economic activity

The economic potential damage is calculated based on land use maps (in this case, Corine Land Cover Maps = CLC2006) and the three water depth maps for the three flood scenarios, using damage functions "water depth-damages[9]" and financial assets (taken from the ICPR Rhine Atlas 2001) for the categories: settlement, industry, transport, agriculture and forest. Financial assets are adjusted (in terms of time) for the actual situation/period, using the rate of economic growth and/or the consumer price index. The multiplication of the damage with the flood probability, which may also change due to the relevant implementation of additional water level-reduction measures (cf. Section 1.6), produces the risk (cf. Figure 5).

Indirect economic damage due to production stoppages in the affected businesses or due to the interruption of supply chains are not taken into account. This damage may sometimes, for example in the automotive sector, exceed the direct potential damage by several orders of magnitude. Within the framework of the large-scale analysis of flood risks intended by this study, detailed data – which would have been required for the calculation of indirect economic damages with the basic approach taken here at a micro level – was not available.

9 For this large-scale approach, the flow velocity is not taken into account.

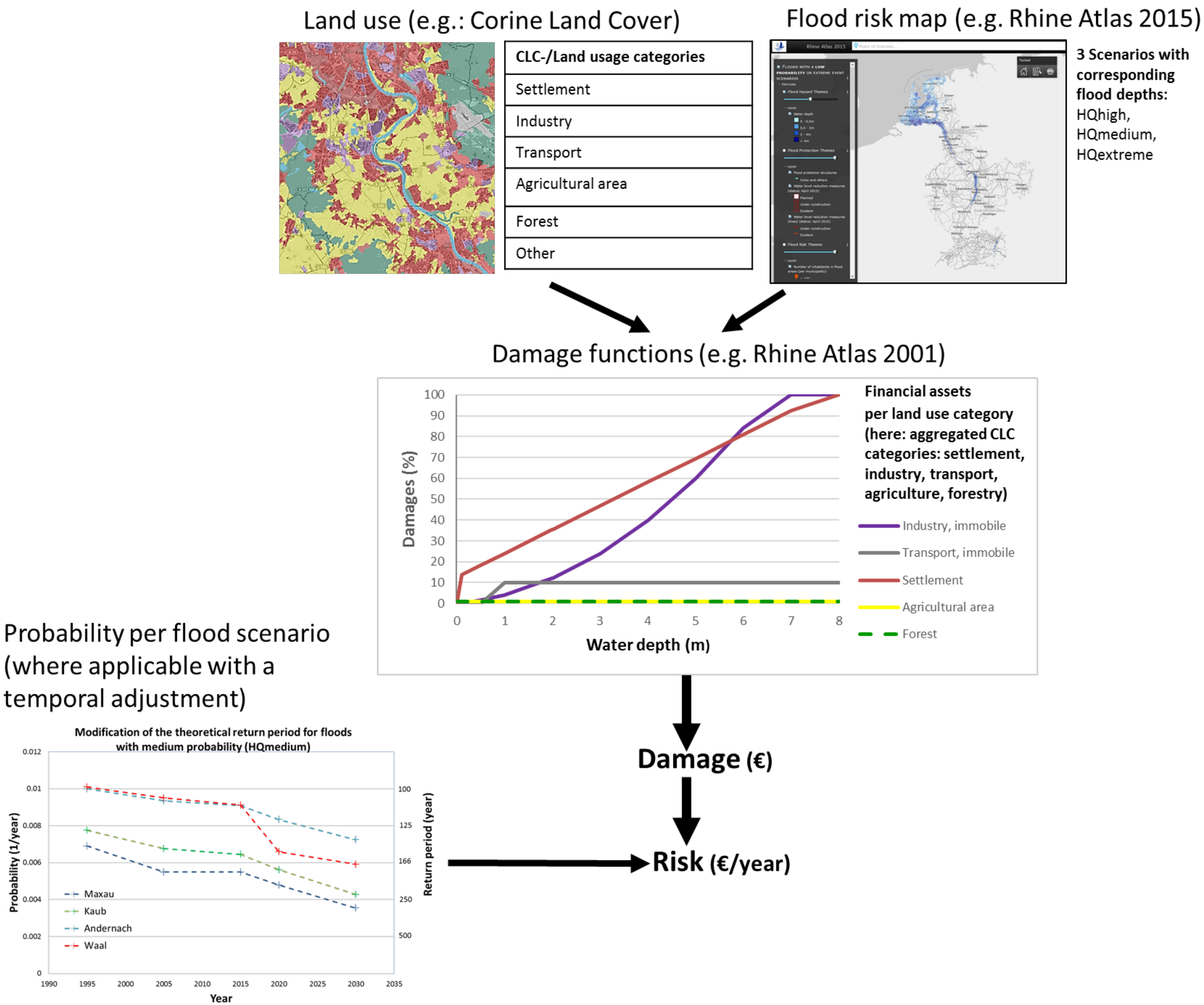


Figure 5: Approach for the analysis of the flood risk upon economic activity

1.6 Change in flooding probability due to flood-level reducing measures

Only the technical protection measures have an effect on the evolution of the risk, by changing the flood probability.

The flood protection measures already implemented and those yet to be implemented in the future within the context of the APF up to 2015, and the forthcoming implementation of the FD, have been taken into account in the present analysis by calculating the change in the probabilities.

After the ICPR evaluated the effectiveness of both the realised and planned flood-reducing/water level-lowering measures for the Rhine (retention measures, measures from "Room for the River" in the Netherlands) (cf. ICPR Report No. 199), the ICPR developed a method to estimate the change in flood probability (cf. ICPR Report No. 229).

It should be emphasised here that the water level-reducing measures taken into account relate to the stretch of the Rhine downstream from Basel, i.e. the change in probability was calculated using the level gauges from Maxau to the Dutch branches of the Rhine. Measures upstream of Basel, which influence the probabilities, were not taken into account in the analysis. It was assumed that the condition of the dyke at that time was sufficient, according to national standards. The actual condition of the dykes and consequently the later improvements (e.g. within the framework of the Dutch Delta Plan Grote Rivieren - DGR) were therefore not included in the calculation of probabilities in accordance with ICPR Report No. 229.

The results of the estimation of the change in flooding probability are modified return periods for floods with a high, medium and low probability (HQhigh, HQmedium, HQextreme) for the time periods or development conditions leading up to 1995, 2005, 2010[10], 2020 and 2030 (cf. detailed values and information in ICPR Report No. 229).
These probabilities are entered as data into the present calculation of the risk using the instrument/tool (cf. Figures 7-9).
In general, the results show that reductions in the water level due to various water level-reduction measures on the Rhine also cause a reduction in flood probability, which conversely means that the return period increases.

[10] In the present risk calculations, the 2010 development condition was used for the time period up to 2015.

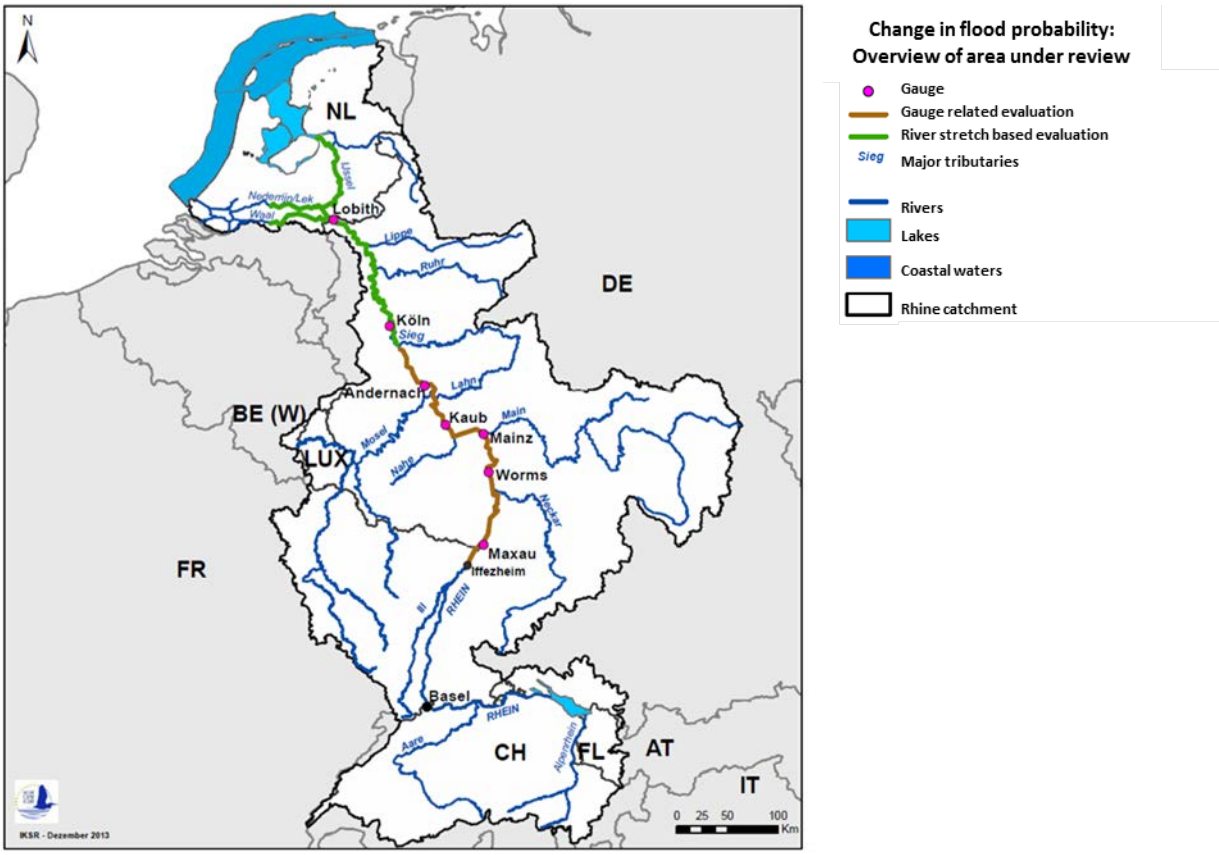


Figure 6: Overview of gauges within the framework of assessing change in probability

At four selected gauges (cf. map in Figure 6: three gauges in Germany and one on the Dutch branch of the Rhine "Waal"), the probabilities (left-hand Y axis) and the return periods (right-hand Y axis) are shown for HQhigh, HQmedium, HQextreme in the three graphs below for various years. The three Figures 7, 8 and 9 correspond to HQhigh, HQmedium and HQextreme.

The reduction of the water level achieved or yet to be achieved via retention measures and measures relating to more room for the river produces the result that the flood probability is lowered, and therefore the flood risk will also continue to decline.

Illustrative example - Figure 7: The red dashed line (Waal) shows a temporal change in the return period for HQhigh, from a 10-year period in 1995 to a 12-year period in 2030, i.e. by reducing the flood probability, a HQhigh event becomes rarer.

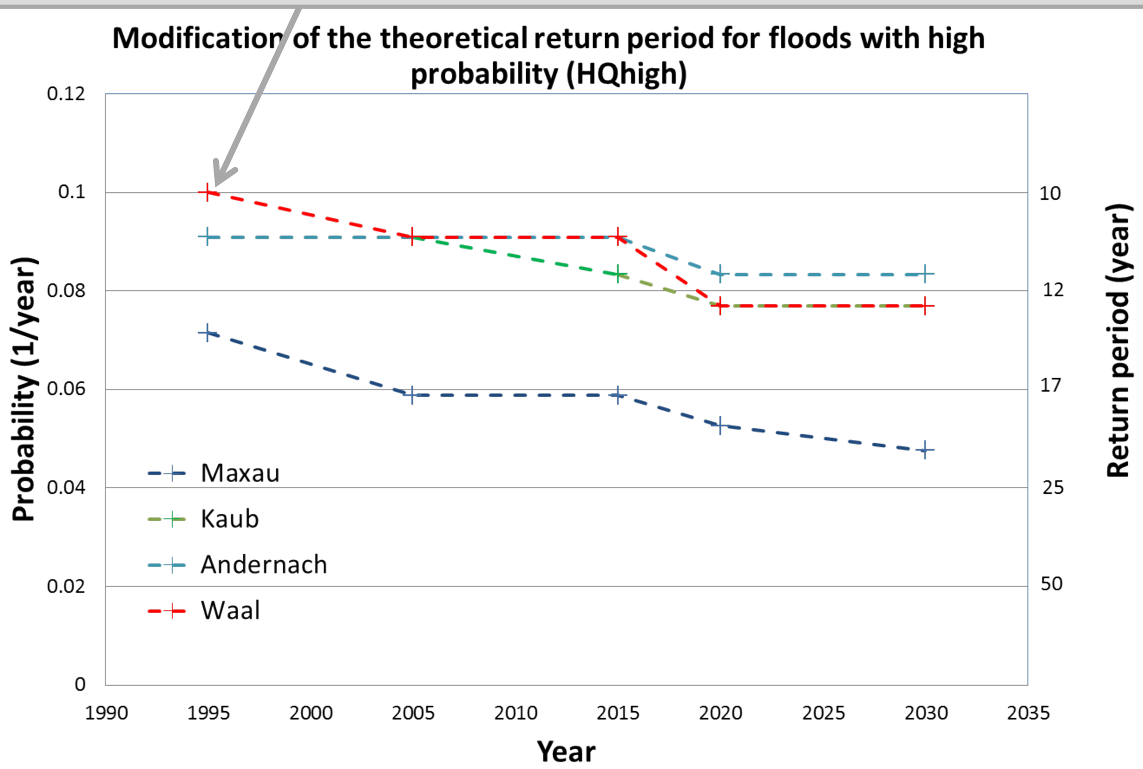


Figure 7 - Probability - (left hand Y axis) and Change in return period (right-hand Y axis) for HQhigh scenarios for different years and at four different gauges (Rhine/Waal)

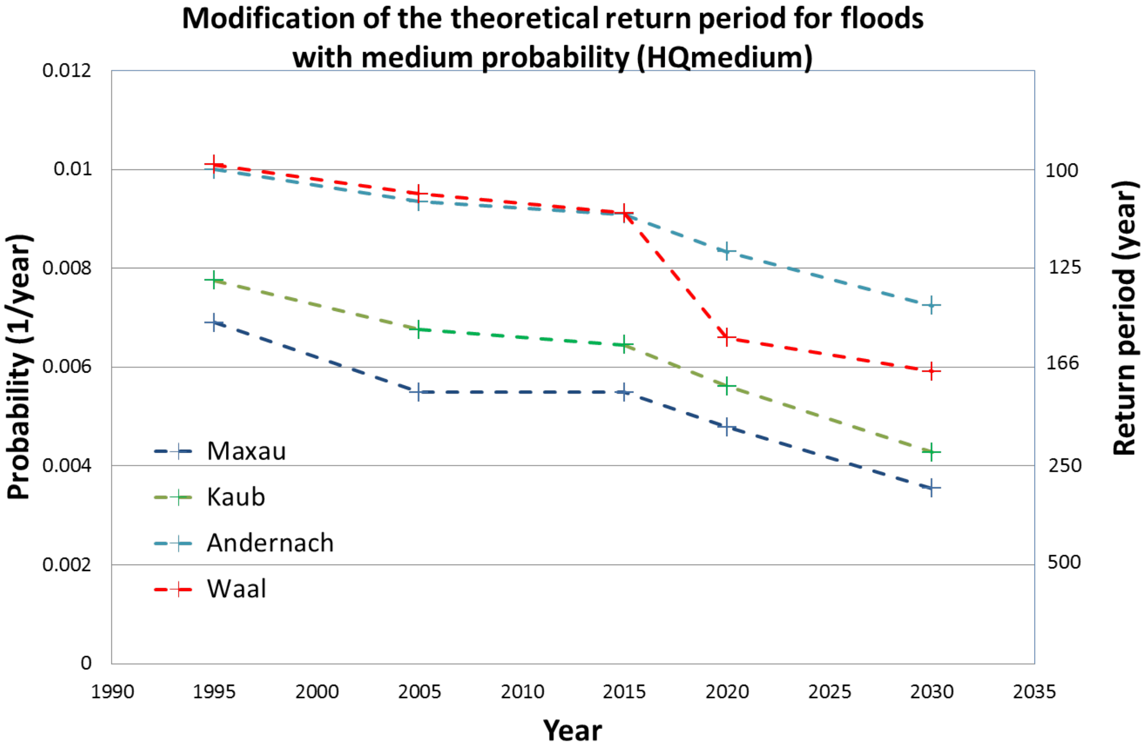


Figure 8 - Probability (left hand Y axis) and Change in return period (right-hand Y axis) for HQmedium scenarios for different years and at four different gauges (Rhine/Waal)

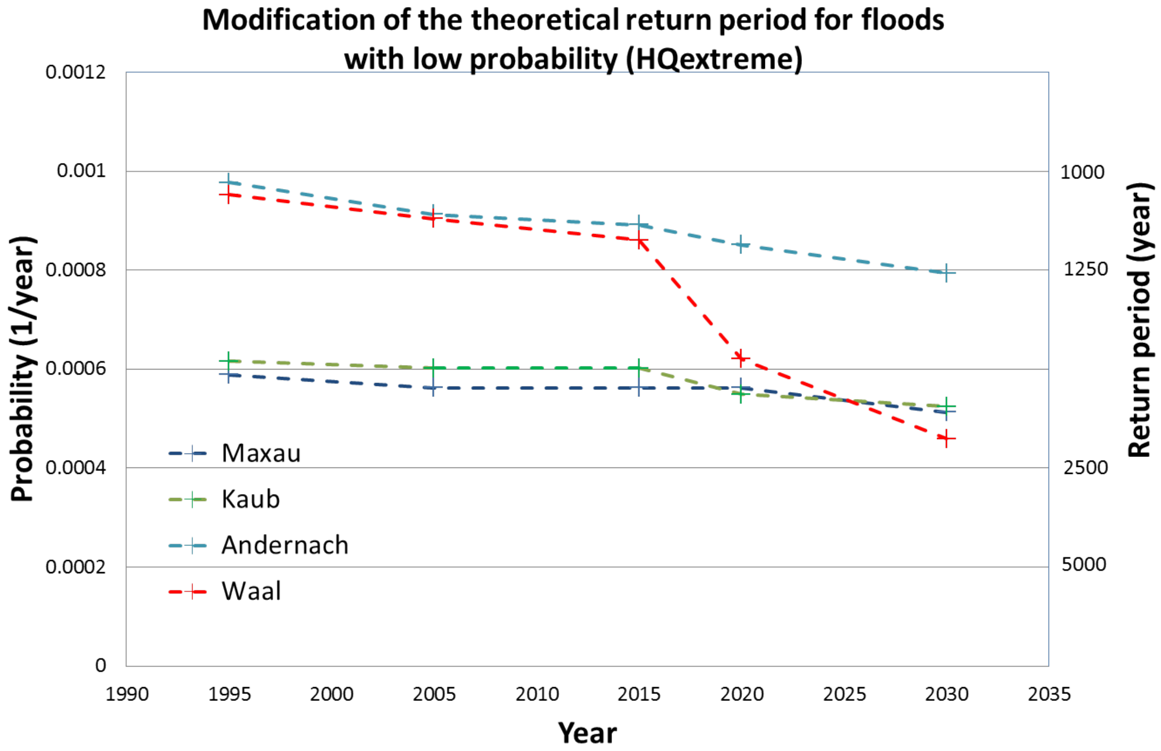


Figure 9 - Probability (left hand Y axis) and Change in return period (right-hand Y axis) for HQextreme scenarios for different years and at four different gauges (Rhine/Waal)

2. Results of evaluation

In Section 2, the method and results of the calculations for the time periods leading up to 1995, 2005, 2015, 2020 and 2020plus (~2030) are presented for the four receptors: human health, the environment, cultural heritage and economic activity. The results are presented in relation to the attainment of the action target 1 of the APF (= reducing the risk of damage by 10% in 2005 and 25% in 2020 in comparison to 1995[11]) and the objective/aim of reducing/reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods within the framework of the FD.

2.1 General

The essential aspects and conclusions of the evaluation of the calculation results for the four receptors at the level of the entire main stream of the Rhine are summarised in Sections 2.2 to 2.4.

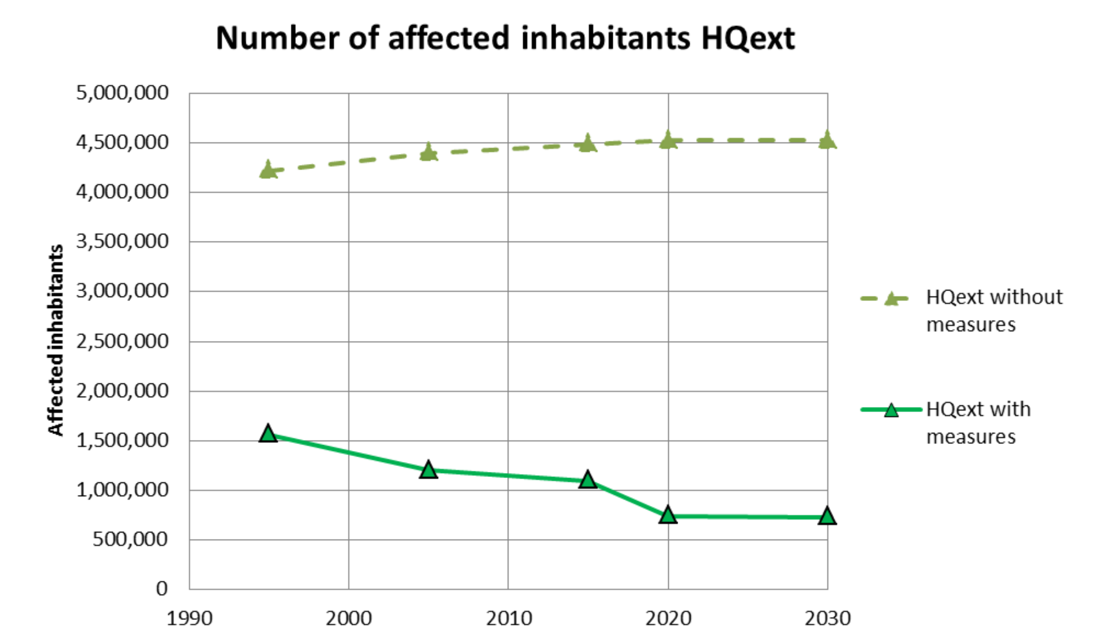
In general it can be said that the combination of measures for reducing damage, and the change in the probabilities by realising water level-reduction measures, leads to a reduction in the risk during the period for the 4 receptors.

The ICPR methodology for human health, the environment and cultural heritage is to a certain extent experimental, and may differ from national findings.
Indeed, absolute values for the risks are being calculated for the four receptors; however relative changes are seen to be more reliable.

[11] Assumed status in 1995: no measures

2.2 Human health (persons potentially affected)

The population (= people potentially affected during floods) increases or remains the same throughout the period under review (1995-2030) without measures (cf. Figure 10). Most of those affected are detected in the event of extreme flooding, because the flood area is largest in this scenario.



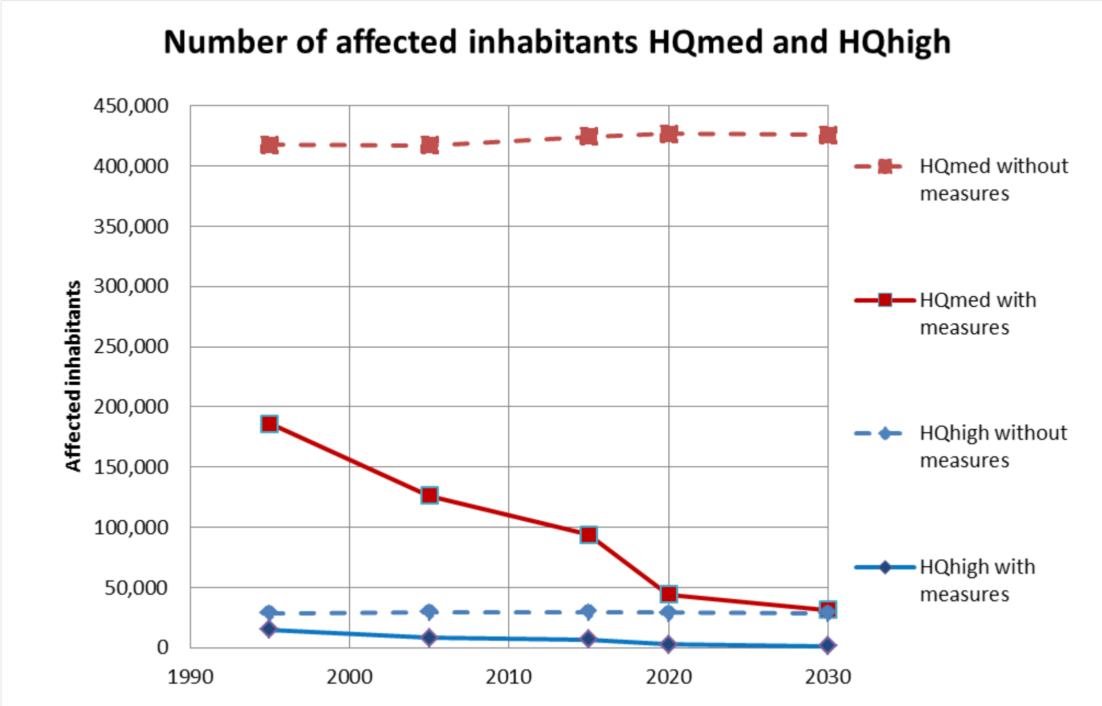


Figure 10: Changes to the number of people affected by flooding

For the period under review, the risk is reduced, mainly due to the impact of measures such as safeguarding/evacuation, as well as the change in probability through the implementation of water level-reduction measures. The highest risks for human health (= number of people potentially affected) according to the calculations, are in the event of HQmedium and HQextreme (cf. Figure 11 and Table 2).

Measures such as "land use control" and "precautionary building/flood proofing property" have relatively little impact on the number of people affected prior to the implementation of safeguarding measures (i.e. prior to evacuation, i.e. before people were brought to safety).

Table 2: Evolution of risk

	Relative risk change since 1995 (%)				Relative risk change since 2015 (%)	
	1995-2005	1995-2015	1995-2020	1995-2030	2015-2020	2015-2030
HQhigh	-45	-50	-85	-90	-70	-80
HQmed	-35	-50	-90	-95	-80	-85
HQext	-25	-35	-75	-80	-60	-70

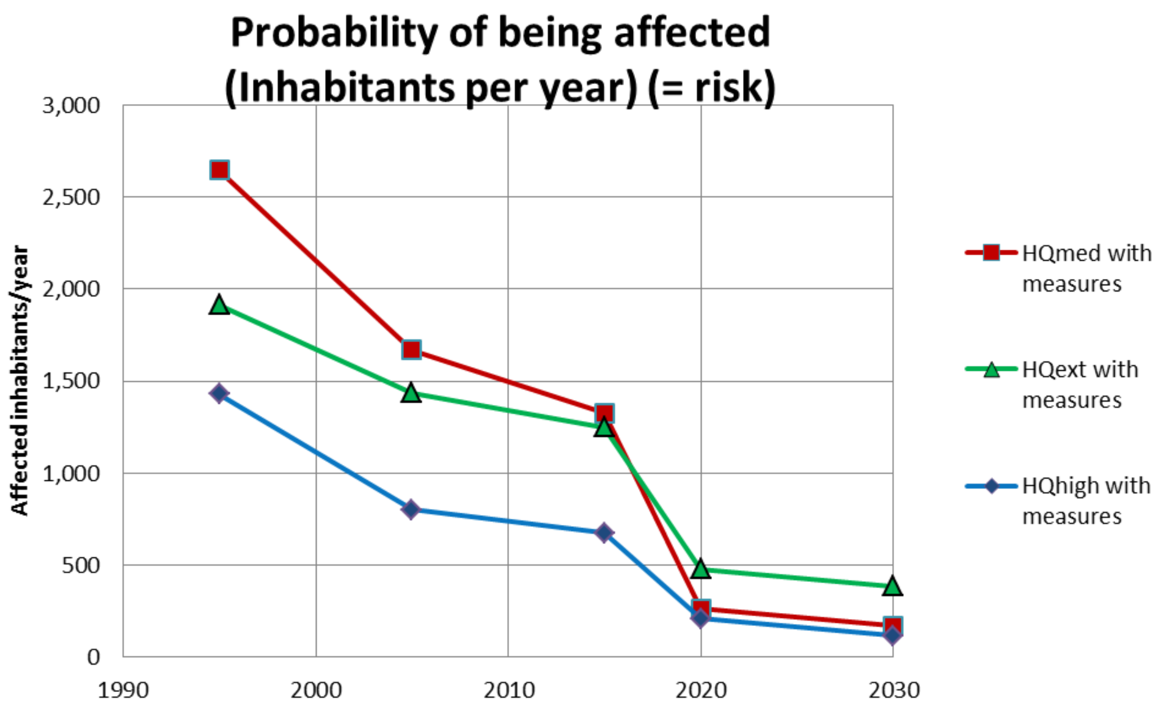


Figure 11: Probability of persons being affected, taking into account all measures (affected persons/year) (= risk)

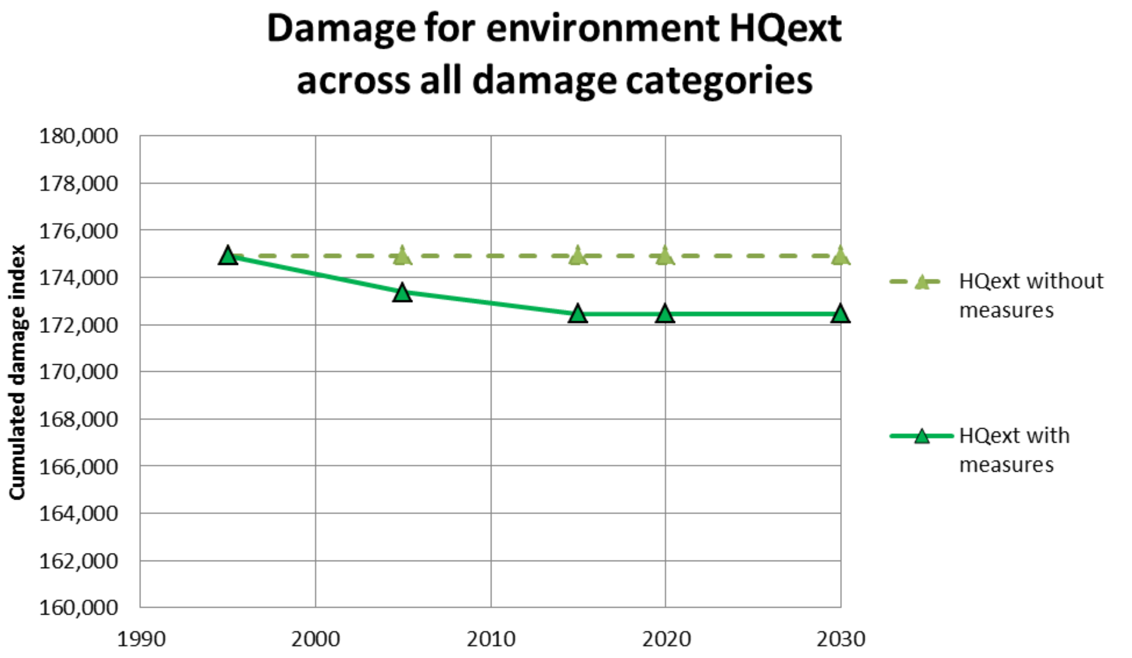
2.3 Environment

In terms of the environment, it is found that the accumulated damage index[12] (taking measures into account[13]) decreases slightly or remains the same for the period under review (1995-2030). Most damage is detected during extreme floods. Furthermore, the span of water-dependant protected areas is larger in the event of extreme flooding *(not depicted)*.

Through the measures taken ("precautionary building/flood proofing property" for industrial and water treatment plants and "Flood-proof adapted storage of water-polluting/hazardous substances in industrial plants and households), a reduction in the total damage to the environment in the period 1995-2015 can be achieved for the three flood scenarios. From 2015, there is no further reduction in damage, as the measures remain unchanged for the time periods ending 2020 and 2030 (cf. Figure 12).

[12] Cumulated damage index = sum of damages to the environment across all damage categories

[13] NB: Calculation of the potential damage to the environment without measures implemented is based on the same input data and therefore the same for all five time periods.



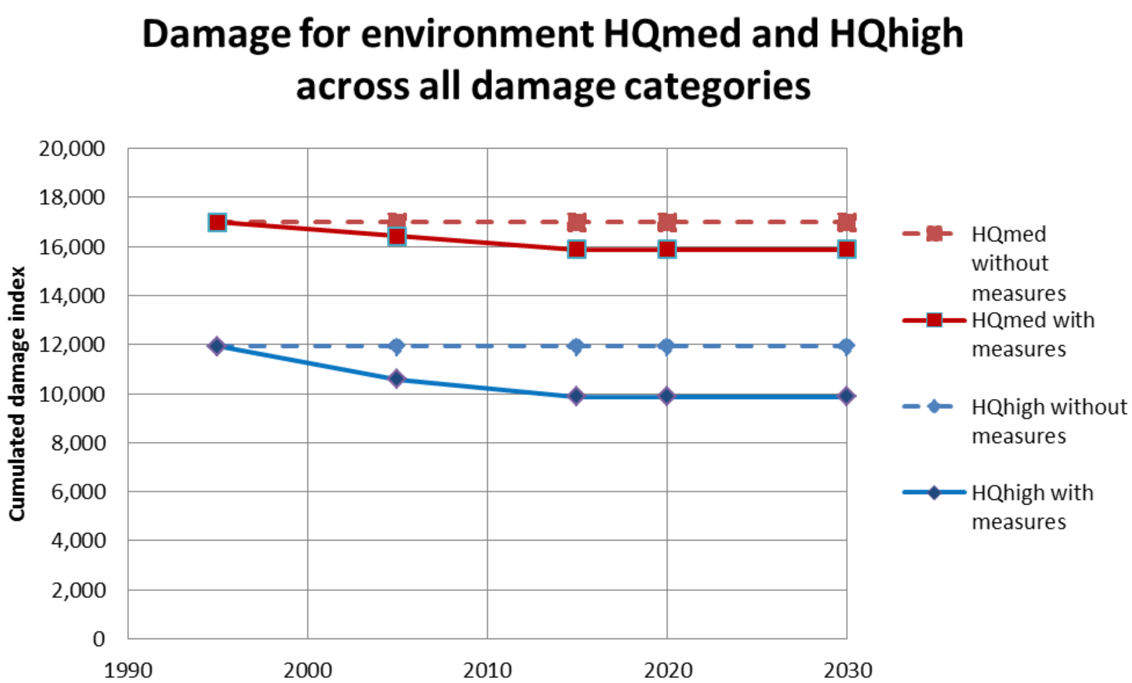


Figure 12: Evolution of potential damage to the environment (cumulated damage index)

For the entire period under review (1995-2030), there is a general change to the flood risk, with the reduction most marked between 2015 and 2020/2030 – contingent upon the changing probabilities. The risk is highest for HQhigh (cf. Figure 13 and Table 3). As with all receptors, the change in risk to the receptor "environment" is largely determined by the change in flood probability, in particular from 2020, downstream from Iffezheim.

Table 3: Evolution of risk

	Relative risk change since 1995 (%)				Relative risk change since 2015 (%)	
	1995-2005	1995-2015	1995-2020	1995-2030	2015-2020	2015-2030
HQhigh	< -5	< -5	-45	-45	-45	-45
HQmed	-5	-10	-70	-75	-70	-75
HQext	-5	-10	-65	-70	-60	-70

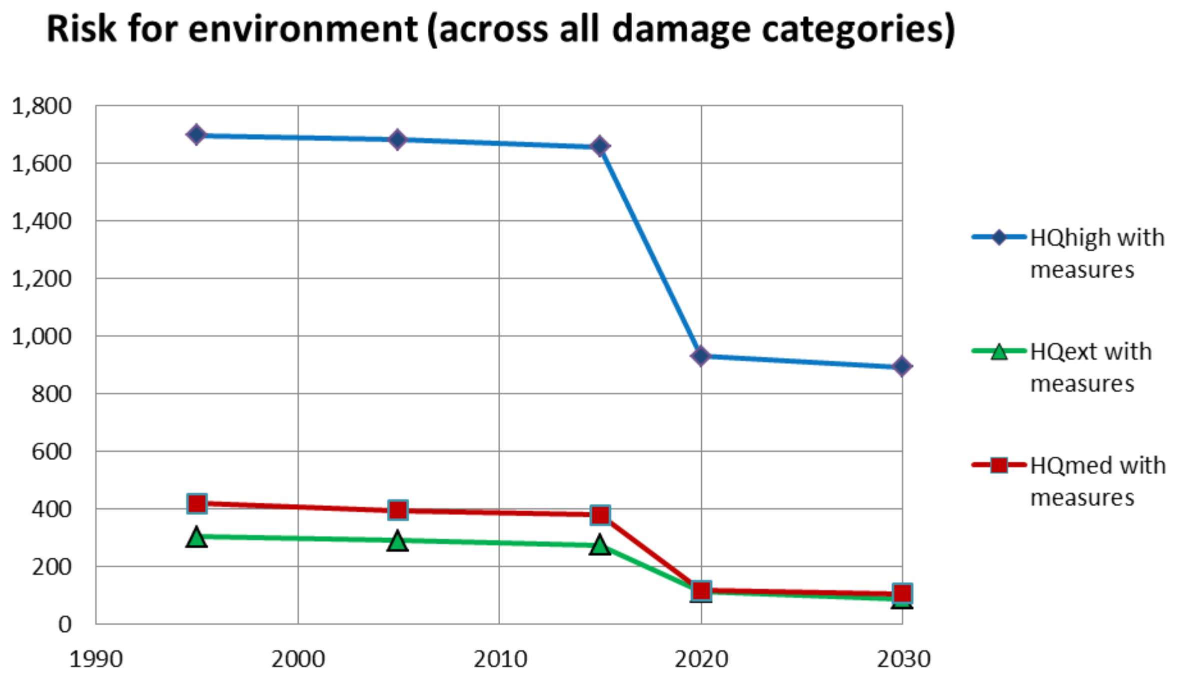


Figure 13: Evolution of risk taking into consideration all measures (cumulated damage index per year across all damage categories) (Y axis)

2.4 Cultural heritage

In terms of cultural heritage receptors, it is found on the basis of calculations that the cumulated damage index[14] (taking measures into account[15]) indicates a reduction for the period 1995 to 2005 and a (very) slight reduction in damage between 2005 and 2030. Here, most of the damage is demonstrated in the event of extreme flooding (cf. Figure 14).

Due to the implementation of measures, the risk is significantly reduced over time for all scenarios, i.e. by more than 50% by 2030 (here the highest damage is detected in the event of HQhigh) (cf. Figure 15 and Table 4).

The number or area *(not depicted)* of affected receptors increases with decreasing flooding probability, i.e. in the event of major floods, and – as with the other receptors – the change in risk is largely determined by the change in flood probabilities (in particular from the time period ending 2020) downstream of Iffezheim.

[14] Cumulated damage index = sum of damages to cultural heritage receptors across all damage categories

[15] NB: Calculation of the potential damage to the cultural heritage without measures implemented is based on the same input data and therefore the same for all five time periods.

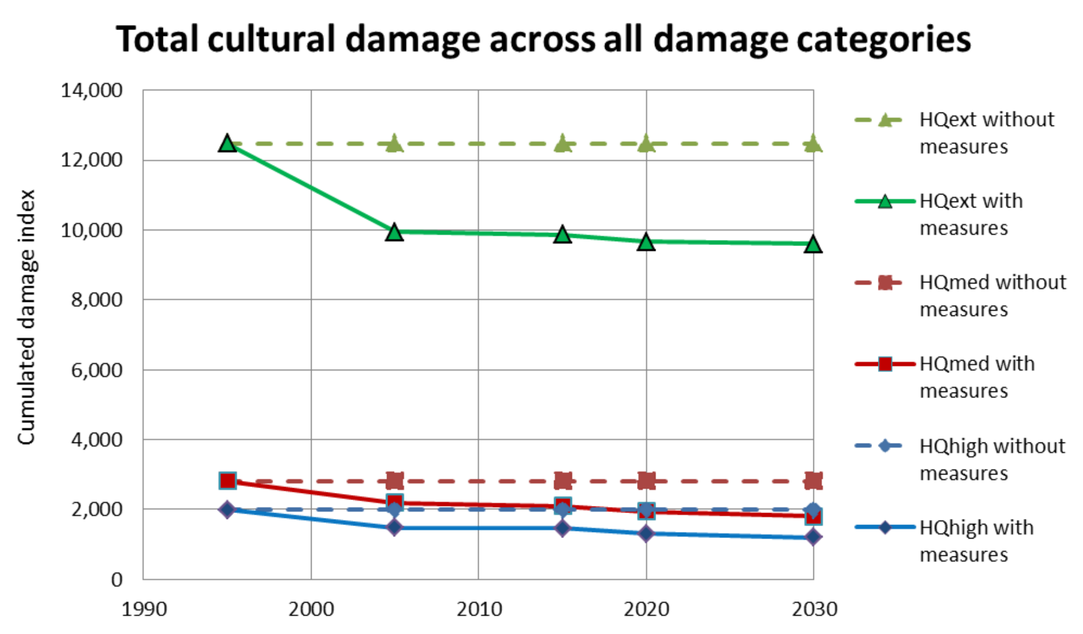


Figure 14: Evolution of potential cultural damage (cumulated damage index) (Y axis)

Table 4: Evolution of risk

	Relative risk change since 1995 (%)				Relative risk change since 2015 (%)	
	1995-2005	1995-2015	1995-2020	1995-2030	2015-2020	2015-2030
HQhigh	-15	-15	-50	-60	-40	-50
HQmed	-15	-20	-65	-70	-55	-65
HQext	-10	-15	-55	-65	-50	-55

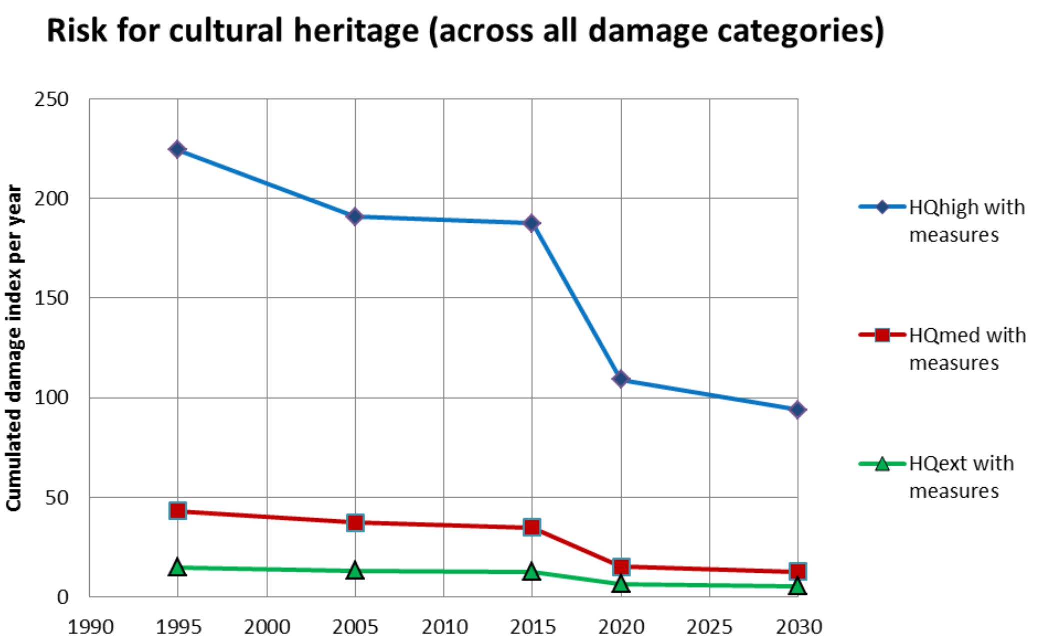


Figure 15: Evolution of risk taking into consideration all measures (cumulated average damage index per year across all damage categories)

2.5 Economic activity

The results for "economic activity" (economy) indicate that despite the fact that potential damage usually consistently increases over time (1995-2015, 1995-2020/2030 or 2015-2020/2030) due to economic growth, the greatest damage is found for low probability levels, i.e. in the event of extreme flooding (cf. Figure 16).

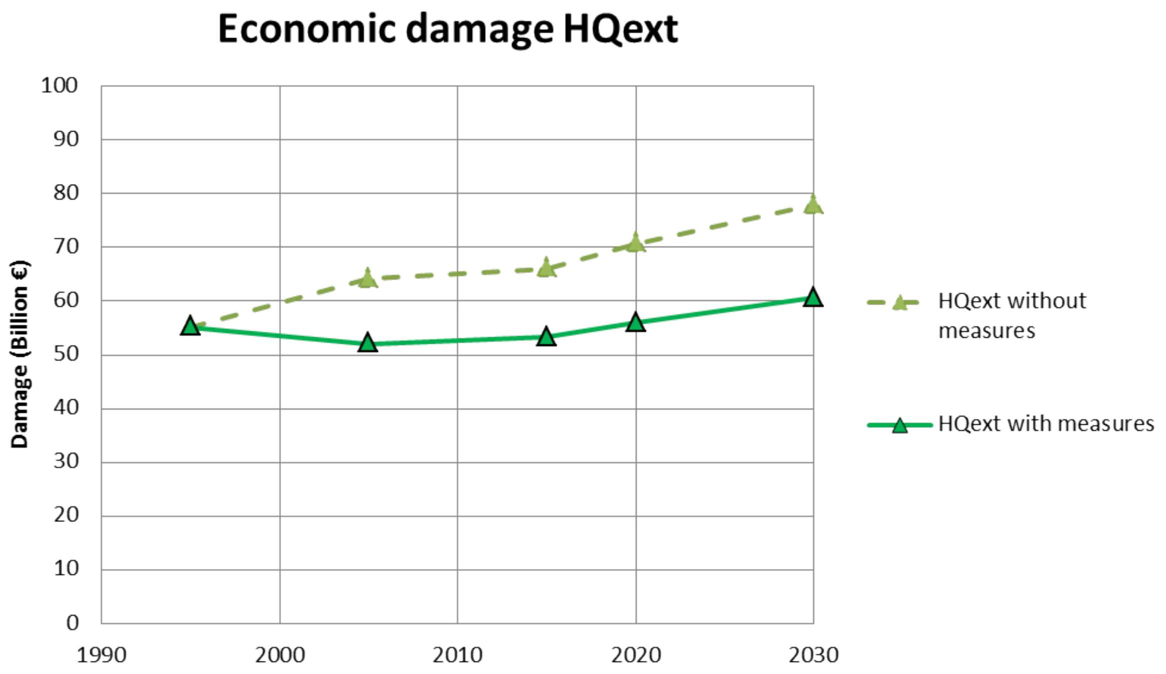
However, when the risk is considered, it is found that HQhigh demonstrates the highest risk. Over the total period (1995-2030), the risk is reduced for the 3 flooding scenarios (cf. Figure 17 and Table 5). As with the information regarding water depth and the extent of flooding, taken from national flood hazard maps in 2015 (cf. relevant explanations in Section 1.5), it is to be noted here that the damage calculations for all time periods for the description of land use were only carried out on the basis of the latest and most reliable land use data set (CLC 2006).

For this reason, the aspects specified above (evolution of water levels, extent of flooding and the evolution of land use over time) could not be taken into account in the temporal evolution of the damage, and concomitantly, the risk.

The results (Table 5) show that in terms of the **economy, it was possible to mathematically prove the APF target to reduce the risk of damage by 10% by 2005 in comparison to 1995. The same is true of the APF reduction target of 25% by 2020 in comparison to 1995.**

These findings confirm the previous ICPR investigations of the situation in 2005 as part of the implementation of the APF (see ICPR Report No. 157). These results are due to the implementation of various measures over time and their influence on the reduction of risk[16]. In particular, the many retention measures as well as measures from the Dutch programme "Room for the River" (through reducing water levels and the resulting change in probability), which should be realised downstream of Iffezheim in the period leading up to 2020 and/or 2030, contribute considerably to reducing the risk of flooding along the main stream of the Rhine. In addition to measures to lower the water levels, various other measures in terms of prevention and preparedness, including flood forecasts, early warning systems and (the preparation of) crisis management, have contributed since 1995 to the weakening of damage growth in flooding areas (cf. Figure 16).

[16] Damage reduction is more effective, however, in the event of HQhigh and HQmedium (slight increase in damage over time) than in the event of HQextreme (higher increase in damage over time).



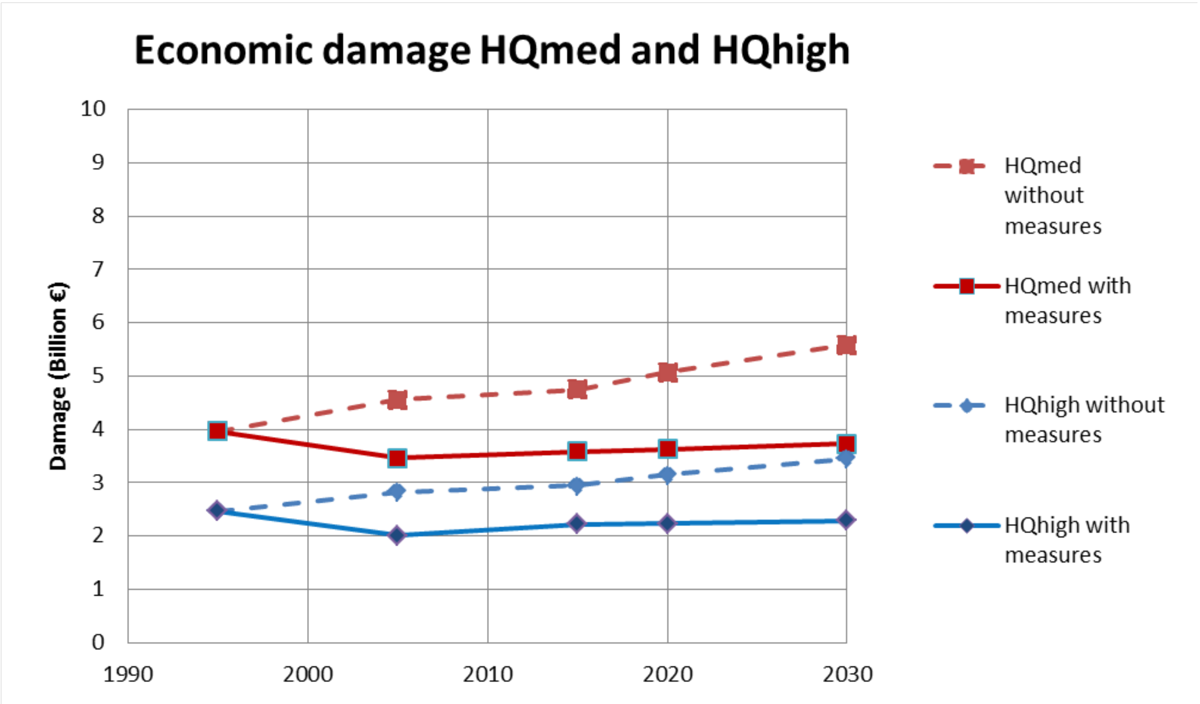


Figure 16: Scale of damage progression (billion Euros)

Table 5: Evolution of risk

	Relative risk change since 1995 (%)				Relative risk change since 2015 (%)	
	1995-2005	1995-2015	1995-2020	1995-2030	2015-2020	2015-2030
HQhigh	-15	-10	-30	-30	-20	-20
HQmed	-15	-15	-50	-55	-40	-45
HQext	-10	-10	-45	-50	-40	-45
Integral	-10	-10	-45	-45	-35	-40

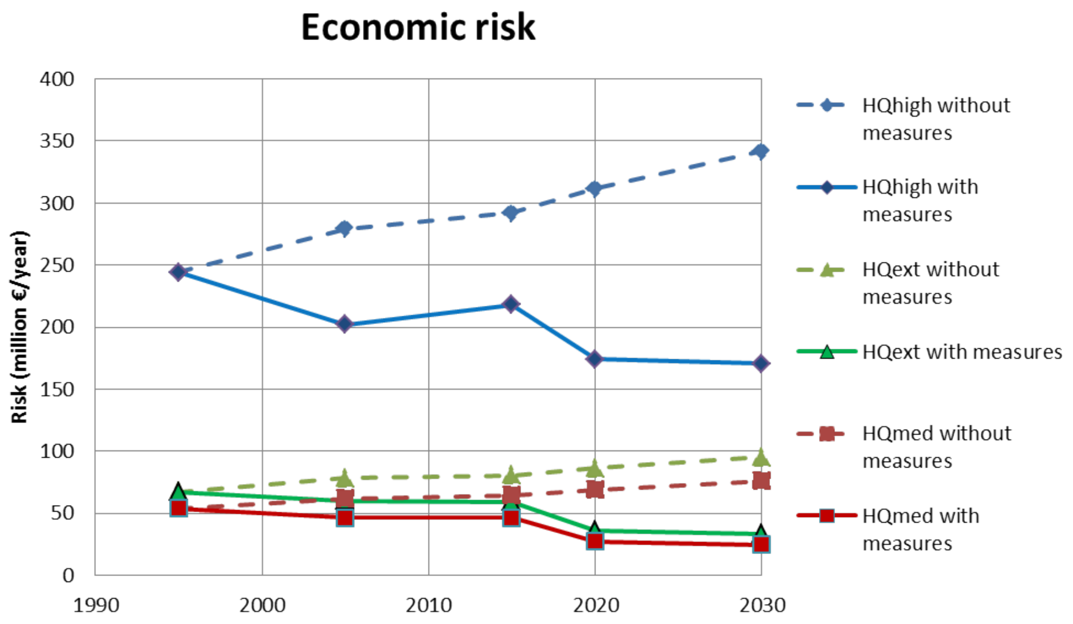


Figure 17: Evolution of risk (million Euro/a)

3. Review of indicators and method

3.1 Indicators

In order to calculate the effect of measures, indicators were defined. Here, the measure category system of the FD was used. For each measure category, an indicator was established which is representative of the relevant group of measures. On the basis of literature and partly on expert knowledge, the maximum reduction in damage per indicator was estimated and defined.

The degree of realisation, i.e. which and how many measures have been implemented or will be implemented in the future, was integrated into the calculations. The data/information regarding the realised or planned measures was supplied by the states bordering the Rhine.

The calculations regarding the evolution of risk which were carried out for the four receptors enable conclusions to be drawn about the effect of the sum of the measures. In addition to these calculations, a "sensitivity analysis" was carried out (cf. details and summary in "Technical Report – ICPR Report No. 237", Figure 18), through which it was possible to estimate the effect of individual hypothetical measures on the evolution/reduction of economic damage/risk.

The sensitivity analysis related to the measures in the fields of "prevention" and "preparedness" which have an impact on damages. The measures in the field of "protection" have a major direct impact on the reduction of risk, as already outlined in Section 1.1 and 1.6.

Illustrative example - Figure 18: The relative change in risk relating to the measure "flood forecasting" in comparison to the variant "Status in 2005 without measures" amounts to approximately 15% for the scenario HQmedium (blue column). This means that due to the measure "flood forecasting", the risk for the HQmedium scenario is reduced by 15 %.

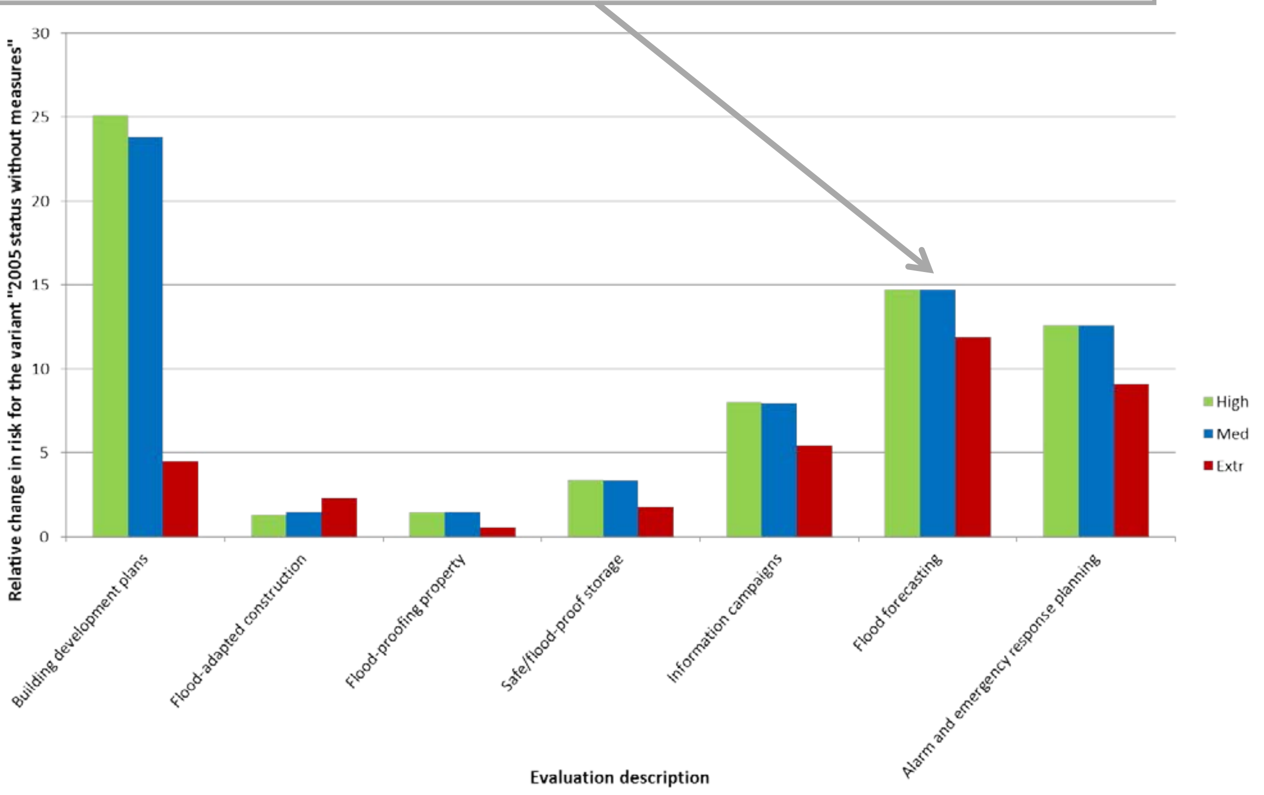


Figure 18: Risk changes with individual indicators in comparison to the scenario without measures (results of sensitivity analysis on impact of measures)

The most significant findings regarding the **measures** used in this analysis are that:

- Most of the measures that were planned for the frequent and the medium flood scenario (HQhigh and HQmedium) in the fields of "prevention" and "preparedness", demonstrate a greater impact in these two flood scenarios than is the case for the extreme event scenario (HQextreme).
- At the level of the Rhine catchment, the measures relating to "precautionary building" demonstrate the least impact. In terms of smaller units of observation/areas, measures relating to precautionary building do contribute significantly to the reduction of risk, however.
- Measures such as "information campaigns", "flood forecasting" and "alarm and emergency response plans" contribute significantly to improving the situation in the Rhine catchment.
- By far the greatest impact is achieved through measures relating to "building development plans" for HQhigh and HQmedium, as regards economic activities including the regulation of construction in flood prone areas or keeping flood prone areas open/clear (prevent the location of new or additional receptors).

- Although not directly included in the sensitivity analysis, the measures in the field of "protection" contribute significantly to the reduction of risk.

An **evaluation of indicators** (cf. Annexe) was carried out on the basis of theoretical and real analysis results, effort expended in finding and retrieving data (data availability), and data preparation. Based on this evaluation and in view of the tasks of the ICPR in relation to the calculations on risk evolution for the review of the implementation of the FRMP in the IRBD Rhine, the following indicators are the most relevant:

- Keeping flood prone areas clear/open (prevent the location of new or additional receptors) and establishing building regulations (*indicators: change in the land use data and building regulations and codes/building development plans)*
- Implementation of measures to lower water levels *(indicator: change in flooding probability)*
- Flood protection *(indicator: indication of a probability/a protection level and an evolution/modification over time)*
- Raising public awareness by, inter alia, provision of flood hazard and risk maps *(indicator: frequency/update intervals with regard to information campaigns)*
- Flood forecasting and warning *(indicator: improvement in flood forecasting)*
- Crisis management *(indicators: presence and update frequency of alarm and emergency response plans; number of warning systems; specifying civil protection exercises, specifying a minimum and maximum safeguarding rate for those affected in a certain area)*

This means that for the aforementioned indicators (and corresponding measures), sufficient data is available or can be expected to be available in the future for the demonstration of effectiveness. An evaluation of the effectiveness of measures at the level of the river basin district of the Rhine is possible using these indicators.

In addition, measures such as "flood-adapted construction", "precautionary building/flood proofing property" and "flood-proof storage" at a local or regional level can have a significant impact on the reduction of risk or damage. However, in terms of the main stream of the Rhine, the indicators of these measures are less suitable, since the corresponding data collection is highly complex. In addition, it has been found that the information required for these measures is not always available.

3.2 Further clarification regarding the method

For the application of the method and the indicators, reference is made to important assumptions and limitations:

Common database and large-scale approach

- Due to the specific methodology and the large-scale common data utilised for the Rhine catchment, the results established through this study may differ from those based on a more accurate database founded upon national calculations. An example of this is the CLC data used by the ICPR, which formed a common database for the entire Rhine catchment. In absolute terms, there are differences, but relatively speaking, these are of minor importance for the evaluation.
- There are various reasons why the absolute values calculated should be used with precaution, and why these are certainly not suitable for use in a cost-benefit analysis:
  - o In the calculations the same flood hazard maps were used for all time periods. This means that it is not the actual reduction of the flooding area that is depicted as a

  result of the water level-reduction measures. This may therefore lead to a distortion of the recording of damages.
  - Not all measures have been taken into account in the calculations in detail, this is the case for e.g. protective measures, such as dyke reinforcements. This could result in the underestimation of the reduction in risk.

- The indicator "Keeping flood prone areas open/clear (prevent the location of new or additional receptors) and adapted usage of areas" i.e. the **area-based evolution of the land use** could not be considered in the calculations for the period 1990-2006 (this is particularly the case for the economy). The reason for this is that for all economic activities, only the data set CLC 2006 was used in the calculations, since the earlier CLC records (1990 and 2000) exhibited too many weaknesses. An improvement in the result can only be achieved through use of improved/more accurate land use data in future calculations.

Utilisation of expert knowledge

- The information about the effects of measures in the fields of "preparedness" and "prevention" used in the calculations required better scientific substantiation, which was not possible in this study, however. The ICPR's findings were therefore based on the available data sources in relation to information about the measures, their effects and level of implementation, as well as on expert knowledge. The estimates and assumptions concerning the measures should in future be replaced by greater knowledge and more detailed records.
- In the case of identical indicators, at times different/heterogeneous information and "interpretations" may be present.

Data availability and collection

For some indicators, it was not possible for the countries to collect data. This is the case, for example, for the indicators "flood-adapted construction", "precautionary building/flood proofing property" and "flood-proof storage", for which a great deal of detailed information is needed.

Annexe 1 - Evaluation of measures and indicators: effectiveness, effort and suitability for the Rhine basin

Type of measure according to FD	Indicator	**Effect on:** Potential damage Risk **Reviewed/affected assets:** Human health Environment Cultural heritage Economy	**Degree of effect on risk** *(based on sensitivity analysis and calculation results)* High Low to medium	**Effort in data collection and processing** Low (high availability) Medium (intermediate availability) High (low availability)	**Indicator suitable for analysis <u>at level of Rhine catchment</u>** Suitable Unsuitable
Prevention					
Spatial planning, regional planning and land use planning	Building regulations and codes/building development plans, in which requirements for flood protection are contained (flood-adapted construction)	Potential damage Human health, cultural heritage Economy			
Keeping flood prone areas open/clear (prevent the location of new or additional receptors) and adapted usage of areas	Modification of land use data (CLC data)	Potential damage Human health Economy			
Flood-adapted design, construction, renovation	Measures implemented for flood-adapted development/building	Human health, cultural heritage, economy			
Precautionary building/flood proofing property for households/municipalities Precautionary building/flood proofing propertyfor facilities at risk	Protected areas due to precautionary building/flood proofing property and/or mobile systems	Potential damage Human health, cultural heritage, economy Environment			
Flood-proof storage of water-polluting/hazardous substances for households/municipalities Precautionary building/flood proofing property for facilities at risk	Securing of oil tanks and/or safe storage in upper storeys	Potential damage Cultural heritage, economy Environment			
Provision of flood hazard and risk maps/establish awareness for precautionary behaviour, education and preparedness for flood events	Frequency/update intervals with regard to information campaigns	Potential damage Human health, cultural heritage, economy			
Flood protection					
Retention measures	Modification of probability	Potential damage Risk Human health, environment, cultural heritage, economy			
Dikes, dams, flood walls, mobile flood protection, ... Maintenance/renewal of technical flood protection structures	For these measures, a probability is also indicated: Percentage evolution/modification of flood probability between 1995 and present day due to improvements in protection	Potential damage Risk Human health, environment, cultural heritage, economy			
Preparedness					
Flood information and forecast	Improvement in flood forecasting within defined time period	Potential damage Human health, cultural heritage, economy			
Alarm and emergency response planning (incl. recovery/aftercare)/warnings for those affected/ exercises/training	Presence and update frequency of alarm and emergency response plans; number of warning systems (warning methods/means of communication);	Potential damage Human health, cultural heritage, economy			
	Details of civil protection exercises incl. frequency	Potential damage Human health, cultural heritage, economy			
Safety/safeguarding/evacuation of (potentially) affected persons	Details of minimum and maximum safeguarding rate for those affected in a particular area	Human health			