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IRMA-SPONGE

Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins

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Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins,

Main results of the IRMA SPONGE research program

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The Rhine and Meuse river basins.

The main messages from IRMA-SPONGE

Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins

(Conclusions and recommendations based on the outcomes of 13 research projects in 6 countries)

A. The future brings increasing flood risk

Conclusion: flood risk (defined as a result of *flood probability* and *potential damage*) along Rhine and Meuse rivers is expected to increase in two ways:

A. Climate change will cause a significant increase in the *probability* of extreme floods (according to a majority of climate change scenarios).

B. The *potential damage* of floods (the level of investments in areas at risk) is doubling every three decades.

Moreover, the room available for improved flood risk management in the future is rapidly decreasing due to urbanisation along the rivers - this decrease in room for measures will increase the cost of future solutions.

Recommendation: flood risk management strategies and measures should be developed in anticipation of higher peak discharges in the future. As uncertainties will remain, room should be preserved for future measures.

B. Upstream flood prevention measures can reduce extreme floods only at the local scale

Conclusion: water retention through land-use change may be useful in lowering the frequency of extreme floods in small basins, and possibly in reducing the level of 'medium-sized' floods in large basins. At the scale of the Rhine and Meuse basins these measures have no significant effect on extreme floods occurring downstream, caused by prolonged heavy rainfall over large areas. Water retention areas along channels far upstream are only marginally more effective in this respect, though detention areas (for 'controlled retention') can have a more significant impact.

Recommendation: along the lower Rhine and Meuse rivers, decision makers should not look far upstream for solutions, but instead focus on measures in or near these downstream areas.

C. The most effective flood risk management strategy is damage prevention by spatial planning

Conclusion: in river valleys and alluvial areas there will always remain a flooding risk. As long as flood risk management authorities focus on flood control rather than on damage prevention, spatial planning will insufficiently take into account flood risks, with the effect that the actual risk continues to rise while the public awareness of the risk decreases. This approach is not sustainable in the long term. An important consideration is also that, in the lower Rhine and Meuse basins, loss of life can nowadays be avoided through improved early warning and evacuation schemes. Flood risk management in these basins could therefore be a matter of optimisation of the costs and benefits of measures, rather than a 'fight against the floods'.

Recommendation: given conclusions **A)** (flood risk is increasing) and **B)** (measures far upstream can not prevent extreme floods downstream), the flood risk management strategy for the lower Rhine and Meuse rivers should change. In view of future developments, and uncertainties therein, flood risk issues should become a major consideration in spatial planning in all areas at risk of flooding (including dike-protected areas), and public awareness of these issues should increase. The basis for this could be risk zoning based on flood hazard maps. A requirement is the (p)reservation of space for flooding (dike relocation, green rivers , detention areas).

D. Flood risk management strategies should be part of integrated development of the river corridor

Conclusion: flood risk management measures can help achieve a combination of economic development and other policy targets, such as creating an ecological infrastructure and improving the quality of the landscape. For this, a comprehensive strategy for the desirable development of the river corridor as a whole should be developed. Local solutions should meet the requirements of this strategy, as well as specific local requirements. Of course, such a strategy must be supported by stakeholders - resistance from the local population to measures may be reduced by good information supply, fair compensatory measures and proper use of regulations.

Recommendation: flood risk management strategies should not be developed in isolation. As space is limited in the Rhine and Meuse basins, the aim should be to optimise more than one function in areas at risk of flooding. Creating and maintaining variation in land use and habitats along the river is also important, from an ecological point of view. This takes a long-term and basin-wide view. It is inevitable that some difficult choices are made, as it is not always possible to attain a win-win solution for all stakeholders.

Participants in the IRMA-SPONGE Umbrella Program

NCR members		
Abreviation	*Organisation*	*Country*
ALTERRA	Alterra	The Netherlands
IHE	International Institute for Infrastructure and Environmental Engineering	The Netherlands
KUN	Katholieke Universiteit Nijmegen (University Nijmegen)	The Netherlands
RWS-DON	Rijkswaterstaat - Directie Oost Nederland (Dutch Ministry of Transport, Public Works and Water Management Directorate East Netherlands)	The Netherlands
RWS-RIZA	Rijkswaterstaat - Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling (Dutch Ministry of Transport, Public Works and Water Management - Institute of Inland Water Management and Waste Water Treatment)	The Netherlands
TUD	Technische Universiteit Delft (Delft University of Technology)	The Netherlands
UU	Universiteit Utrecht (University of Utrecht)	The Netherlands
WL	WL | Delft Hydraulics	The Netherlands
Other participants		
	Organisation	*Country*
BfG	Bundesanstalt f r Gewasserkunde (Federal Institute of Hydrology)	Germany
CC	Carthago Consultancy	The Netherlands
CEREG	Centre d Etudes et de Recherches Ecog ographiques (University of Strasbourg)	France
CHR	Commission international de l Hydrologie du bassin du Rhin (Hydrological Commission for the Rhine)	France, Germany, The Netherlands, Switzerland
CRP	Centre de Recherche Public - Gabri l Lippmann	Luxemburg
DLR	Deutsches Zentrum f r Luft- und Raumfahrt (German Aerospace Centre)	Germany
EPFL	Ecole Polytechnique F d r al de Lausanne (Technical University Lausanne)	Switzerland
ICIS	International Centre for Integrative Studies (University Maastricht)	The Netherlands
IfW	Institut f r Wasserbau (Institute for Hydraulic Engineering)	Germany
IvN	Instituut voor Natuurbehoud (Institute for Nature Conservation)	Belgium
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Dutch Meteorological Institute)	The Netherlands
PIK	Potsdam Institut f r Klimafolgenforschung (Potsdam Institute for Climate Impact Research)	Germany
RA	Resource Analysis	The Netherlands
TUD/WAR	Technische Universit t Darmstadt / Wasserversorgung-, Abwassertechnik-, Abfalltechnik-, Umwelt- und Raumplanung (Technical University of Darmstadt)	Germany
UB	Universit t Bonn (University of Bonn)	Germany
UBerne	Universit t Bern (University of Bern)	Switzerland
UM	Universit de Metz, Laboratoire de Phyto-ecologie (University of Metz, Department of Phyto-ecology)	France
VUB (FUB)	Vrije Universiteit Brussel (Free University Brussels)	Belgium
Other contributors		
	Organisation	*Country*
BWG	Bundesamt f r Wasser und Geologie (Federal Institute for Water and Geology)	Germany
ETH	Eidgen ssische Technische Hochschule (University Z rich)	Switzerland
OVB	Organisatie ter Verbetering van de Binnenvisserij (Organisation for the improvement of Inland Fishery)	The Netherlands
RIVO	Rijks Instituut voor Visserij Onderzoek (Institute for Fish Research)	The Netherlands
Stroming	Bureau Stroming B.V.	the Netherlands
UHo	Universit t Hohenheim (University of Hohenheim)	Germany
UKa	Universit t Karlsruhe (University of Karlsruhe)	Germany
URou	Universit de Rouen (University of Rouen)	France
USt	Universit t Stuttgart (University of Stuttgart)	Germany
UTr	Universit t Trier (University of Trier)	Germany
WUR	Wageningen University and Research centre	The Netherlands
WWF	World Wildlife Fund - Auen Institute	Germany

1 Introduction: the IRMA-SPONGE Umbrella Program

Organisation of the IRMA-SPONGE program - the basics

The Umbrella Program IRMA-SPONGE aims to contribute to the measures of Theme 3 (Improvement of Knowledge and Co-operation) of the Joint Operational Programme IRMA (Interreg Rhine Meuse Action Plan). IRMA is an Interreg II-C initiative of the European Commission, aiming to reduce flood risks in the Rhine and Meuse basins. The EU member states Germany, Belgium (Flanders and Wallonia), Luxembourg, France and The Netherlands have, in co-operation with Switzerland, chosen to jointly develop and promote improved methods for sustainable flood risk management.

IRMA-SPONGE is a cluster of 13 innovative, mutually consistent and complementary projects in which more then 30 institutes from all countries in the Rhine-Meuse basins co-operate. The IRMA-SPONGE program management was executed by NCR (the Netherlands Centre for River studies) in which nine Universities and research institutes (governmental and independent) participate. NCR was supported in its task by an International Scientific Advisory Committee (ISAC).

Aim and scope of the IRMA-SPONGE program - explanation of key concepts

As the title of this report suggests, the IRMA-SPONGE program intended to contribute to the development of <u>strategies for sustainable flood risk management in the Rhine and Meuse River basins</u>. The main concepts involved can have a different meaning to different people and will therefore be clarified first.

What are <u>Floods</u> and how are they generated?
This report deals with high-water events that can cause damage by inundating normally 'dry' areas. The focus is on extreme flood events along the middle and lower reaches of the Rhine and Meuse basins. It should be kept in mind that the results may not always be applicable to more frequently occurring flood levels, or to floods in the upstream parts of the river basins.

The generation of a flood peak (not including dam break) is essentially a matter of how precipitation is transformed into river discharge. Five factors determine whether rainfall will cause a discharge peak: 1) characteristics of the rainstorm, 2) conditions prior to the rainfall event (wet or dry soils) 3) the transfer mechanism of rain to stream flow, 4) the size and shape of the channel which determines the propagation of a flood wave, 5) (for large basins) timing of events in different tributaries. In small basins, a single thunderstorm can result in a flood, as rainfall may cover much of the area. In large basins like those of the Rhine or Meuse, however, floods typically result from prolonged rainfall (several days to weeks) over large areas. There are additional factors which determine whether snowmelt contributes to floods: mainly the location and amount of snow accumulation, and the timing and rate of temperature rise.

How do is <u>flood risk</u> determined?
Flood risk management deals with rare events, with a low *probability*. The effect of such events is measured by the *damage* they cause. A good working-definition of 'flood risk' is then:

Flood Risk is a function of Probability (of flooding) and Damage (due to flooding)

Moreover, it should be realised that flood risk management not only involves minimising the actual risk, but it should deal with the 'perceived risk' as well - and there is often a difference between the two.

Grouping of IRMA-SPONGE projects by their main focus* [project numbers and leading organisations are indicated in brackets]**

Fundamental research into flood generation and risk quantification

- FRHYMAP: the influence of past and future climate and land-use changes on flooding events was determined through hydro-climatological analyses and socio-economic risk assessment, in the transboundary Alzette river basin. [*project 3, lead: CRP*]

Research on the effectiveness (and side-effects) of specific measures

- Cyclic rejuvenation of floodplains: assessment of a method for increasing discharge capacity that involves cyclic lowering of the floodplains, (re)construction of the secondary channels and setting back the vegetation succession [*project 7, lead: RWS-DON*]
- The value of floodplain wetlands: assessment of the contribution of floodplain wetlands to flood risk reduction and nutrient retention [*project 8, lead: IHE*]

Assessment of methods to improve the role of integrative planning in flood risk management

- INTERMEUSE: assessment of optimisation of flood protection along the Meuse in combination with sustainable floodplain ecosystem rehabilitation. [*project 9, lead: RIZA*]
- Living with Floods: design and evaluation of resilience strategies for flood risk management and multiple land use in the Lower Rhine river basin. [*project 10, lead: RIZA*]
- Integrated management strategies for the Rhine and Meuse: a set of FRM strategies was developed and evaluated in the light of likely scenarios [*project 2, lead: UU*]
- Assessment of the (use of-) spatial planning instruments for flood risk management purposes, by European, national, regional and local authorities [*project 5, lead: TUD/WAR*]

Development of decision support (and research) tools and methods

- DEFLOOD: a method for assessment of the combined hydrological effect of local flood reduction measures on flood generation in large complex catchments. [*project 1, lead: CHR*]
- BIO-SAFE: a method for assessment of the impact of measures on nature policy targets, on the basis of the status of river characteristic species [*project 11, lead: KUN*]
- DSS Large Rivers: a decision support system for planning of flood risk management measures — with a focus on retention and detention areas along the Lower Rhine. [*project 4, lead: RIZA*]

Development of communication tools

- STORM-Rhine: an interactive simulation tool aiming to improve understanding of river and floodplain management amongst policy makers and stakeholders [*project 13, lead: IHE*]
- Guidelines for rehabilitation measures and management of floodplains — optimising both ecology and safety [*project 6, lead: RIZA*]
- FloRIJN: development of a flood early warning system for the Rhine, with a 4 days forecasting time at the Dutch-German border. [*project 12, lead: RIZA*]

*For further information on the scope of projects: see the Annex with project abstracts, and the Executive Project Summaries for full project descriptions.
**More than 2 organisations co-operated in all projects.

How are flood risks managed?
The goal of flood risk management can be defined as*: to minimise flood risk by implementing measures that reduce risk most efficiently*. From the above definition it follows that flood risk management can aim to reduce the probability of flooding, or minimise the potential damage. Often, flood risk management is a combination of both.

What do we consider sustainable flood risk management?
A flood risk management strategy can only be truly sustainable if A) it provides sufficient safety now and in the future, and B) an acceptable balance can be found between the restrictions imposed by flood risk reduction measures on the one hand, and the conditions needed for economic, social and environmental development in areas at risk of flooding on the other hand. The 'ideal' sustainable flood risk management strategy may not be the same for every region: not only may there be physical differences between regions, but there are also important cultural, economic and ecological differences. The aim of this report is therefore not to present a new flood risk management strategy, but to help in developing such a strategy.

This report

The IRMA-SPONGE program consisted of 13 interrelated research projects. The various projects addressed a wide range of issues related to flood risk management in the Rhine and Meuse river basins. Over 50 scientists from different scientific disciplines and countries exchanged ideas, and discussed research results with each other and with decision-makers. Based on the results of the research projects, the outcome of the program is a shared insight in the problems of flood risk management in the Rhine and Meuse basins, and a consistent view on how improvements can be made. This summary report presents these insights.

The following set-up was chosen in this report:

- In *Chapter 2*, the most important findings concerning the urgency of the **flood risk problem** and current flood risk management practice in the Rhine and Meuse basins are presented.
- The conclusions and recommendations regarding the flood risk reduction **effectiveness of alternative measures** studied in IRMA-SPONGE are summarised in *Chapter 3*.
- In *Chapter 4*, findings on the development of flood risk management **strategies** are presented.
- Conclusions and recommendations regarding the **implementation** of possible measures and strategies are discussed in *Chapter 5*.
- Some **lessons learnt** with regard to running a large, multidisciplinary international program like IRMA-SPONGE are discussed in *Chapter 6*, as well as remaining knowledge gaps.

The text of this report reflects the fact that IRMA-SPONGE was both a collection of separate projects and a platform for communication and information exchange. Where conclusions and recommendations are based directly on results of individual projects, this in indicated by the project number in the margin. However, much of this report deals with conclusions and recommendations that are based on the findings or experience of most participants, as shared and discussed in the program - in these cases, no project numbers are given.

Included in this report, as Annexes, are brief abstracts of the research projects, and a glossary with explanations and translations (English-Dutch-French-German) of technical terms. More detailed information can be found in separate publications:

- Executive Summaries of individual projects are published simultaneously with this summary of the entire program.
- Another recommended source of information on flood risk management in The Netherlands is the summary of results of the 'Room for the Rhine' project that was linked to many of the IRMA-SPONGE projects in The Netherlands. This summary report is available from NCR in English, German and Dutch.

Scenes of flood events along the lower Rhine and Meuse rivers (source: Rijkswaterstaat, IRMA-SPONGE projects).

2 The need for improved river flood risk management

A number of developments have recently stimulated debate on whether current flood risk management practices in the Rhine and Meuse basins are sustainable, in view of:

- the expected hydrological consequences of climate change and land use developments,
- economic and ecological developments in the river corridors, and
- changing views in society on issues like safety and ecological functions.

One could say that this question of sustainability lies at the basis of the IRMA-SPONGE program. The IRMA-SPONGE projects that looked at alternative flood risk management strategies have, of course, also looked at the current situation. This comparison leads to the conclusion that wise use of our river systems requires that flood risk management practices be improved.

Trends in flood risk

Trends in flood frequency

The frequency of floods (indicated by return times) is generally determined from statistical extrapolation of observed time series for discharges or water levels. This extrapolation is possible if the factors causing floods have not changed during the observation period - in statistical terms this concept is called 'stationarity', and it applies to flood frequency analysis only if no changes in land use, climate or river morphology occur. It is therefore important to realise that there is a fundamental uncertainty in any prediction of changes in flood frequency due to land use change or climate change. Nevertheless, it was found that the impact of climate change on flood frequency is likely to be significant. Although it was shown that land use change can have an impact on flood flows in small basins, it was concluded that on the scale of large basins the effects of future climate change (according to most climate scenarios) far exceed the effects of remedial land use changes that are considered as flood risk reduction measures. The following types of evidence were used:

- *Assessment of the impact of past and future climate changes on atmospheric circulation patterns and rainfall distribution..*
- *Analysis and modelling of the effect of existing climate scenarios on future hydrology of the Rhine, focussing on flood flows.* The majority of climate change scenarios for the Rhine and Meuse basins indicate that A) air temperature will rise, B) winter precipitation will increase (and summer rainfall will decrease) resulting in higher flood peaks everywhere, C) there will be a shift away from snowfall towards rainfall in the Alps, which will further increase downstream flood flows as peak flows from the Alps will be in phase with peak flows from central Germany.
- *Analysis and modelling of recent and projected changes in land use and climate on flood flows from small basins.* It was shown for the Alzette basin that historic changes in precipitation patterns resulted in significant changes in peak flows. This is in agreement with hydrological models for other basins like that of the Lein River. Effects of land use change were found to be significant at a local basin level.
- *Literature on changes in discharges over the last century.*

Trends in potential flood damage

Despite the goals set in the Flood Action Plan for the Rhine (by the International Rhine Commission), it appears that the economic damage potential (total of investments + production) of areas at flood risk (including the dike-protected areas in The Netherlands) will continue to rise at a rate close to the mean economic growth, i.e. more or less doubling each 30 years. This problem appears to be even more serious in view of the conclusion that minimising the damage potential of flood-prone areas is often the most cost-effective flood risk management measure.

Basics of the IRMA SPONGE Umbrella Program

Background and scope of IRMA-SPONGE
Recent flood events and socio-economic developments have increased the awareness of the need for improved flood risk management along the Rhine and Meuse Rivers. In response to this, the IRMA-SPONGE Program incorporated 13 research projects in which over 30 organisations from all 6 countries involved co-operated. The program is financed partly by the European INTERREG Rhine-Meuse Activities (IRMA). The main aim of IRMA-SPONGE is defined as: *The development of methodologies and tools to assess the impact of flood risk reduction measures and of land-use and climate change scenarios. This to support the spatial planning process in establishing alternative strategies for an optimal realisation of the hydraulic, economical and ecological functions of the Rhine and Meuse River Basins."* Further important objectives are to promote transboundary co-operation in flood risk management by both scientific and management organisations, and to promote public participation in flood management issues.

During the program, project results were evaluated and presented along 3 ***Topics*** which are linked to the objectives in IRMA Theme 3, with an emphasis on the first one:

- Effectiveness and side-effects of flood risk management measures - how to determine and balance them?
- Science - what is its current and future role in flood risk management?
- Transboundary co-operation in flood risk management - how can it be improved?

Evolution of the IRMA-SPONGE recommendations in this Program Summary
The IRMA-SPONGE Umbrella Program is not a single research project, but a structure for co-ordination of 13 studies in the field of flood risk management. Many different issues were studied from different angles. Having such a large group of scientists working together provides a chance to identify the recommendations that will be most useful and relevant in practice, while being broadly supported by the scientific community. However, a thorough and careful selection process of discussion and screening is required to achieve this. From over 200 conclusions and recommendations produced by the individual projects, the ones presented in this summary were selected in the following steps:

1. From the start, all projects aimed to produce results that can be the basis for clear conclusions and practical recommendations. The underlying idea of the program was that much scientific knowledge exists, but too much of this is accessible only to a relatively small group of specialists. The focus of the program was therefore on integration and application of results.
2. The outcomes of related projects were discussed in *scientific clusters*, which acted as a focussing instrument for the main conclusions and recommendations in this report:

- *Flood Risk and Hydrology:* projects in this clusters focussed on the generation of floods (processes, models), the predictability of flood events (e.g. risk maps, early warning systems) and changes in flood probability (due to changes in climate and land use).
- *Flood Protection and Ecology:* in this cluster, projects dealt with ecological effects of changes to the river system for flood control purposes.
- *Flood Risk Management and Spatial Planning:* projects in this cluster focussed on the interactions between flood risk management strategies and spatial planning, and on the role of public awareness and management styles in this process.

3. The conclusions and recommendations from the scientific clusters were discussed by 120 participants (many of whom were from river management organisations) at the IRMA-SPONGE Final Conference in Bonn, and screened by the International Scientific Advisory Committee (ISAC), which consists of experts from all 6 Rhine/Meuse countries.

Trends in the future options to take proper flood risk management measures
Future flood risk is also increasing because current investments are limiting the options of future spatial planners - land that may be needed to give 'room to the rivers' is irreversibly made unavailable by urbanisation. Even when there is no agreement at the moment on whether such measures will really be needed, future generations should be given the chance to react properly to increasing flood frequencies and levels.

Current flood risk management approach and its deficiencies

The present flood risk management strategy aims at providing equal safety levels for all areas protected by dikes, by fully controlling floods. However, the unwanted effect is that discharges above the design discharge may cause flooding anywhere: the course of events is then *fundamentally unpredictable* instead of fully controlled. It was found that this control flood
risk management aim is questioned by many: some consider it ecologically unsustainable, 02
others too expensive. When these other views would have more influence, a flood risk management strategy would likely result in either A) acceptance of more risk (based on financial cost-benefit balancing) or B) more resilience and adaptability in the future.

Lack of spatial planning and regulation for investments leads to increased risk
The feeling of safety created by the full flood-control strategy results in a lack of awareness, amongst spatial planners and the general population, on the implications of flood risk for investments. As a result, investments (in urbanisation and other types of land use intensification) continue in areas that are at risk of flooding - especially in areas protected by dikes. Not only does this increase the flood risk (which is a result of both the flood probability and the potential damage) but it also rapidly, and often irreversibly, reduces the room available for implementation of 'resilient' flood risk management measures, such as compartmentalisation for retention or green rivers . This limits the opportunities for a future development of a sustainable flood risk management strategy for the whole lower Rhine river. The situation along
the lower Meuse river is similar. 05 10

Increasing support for other flood risk management strategies
There is increasing support for 'resilience' strategies at the academic and decision making level, a number of clear advantages over the present flood protection strategy are recognised. However, a move away from 'full flood control' strategies to 'resilience' strategies requires support at the local and regional levels which would have to implement it eventually - and creating this support may require considerable effort. When explaining alternatives to the current strategies it should be stressed that:

1. The core of *any* future flood risk management strategy will be flood control, and maximum flood protection for most areas. Increased flooding can only be allowed in some areas.
2. The room needed for resilience measures is not permanently lost for human land use or other (e.g. ecological) functions, as it is *only temporarily and/or incidentally* needed for storage or discharge of flood water. 10

Flooding is no longer life-threatening along the lower Rhine and Meuse rivers
The forecasting time for Rhine floods will soon be 4 days at the Dutch-German border, and this 12
forecast will be highly accurate. It is envisaged that this can be extended even further in the near future, and that significant extension of the forecasting time for Meuse floods (from 12 to 36 hours) is also possible. This is an important fact to keep in mind, because it means that while there will always be uncertainties regarding the probability of floods, it is now clear that life-threatening situations can be prevented under all circumstances. Flood risk management along the lower river reaches should therefore no longer be seen as a 'fight against the floods', as it has been historically - and still is in some cases. This could make it easier to take difficult but rational steps towards 'resilience' strategies that may require the acceptance of flooding in certain inhabited areas.

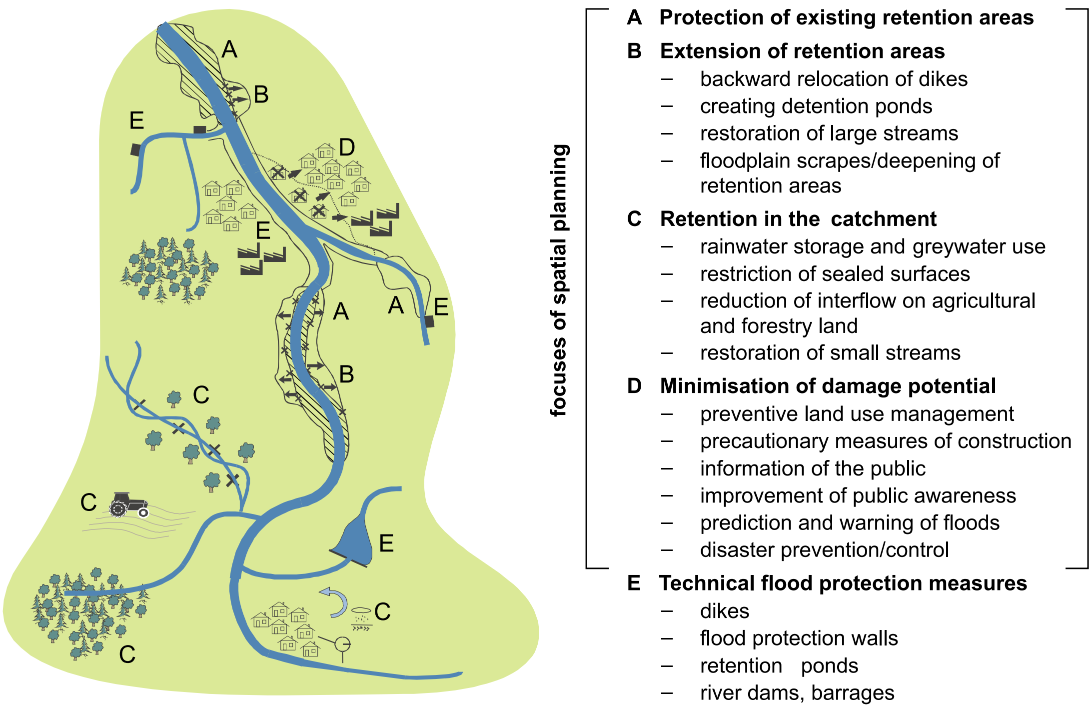
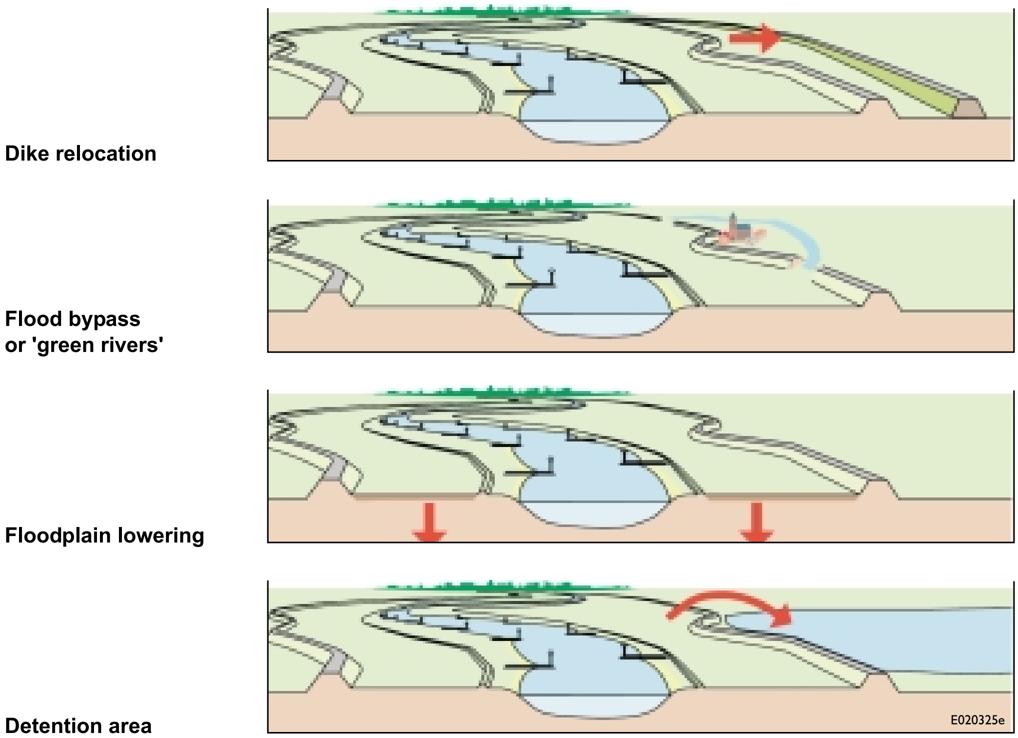


Illustration of typical location of flood risk management measures within the river basin.
(From Project 5).



Some ‘Room for Rivers’ measures practised or considered along the lower Rhine river:
(From ‘Room for the Rhine’)

3 Effectiveness of flood risk reduction measures

Types of flood risk management measures studied by IRMA-SPONGE

Five types of flood risk management measures can be distinguished:

1. Flood generation prevention measures: land use management in the upstream catchment.
2. Preventive flood risk reduction measures: flood control, retention, spatial planning and awareness raising.
3. Preparatory measures: flood forecasting and warning and emergency plans.
4. Measures during floods: crisis management, evacuation and local emergency protection.
5. Post-flooding measures: aftercare, compensation, and insurance.

The majority of the research within IRMA-SPONGE dealt with preventive flood risk management measures and the emphasis of this evaluation is therefore on ’preventive’ strategies (types 1 and 2). Within this general strategy, four categories of measures (and policy instruments) are distinguished:

- Technical measures/instruments (detention basins, dikes, etc.).
- Regulatory measures/instruments (zoning, legal instruments).
- Financial measures/instruments (burden sharing, subsidies, financial compensation, insurance).
- Communicative measures/instruments (DSS s, games, role-plays, brochures, etc.).

Generally, the application of a measure from one of these categories is not effective without at least considering a combination with measures from (one or all) other categories as well. The *balanced combination of measures* is an essential aspect of *integrated management*. Policy design should therefore be supported by research on the effectiveness of combined measures.

As flood risk is a result of both the probability (frequency) of flooding and the potential damage due to flooding, flood risk management can aim to reduce both the probability and the potential damage - two very different types of measures.

Preventing floods: catchment measures

It is often said that a problem is best solved at the source, and in theory this also applies to flood risk management. Therefore, flood risk managers often look upstream to see what can be done to prevent floods. Such catchment measures have also been studied in IRMA-SPONGE, but proved ineffective for the prevention of extreme floods coming from large river basins.

Land use changes like urbanisation and deforestation can have significant detrimental effects on peak flows, low flows and water quality. These effects are particularly noticeable in small basins (headwaters). Therefore, one measure that has been advocated is to reverse such developments by increasing the amount of rainfall that infiltrates into the soil, thus reducing the amount of overland runoff into the headwaters of rivers. Indeed this approach, when implemented over a large fraction of the basin area, may well be effective to enhance base flows and to reduce low to medium peak flows at the local to regional basin scales [’Room for the Rhine’]. However, the effects on extreme peak discharges are limited even in small catchments, and strongly depend on the type of precipitation (convective vs. advective) and antecedent conditions.

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Scope of the 13 research projects in the IRMA-SPONGE Umbrella Program

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Project name / brief description	Set-up of scenarios and measures: Climate change scenarios	Detention areas	Winterbed enlargement	Floodplain lowering	Wetland rehabilitation	Land use options	Various measures	Evaluation criteria: Hydraulic functions	Ecological functions	Socio economic functions	Sustainability	Intangibles	Various criteria	Risk assessment: Valuation methodology	Mapping GIS DTM	Risk mapping	Decision support & awareness: Development DSS	Information management	Public awareness
1 DEFLOOD - flood reduction measures and reference floods	■						■	■											
2 Integrated management strategies for the Rhine and Meuse	■					■		■						■					■
3 FRHYMAP: flood risk and hydrological mapping	■														■	■			
4 DSS-LARGE RIVERS - a tool for assessing measures		■						■	■								■		■
5 Improving spatial planning instruments for flood risk management		■				■				■				■		■	■	■	■
6 Guidelines for the implementation of ecological measures along rivers			■	■					■										
7 Cyclic rejuvenation of floodplains				■	■				■		■								
8 The added value of wetlands - flood reduction and water quality					■				■					■		■			
9 INTERMEUSE - integrated spatial planning for the river Meuse						■			■	■					■				
10 Living with floods: resilience strategies for flood risk management							■					■	■	■					■
11 BIO-SAFE - a tool for assessing impacts of measures on biodiversity							■		■								■		
12 FloRIJN - improvement of the Rhine flood forecasting system																	■		
13 STORM-Rhine - a role play for transboundary river management																	■		■

Spatial coverage of evaluation of scenarios & measures in the IRMA-SPONGE Program

Study area:	*Upper Rhine*	*Middle Rhine, Mosel*	*Lower Rhine (D)*	*Lower Rhine (NL)*	*Rhine basin*	*Meuse - tributary*	*Meuse - Wallonia*	*Meuse basin*
Flood risk mapping	■	■		■			■	
Climate change			■	■				■
Detention options	■	■	■	■	■	■		■
Wetlands		■	■	■		■		
Winterbed enlargement		■				■		■

Moreover, no evidence was found that 'reversing' land use changes on a fraction of the basin area can have a significant effect on extreme peak flows in the main channels of the rivers Rhine and Meuse. This is in line with results of other hydrological studies. There are two main explanations for this limited effect of upstream catchment management on extreme downstream floods:

- T*here is a direct relation between the effect of land use changes on discharges and the fraction of the catchment area undergoing such changes.* Point-measures such as improved urban water management (aiming to enhance infiltration) will only affect relatively small areas and will therefore never be very effective in large catchments.
- *Reversing a land-use change may not reverse hydrological change within a time scale that is useful to management.* For example, deforestation of densely forested basins can result in higher annual discharge as well as higher flood flows. However, after reforestation it takes decades or even centuries before the forest and soil structure have matured and the original hydrological situation is restored.

It is concluded that extreme floods in the Rhine and Meuse rivers can not be significantly reduced by catchment measures. Consequently, flood risk management along the lower Rhine and Meuse rivers should not rely on such measures - even if it were certain that these could be implemented. Also, it should be realised that effects of climate change on peak flows can not be compensated by land use changes in the long term, as the influence of climate change (according to the current projections) on extreme floods is much stronger than the influence of land use measures.

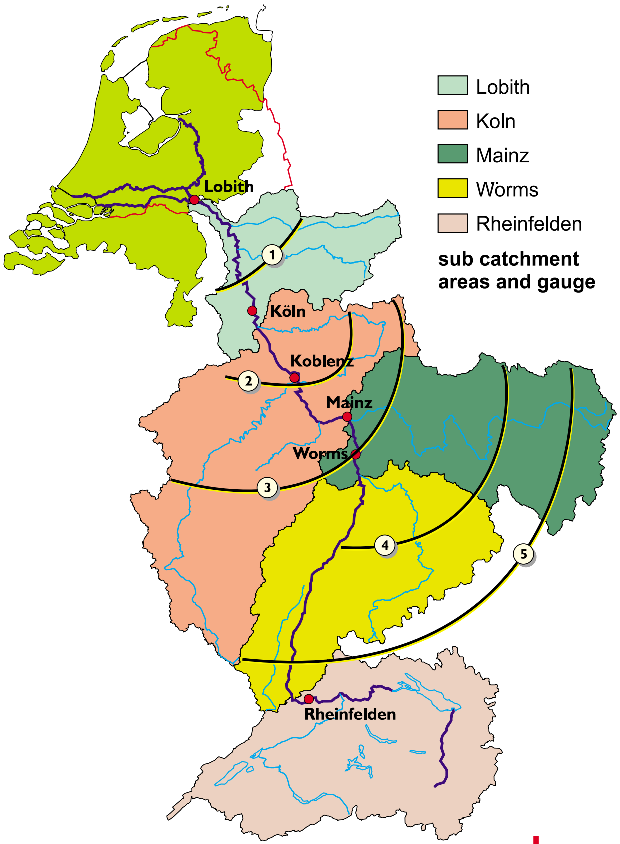
Flood peak attenuation: retention and detention along the upstream channel

Another measure that is often considered is to develop and extend retention areas, well upstream of the river stretch where floods need to be reduced. Flood water retention, by storing it gradually when flood waters rise, results in flood peak attenuation: peak flow is reduced while the total duration of flood flow is lengthened. It is sometimes suggested that this could be achieved by increasing the retention capacity of wetlands, but it was found that the area available for this measure along the Rhine can only make a significant contribution to the attenuation of low to medium peak flows, and not in the case of extreme or prolonged events.

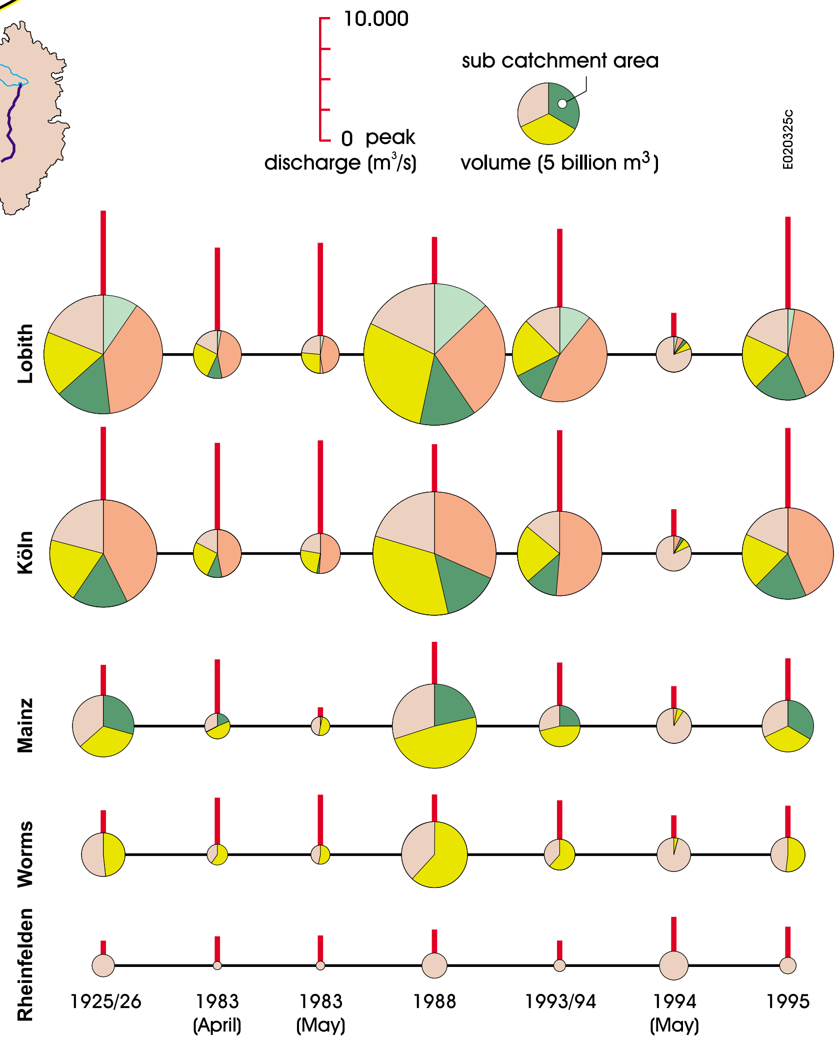
What is true for retention areas directly along the channels, where flooding is uncontrolled, is true to a lesser extent for detention areas, which have a controlled inlet for flood water in order to store river water only when the flood level is at its highest. Detention areas far upstream in the Rhine basin are not very effective in lowering extreme floods that endanger the downstream areas of Nordrhein-Westfalen and The Netherlands. This results from the following factors:

- The timing of flood peaks from tributaries to the main stream is highly complex. Contrary to intuition, attenuation of a flood peak in a tributary river may even increase downstream peak discharge in the main river, rather than decrease it.
- The storage volume available in detention areas is utilised most effectively for 'peak shaving' - i.e. when it is filled during flood peaks and not during the earlier stages of floods. However, reduction of local flood risk may require a different timing of use of available storage capacity than when an optimum reduction of downstream flood risk were the goal. In reality, it will be hard to not let local interests prevail, even if very good communication and co-ordination between organisations in different regions would exist.

The conclusion with regards to both retention and detention areas must be that the further upstream they are, the less they can be relied upon for reducing extreme floods along the lower Rhine and Meuse rivers. However, it should also be noted that detention areas are generally more efficient than retention areas for flood reduction purposes. Of course, retention and detention areas often also have a role in nature management, which may lead to other considerations.



A map of the Rhine basin with flood travel times to the Dutch-German Dutch border. Also shown are the contributions to floods from different parts of the river basin
(Result of Room for the Rhine).
An improved flood early warning system will provide a forecasting time of 4 days to The Netherlands.
(Result of Project 12).



(P)reserving room for the rivers

The so-called 'room for rivers' measures increase the lateral space which rivers can occupy during floods, by creating additional room for storage and discharge in currently dike-protected parts of the alluvial plains. These measures can contribute to increased discharge capacity, peak attenuation or peak shaving. The main options are:

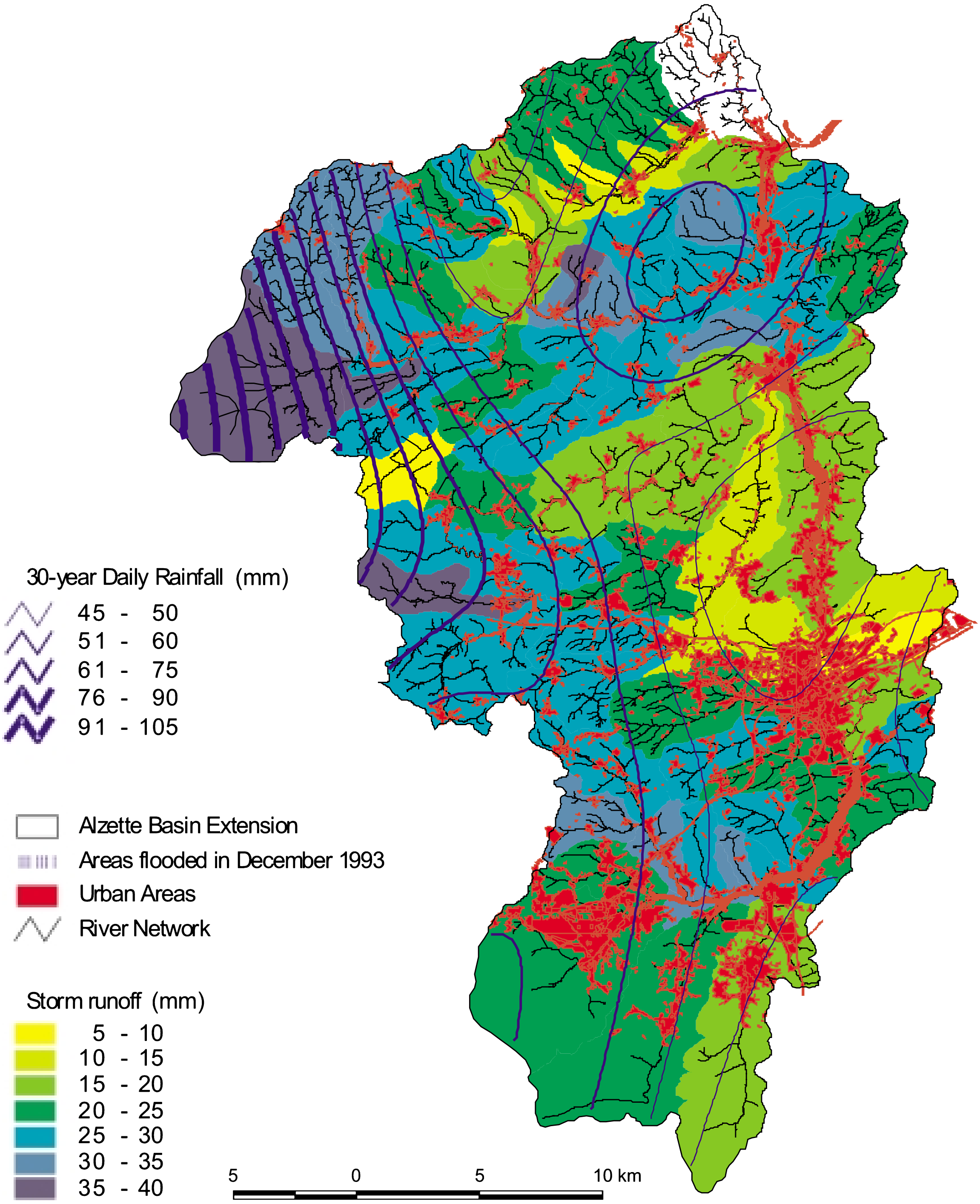
1. Dike relocations - widening the unprotected floodplain.
2. Creating flood bypasses, with or without a permanent channel ('green rivers').
3. Creating detention areas behind the current dikes - such areas provide controlled storage capacity for flood water. This is considered a 'room for the river' option even though it is activated only during emergencies.
4. Cyclic floodplain rejuvenation - this measure involves the periodic excavation of parts of the floodplain, after which natural river dynamics and vegetation succession can be allowed for a period of several decades. This option does not increase room for rivers laterally, but it is often discussed in combination with the measures discussed above.

The 'room for rivers' measures are very different in their scope and effects, but they have in common that they increase storage capacity or discharge capacity for flood water, close to the area at risk. Taken further upstream, these measures have some effect on the timing of the entire volume of flood water, but only a minor impact on the level of the flood peak. However, taken downstream, along the lower reaches of the Rhine and Meuse rivers, they can be effective. For example: it was found that implementation of detention areas and dike-relocation (to increase retention) on 11 proposed locations in Nordrhein-Westfalen alone can lower the design water levels during an extreme flood (with a 1/1250 year probability) in the river with a 04
maximum of 10 cm. Other studies have found flood water level reductions in the order of 30 cm following a combination of dike relocation and cyclic rejuvenation measures ['Room for the Rhine'].

Even though 'room for rivers' measures are effective and technically feasible, it is clear that there will be resistance when implementation is seriously considered. This is especially true for the measures that require space laterally, as they will require inhabited areas to be flooded sporadically. Implementation of such measures would require major changes in spatial planning, and they are economically only viable if costs and benefits of flood risk management are considered over a very long period (decades). However, they offer clear advantages when considered as part of a strategy for integrated development of the river corridor that aims to optimise more than one function, as they offer good possibilities for nature rehabilitation and landscape improvement.

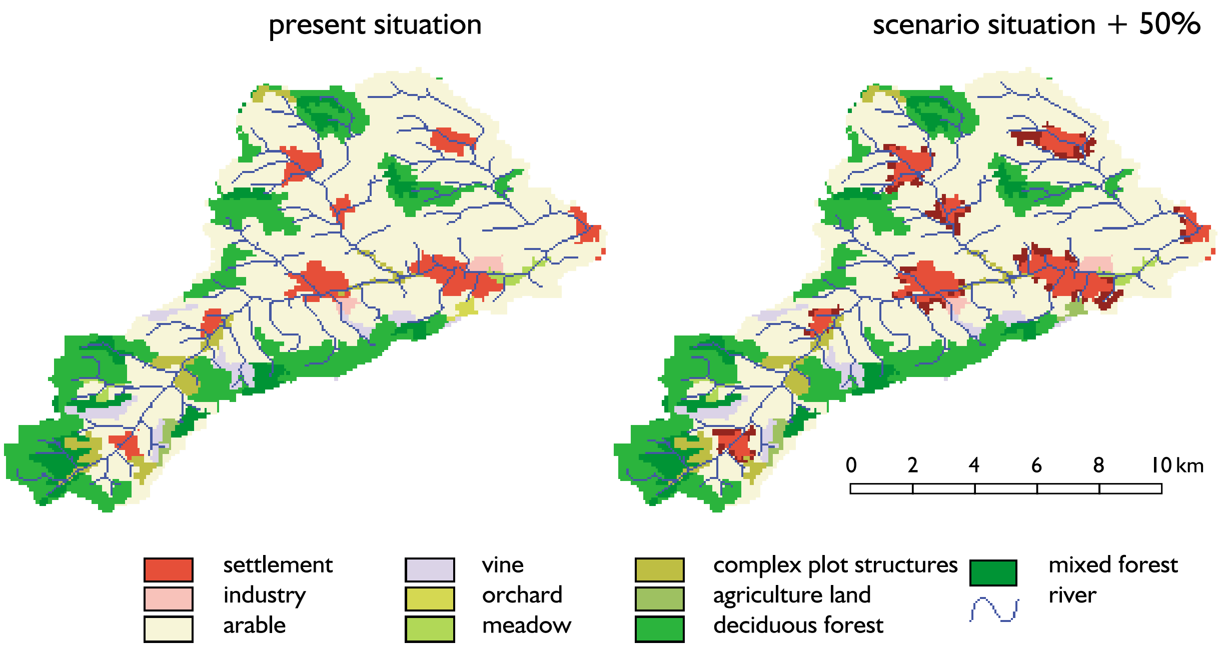
Damage prevention

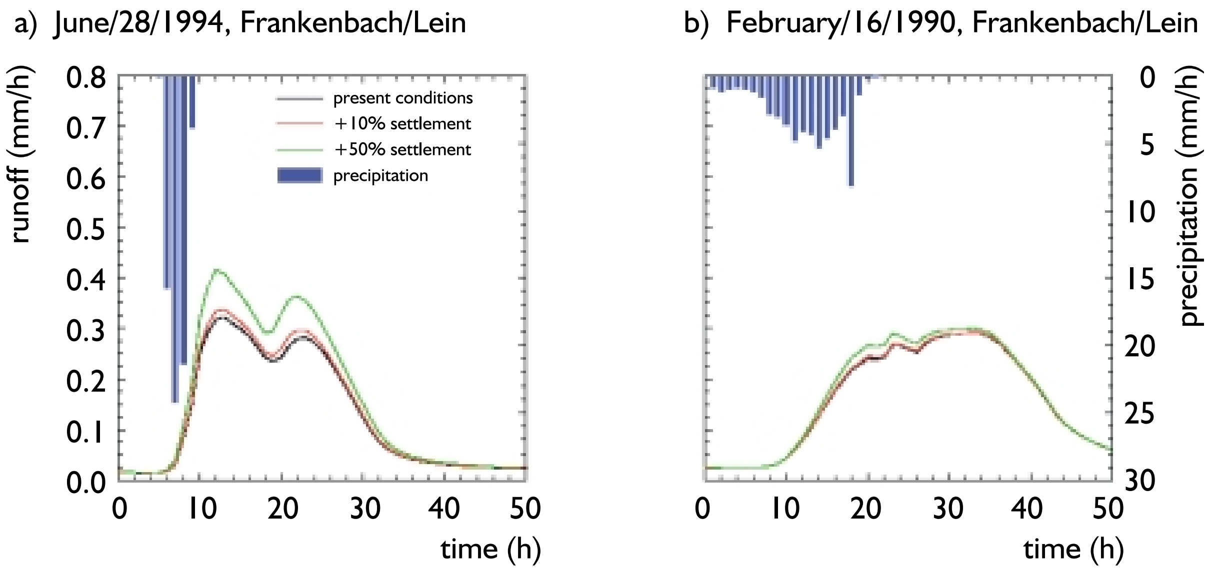
Whether or not a 'room for the river' strategy is adopted, there is a need to reduce the damage potential in the occasionally or potentially flooded areas. In fact, damage prevention was found to be the most cost-effective flood risk management measure. It can be applied on local and regional scales in floodplains and dike-protected areas, anywhere in the Rhine and Meuse basins. At present, damage prevention is insufficiently practised in most of the Rhine and 05
Meuse river basins and the economic damage potential in river valleys and dike-protected areas therefore continues to rise.



Map of 30-year maximum daily rainfall amounts and corresponding peak discharges for the transboundary Alzette basin (France, Luxemburg and elgiun). This type of map provides insight in which areas produce floods, and which areas may be at risk of flooding.
(Result of Project 3).

Using spatial planning instruments for flood risk management: regulations and hazard zoning
An important reason for the lack of effort put into reducing potential damages in areas at risk of flooding is the fact that while useful regional spatial planning instruments exist in most countries in the Rhine basin, their actual contribution to flood damage prevention is insufficient. Existing planning tools are rarely used properly by local authorities to ensure that fewer investments will take place in flood-prone areas. A lack of awareness of which exactly are these areas is a major part of the problem - therefore, the use of flood hazard maps that visualise this information are an important part of the solution. Such maps are simple and effective tools for communication and spatial planning. In ’open’ river valleys, flood hazard zones can be determined from information on flood frequency, in dike-protected areas a differentiation of safety standards could result in ’safety zones’ with a similar function in spatial planning. For a sound classification of hazard zones, one must understand the flooding regime: especially flooding probability, depth and velocity are important, but duration and timing can also have an effect on damages. Though maps of flooding depth can be produced using digital elevation models and water level records, they will usually not be accurate unless based on 2D-modelling of actual flood patterns (’flood event simulations’). Modelling of flooding of dike-protected areas requires particularly sophisticated models and accurate data. Therefore, only few existing flood hazard maps (of limited areas) provide a suitable basis for spatial planning, evacuation plans and other flood risk management measures. Improving this situation should be a priority, because the use of inaccurate flood hazard maps could enhance flood risk rather than reduce it.





Land use change can increase flood discharges, especially on the scale of small basins.
Shown is a simulation of two flood events in the Lein catchment (115 km˝) as a response to
(a) a locally formed convective storm event and
(b) an advective low-pressure area crossing Europe, for present conditions and two urbanization scenarios.
(Result of Project 2).

4 Integrated flood risk management strategies

The task of flood risk management is to implement those measures that reduce flood risk most efficiently, on the basis of a comprehensive cost-benefit analysis - taking into account not only economic values but also societal and ecological values. The basis for such cost-benefit analysis should be an assessment of the flood risk - as a function of both flood probability and flood damage. However, the following issues complicate matters once the risk of floods, and the costs and benefits of actual measures, are discussed:

- There will always be uncertainty regarding the probability of flooding - even when using the best scientific knowledge and models. A long-term strategy should therefore be valid under different climate scenarios.
- There is no way to determine damage potential that will satisfy everyone. While the value of economic assets like investments and production may already be hard to determine, there are no truly objective figures for the value of non-economic categories like ecological, cultural and social assets and functions.
- Public perception can be as important as scientific facts, and this perception often focuses on the reduction in the probability of flooding rather that on reduction of the overall risk. As it is often the public willingness to accept a certain flood risk that matters to decision makers, measures aiming to reduce probability are often easier to implement than measures aiming to reduce damage - even in cases when the latter measures can reduce overall risk more efficiently (i.e. at lower cost).

Clearly, seeking the 'optimum' flood risk management strategy requires many assumptions regarding developments in the natural environment, economy and society. To clarify these assumptions and the uncertainties therein, is important for public acceptance.

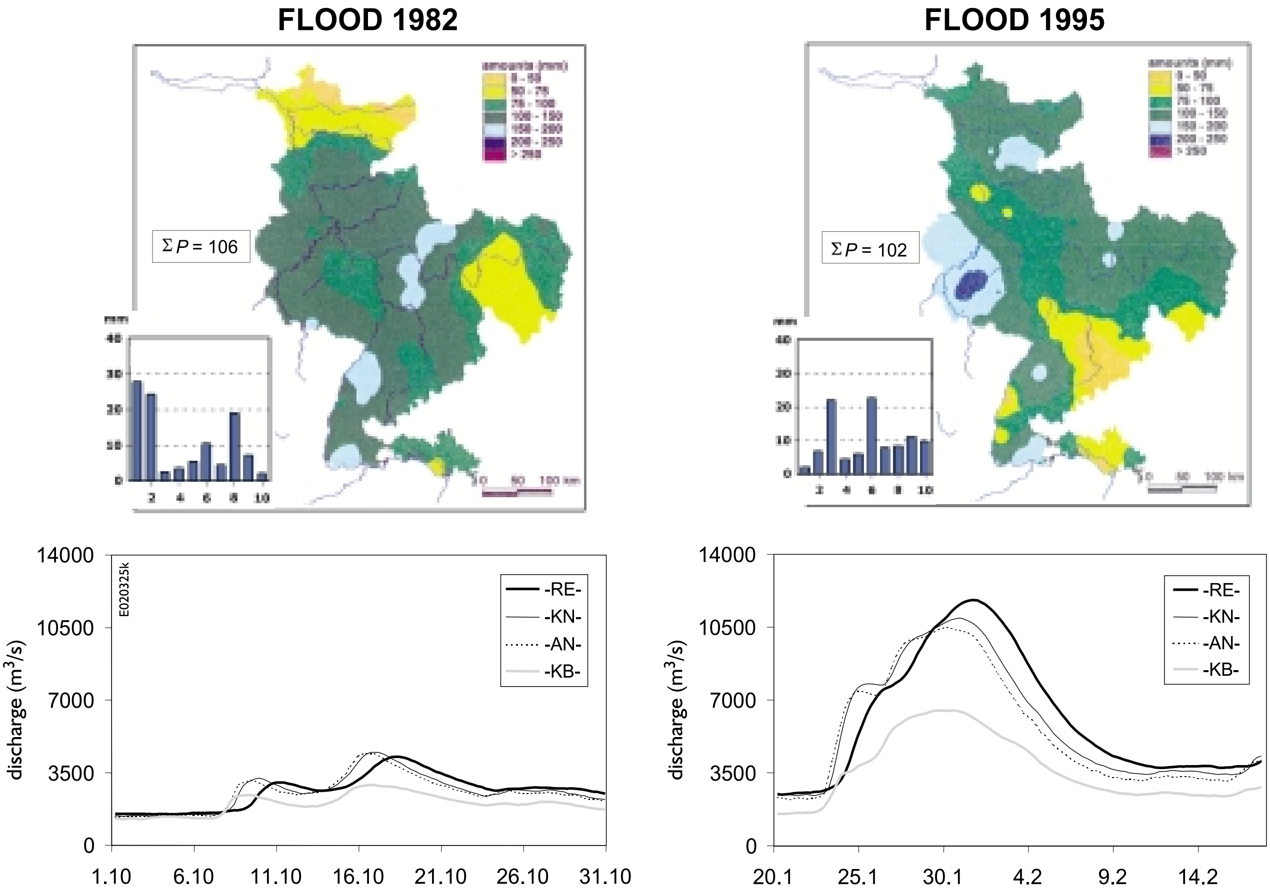
Dealing with uncertainties through resilience strategies

The objective of truly sustainable flood risk management strategies should be to minimise flood risk in the long term whilst also supporting long-term economic, social, ecological and landscape development. Sustainability requires not only a long-term and basin-wide perspective, but also the taking into account of changing boundary conditions . This means that uncertainties regarding biophysical developments (climate change, hydrology, ecology), economic and societal developments, and changes in the normative view ('valuation') of economic, ecological and safety aspects (in a changing culture) must be considered when strategies for flood risk management are developed.

02 08 10

In recent years there has been a significant change in the thinking on flood risk management: the conclusions of IRMA-SPONGE are clearly linked to those contemporary ideas and developments:

- New technologies - such as improved flood forecasting systems, communication, infrastructure and mobility in case of an evacuation - can greatly enhance safety and reduce casualties.
- Ecological values such as biodiversity have a far higher priority.
- Nature and landscape are recognised to be important assets.
- It is recognised that society changes, land use changes and even the climate can change.
- It is also recognised that the probability of extreme flood flows can never be known with 100% certainty, for several reasons:
    - Even using the best data, models and statistical techniques, the frequency of an extreme event (e.g. occurring once every 500 year on average) can not be known with absolute accuracy from observed records (often less than 100 years long).
    - In the current situation, where the frequency of flood flows is probably increasing, any prediction based on extrapolation from past conditions is likely to result in an underestimate of future flood flow frequencies.



Different rainfall patterns result in different flood hydrographs even when total rainfall is very similar, as shown for 4 locations in the German part of the Rhine basin.
(Result of project 1, DEFLOOD; maps after Brandsma and Buishand 1999).

In short: *the context in which flood risk management is practised is not static but dynamic.* Moreover: this context is fundamentally unpredictable. This has some important implications for the development of a flood risk management strategy: it can only be truly sustainable if it can deal with, or be adapted to-, unpredictable future developments. A good guideline for strategy development is therefore the 'no regret principle': decisions taken now should limit future options as little as possible. This realisation has led to the formulation of 'resilient' flood risk management strategies.

If present strategies which aim to prevent flooding by fully controlling floods are referred to as 'resistance strategies', then strategies which allow flooding in certain areas while at the same time reducing the resulting damage can be named 'resilient'. Resilience strategies have a number of major advantages:

- They leave room for future generations to extend, sustain or perhaps even limit the room for flood water storage and discharge - depending on the requirements of the evolving physical, economic, social and ecological environments.
- They are also more sustainable because they can be part of a truly integrated river corridor development strategy - particularly providing opportunities for ecological and landscape restoration.

Most measures that can be considered 'resilient' do require that large surface areas that are now protected by dikes can be flooded: either as detention area or to provide additional discharge capacity. However, this room is not permanently lost for human land use or other functions, as it is only temporarily and/or incidentally needed for storage or discharge. 10

Combining flood risk management and nature management

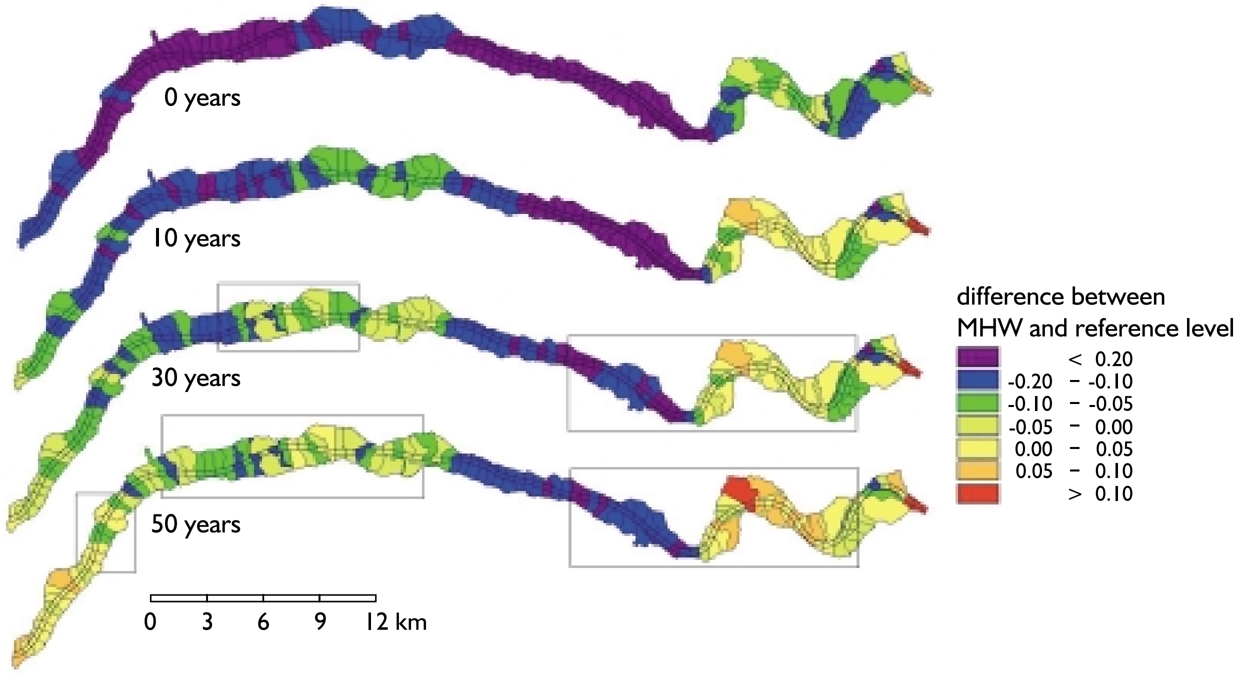
Flood risk management has an impact on all planning objectives in the river corridor: economic, cultural, social and ecological. Within IRMA-SPONGE, several projects have focussed particularly on the interaction between flood risk management and ecological functions, and some relevant findings will be presented in this section. However, it is stressed that while flood risk management can only be sustainable if it allows ecological development, economic and social developments should also be taken into account when the ideas presented here are developed further.

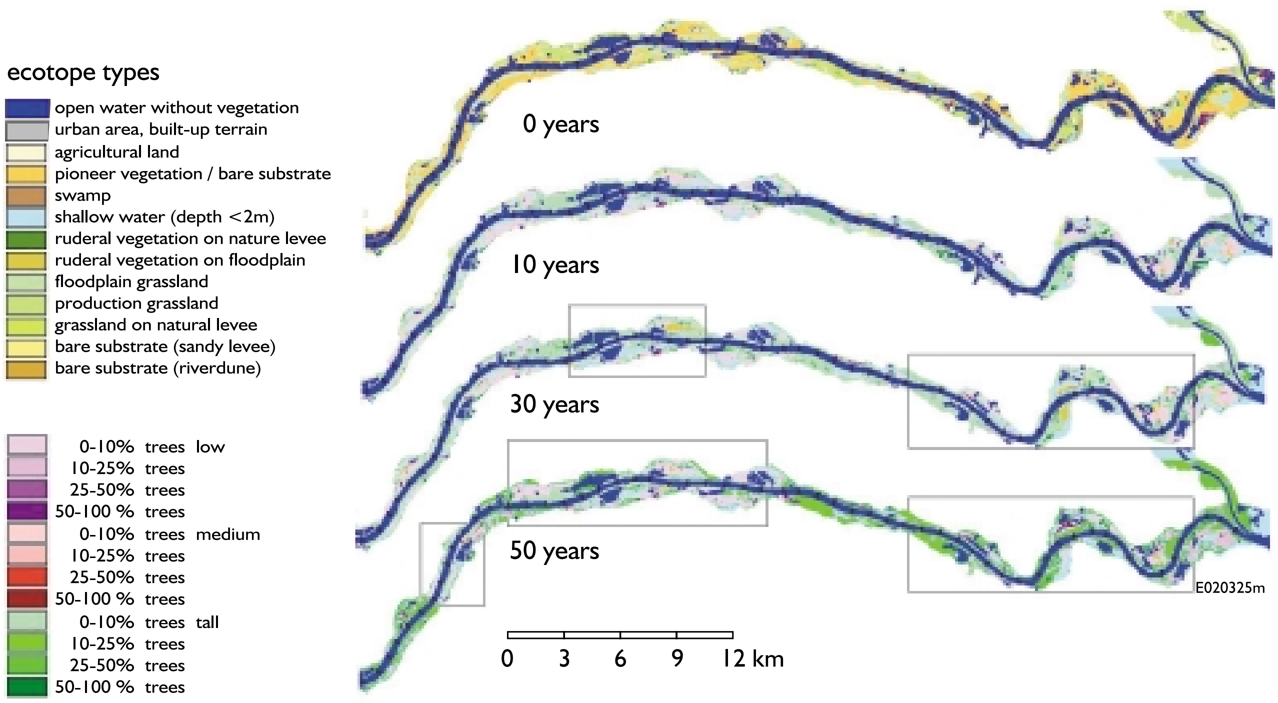
Analysis of different flood risk management strategies for the rivers Rhine and Meuse shows large differences regarding their impacts on biodiversity. Ecological improvement was an aim in the development of most floodplain reconstruction designs assessed within IRMA-SPONGE - and indeed they are likely to enhance biodiversity, but strong negative effects are also predicted. These reconstruction designs can be valuable because new habitats are created, but at the same time they can be disastrous for the current flora and fauna. Moreover, the analysis showed that the most 'natural' situation, which is often the target of nature development projects, does not necessarily correspond with policy and legislation targets and/or does not sustain viable populations. 09 11

How should ecological targets be set?

Making sure that natural assets are not diminished by flood protection measures has in recent years been a policy priority. However, many experts in the field agree that this priority is often not truly put into practice. Two main considerations are relevant here:

- Natural processes can be unpredictable, and nature development is often possible only if this unpredictability is accepted and planners and managers allow (some) natural river dynamics.
- Nature restoration is only likely to give good results when decision makers make clear choices as to what sort of nature they want to develop (as far as this is controllable - see above), and then support this decision in the long term. General choices must be made at an early stage - for example: floodplains can be managed in different ways to optimise nutrient retention, cyclic rejuvenation, development of 'stepping stones' for target species or optimum biodiversity on each location - but these targets can not all be achieved at a single location. 07 08 09 11





Effects of periodic floodplain lowering (cyclic floodplain rejuvenation) on water levels and vegetation development over a period of 50 years. Boxes indicate areas where additional ‘cyclic rejuvenation’ (including excavation) measures were applied after the first year. These vegetation data were used in combination with morphological data to predict the effects on water levels, using hydraulic models
(Result of Project 7).

Setting nature management priorities at the basin scale
International co-operation should define priorities for nature management (e.g. the biodiversity needs be enhanced). To ensure that such priorities can then be translated into clear and concrete choices with regard to the specific ecological targets of flood risk management strategies (e.g.: larger numbers of a certain species are required in a certain region), the impact of a measure on all ecological functions must be considered before it is implemented. This may seem obvious but it rarely happens in practice: even where integrated river management is the aim, decisions are rarely based on integrated effect assessment, limiting the benefits to nature values. 06 07 09 10

Recommended: the ecological network approach
Remaining natural assets in strongly regulated river systems are generally small, fragmented and sometimes isolated. To maintain or create sustainable populations of species (present and after recolonisation) ecological rehabilitation should focus not only on protection of these remaining elements and on enhancement of habitat heterogeneity, but also on the linking of separate populations. The so-called ecological network approach, which takes into account habitat size and spatial arrangement, can enhance nature management along rivers. 09

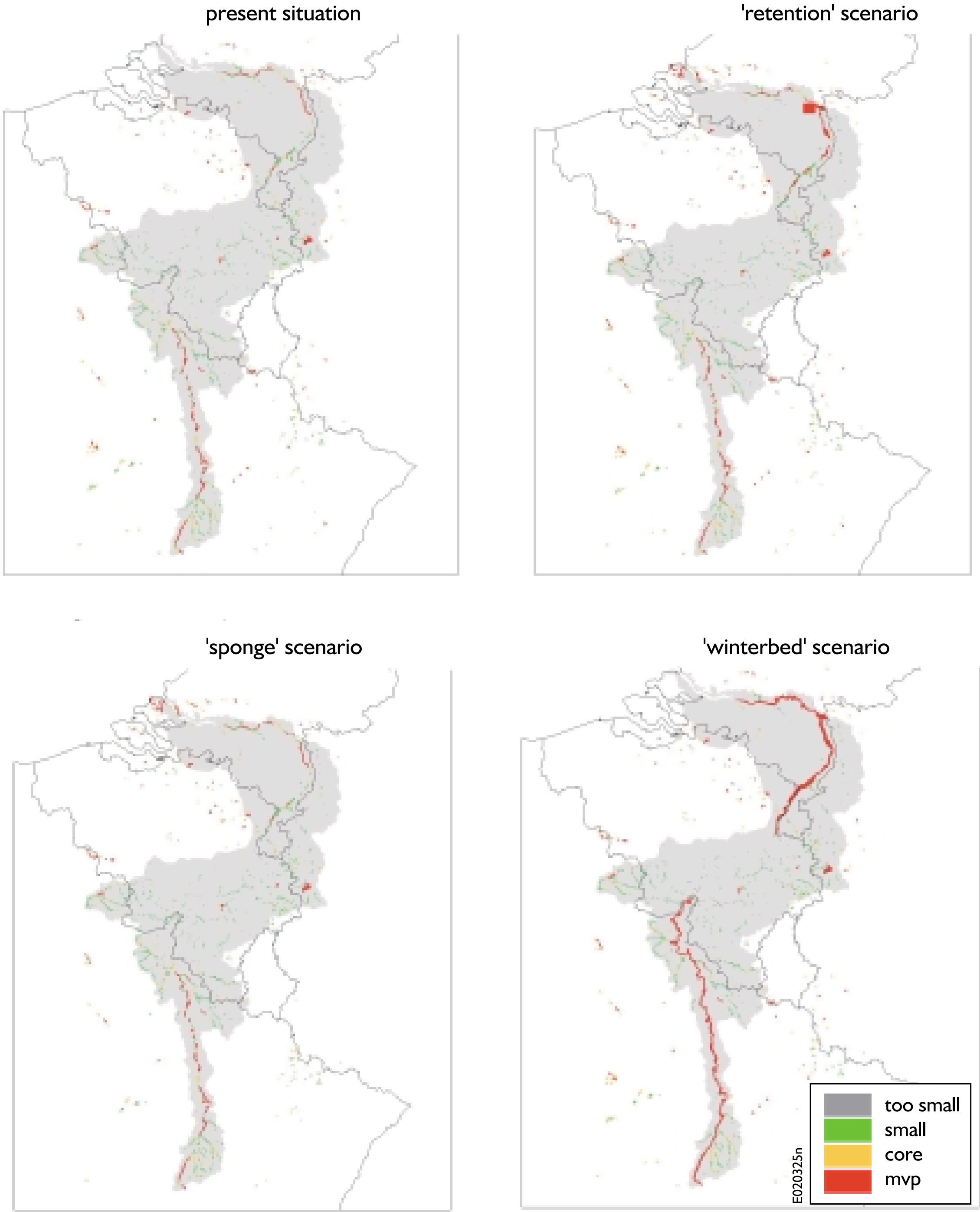
Room for the river is required - but with variation!
A combination of flood risk management measures and enhancement of biodiversity is possible if uniform solutions are avoided - river dynamics should have a different influence in different areas. The 'room for the river' measures that are now discussed are often considered in combination with plans to enhance the ecological and landscape value along rivers, and it is true that these goals can be integrated very well. However, the aim should be to combine different measures at different places rather than to look for a 'one size fits all' solution. For instance, lowering of floodplains is best coupled with measures that enlarge the floodplain area, if the aim is to achieve or maintain a gradient from wet to dry habitats. 07 09 11

Wetlands and flood risk reduction
Many 'room for rivers' measures, aiming principally at increasing the storage and discharge capacity of the floodplains, can be combined successfully with an increase in the area of floodplain wetlands along the lower Rhine river. An additional benefit of more floodplain wetlands can be the increased retention of phosphorus. Wetland restoration can also be combined with *Cyclic Floodplain Rejuvenation*, which combines nature development with the recurrent excavation of part of the floodplain area, every few decades. 06 09 10 08 07

Guidelines for combining floodplain measures with nature management
Once decisions have been taken on general flood risk management strategies and appropriate measures, it is often down to technical organisations and local authorities to implement measures within the floodplains. Individuals involved at this level are rarely interested in the 'ulterior motive' of the measures, but simply carry them out in the way they know best. Without guidance, they may stick to traditional methods that have become inappropriate. For instance, resources may be wasted if restoration of side channels in floodplains produces steep-sided canals that have little ecological benefits - and that will surely be modified into a more natural shape during floods. Therefore, it is important that guidelines for local floodplain management are adapted to suit new management objectives - such guidelines were produced within IRMA-SPONGE. 06

Evaluation of integrated flood risk management strategies

No flood risk management strategy is superior in all respects, and to all parties involved, because sound flood risk management can not be reduced to a scientific optimisation question. Strategic choices that need to be made depend on the perspective of individuals and organisations on the acceptability of a flood risk, and on the importance of economic, cultural and ecological aspects. In the end, safety versus costs (economic, societal and ecological) is a real policy dilemma, and win-win solutions cannot always be attained.



Analyses of the distribution and status of the *large marsh-grasshopper*: for the current situation and for three alternative flood risk management strategies, with different land use scenarios for the river corridor (for explanation: mvp indicates the ‘minimum viable population’).
(Result of Project 9).

Perspectives on flood risk management are very different
It was found in several projects that it can be useful to link different views on the best flood risk management strategy to different 'world views' or 'perspectives'. In the Rhine and Meuse basins three main perspectives can be distinguished; associated management styles may focus on control, on the environment, or on economy - with very different results. It was found that policy planning for flood risk management is primarily a task for regulatory institutions which tend to have a 'controlist perspective, with a supporting role for institutions with an 'environmentalist' perspective (NGOs, research institutions). However, while organisations with an economic perspective (e.g. Economics and Finance Ministries) are rarely part of the earlier stages of the planning process, they are decisive when it comes to the implementation of measures. Therefore, it would be more efficient to better involve all parties from the start, and to formulate, discuss and elaborate explicit (normative) goals and objectives in an early stage of development of a flood risk management strategy.

02

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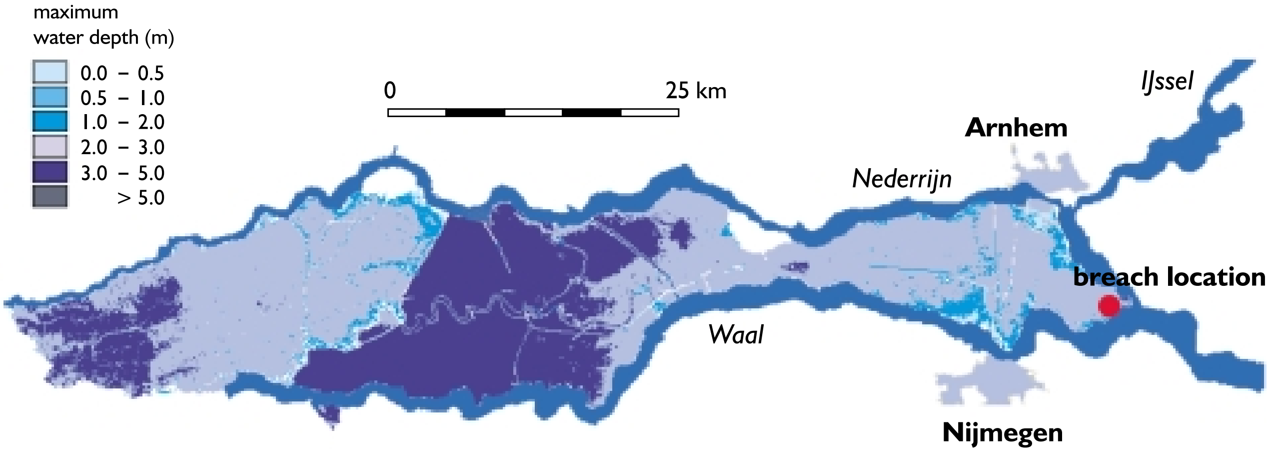
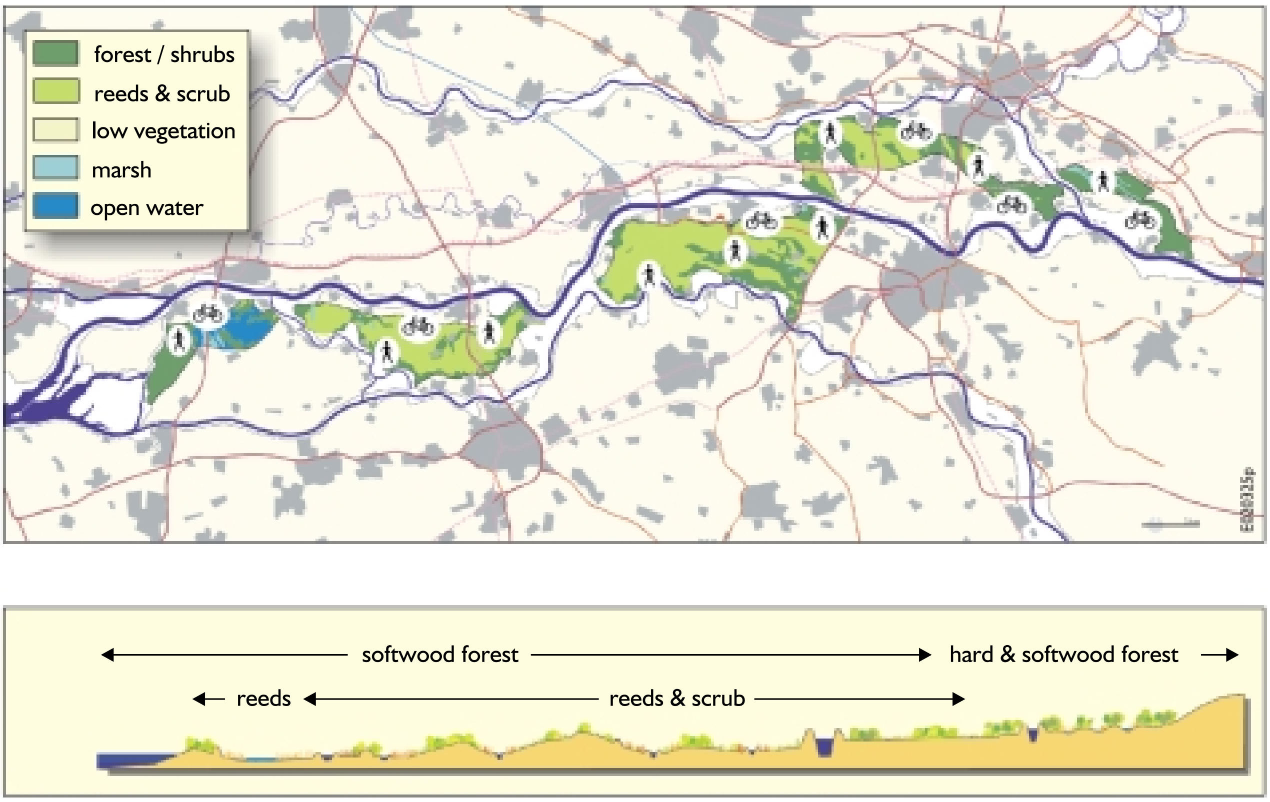
Integrated river basin management is required for integrated flood risk management
Co-operation between the organisations involved is often more important than sophisticated strategies or technologies. It was found by several IRMA-SPONGE projects that despite declarations of good intent by organisations, it was sometimes hard or impossible to obtain essential data in practice. Apparently, information exchange between organisations involved in the management of a single basin is still limited - certainly between countries but also within. Improving this situation may be an important first step towards truly integrated river basin management.



The modelled maximum water depth during a flood in the Betuwe along the Dutch Lower Rhine, after a dike breach and a peak discharge of 18,000 m^3/s.
(Result of Project 10).



Projected vegetation structure and land use along the Dutch Lower Rhine after implemention of the ‘green rivers’ flood risk management strategy. This is the ‘multifunctional development’ alternative, which aims to develop an ecological network alongside use for extensive agriculture, recreation and housing.
(Result of Project 10).

5 Implementation of measures

The (primarily ***technical***) measures discussed earlier can only be implemented accompanied by ***regulatory*** instruments. The technical and regulatory measures, in turn, must be supported by ***financial*** and ***communicative*** instruments, as it is required that society either A) accepts a certain flooding frequency with all its consequences or B) takes/accepts measures to prevent the flooding or to minimise the flood damage. Many different communicative instruments may be distinguished: not only brochures, reports and lectures, but also more sophisticated interactive tools such as computer-based role plays (as developed in IRMA-SPONGE).

Finding support for a measure

Implementation of new flood risk management strategies, e.g. 'room for rivers' and/or damage prevention through spatial planning, requires huge investments on the short term whereas the financial benefits of the strategy only become clear after relatively prolonged periods. Moreover, every possible strategy (including continuation of the present one) will create opposition. Therefore, the way in which support is found and sustained is essential to its implementation, and should be part of the strategy itself. Several project conclusions on possible improvements are relevant:

- One way to make sure a measure will be supported beyond the early decision making stages is to make sure that all relevant organisations are involved from the start. At present, different organisations with different 'perspectives' are decisive at different stages of the decision making process, which reduces overall support for measures and slows down the decision process.
- Specialised Decision Support Systems (DSS's) and communication tools like Role-plays are now sufficiently advanced to have a more prominent role in the decision making process than is now the case, and could make arguments clear to all parties involved. 04 13
- Public risk acceptance can be increased through 'public awareness' building, in several ways:
  - By clear and objective information on current and future risks.
  - By transparency on policy objectives.
  - By fair mechanisms for financial compensation of the consequences of both flood risk management measures and flood damages.

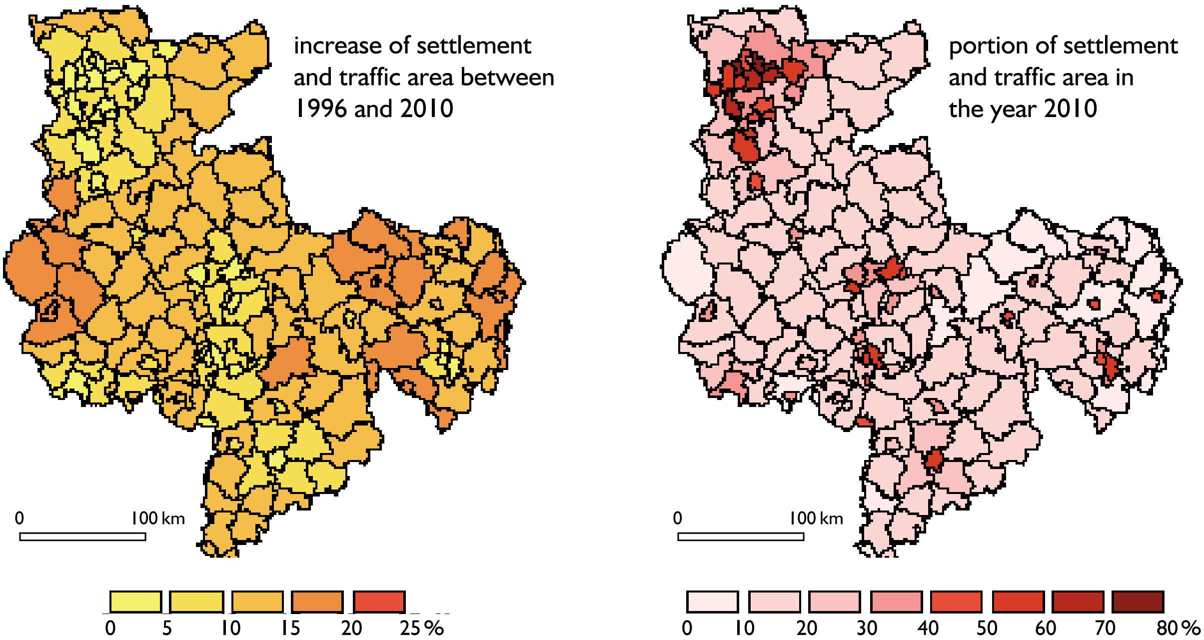
The importance of financial compensation

Financial compensation can have a role at two levels in flood risk management: to individuals (to compensate for losses due to measures or for flood damage) and to regions (to compensate costs involved in taking flood risk management measures).

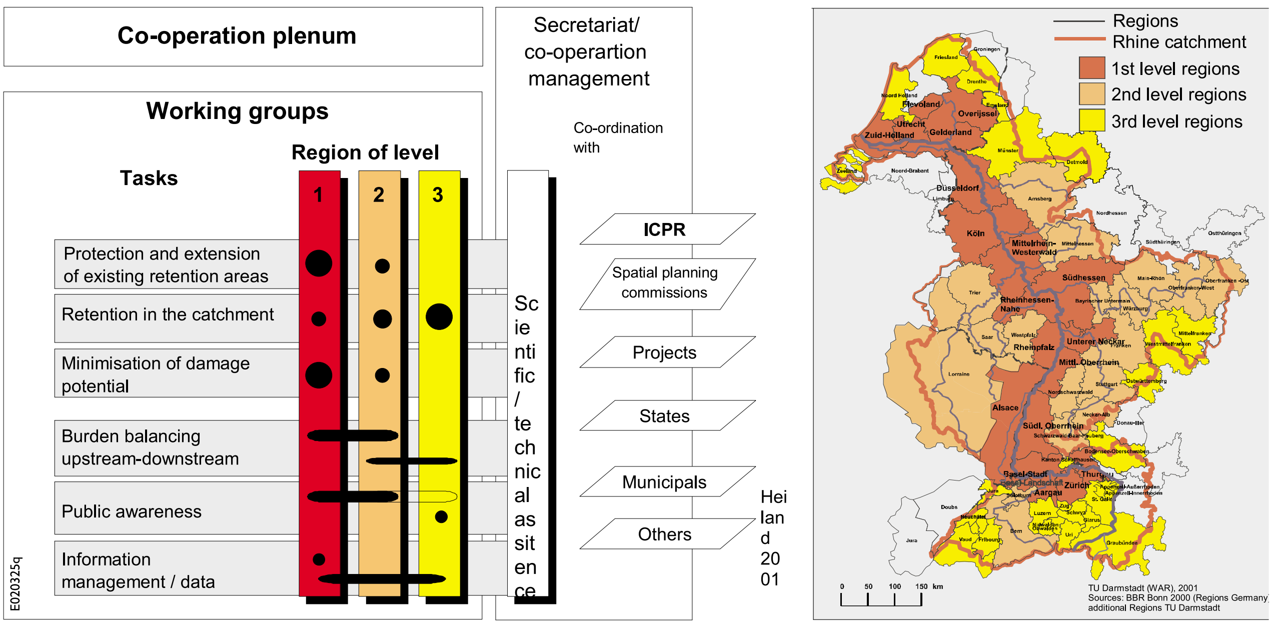
Compensation to individuals

The willingness to accept measures can be raised by having the local population benefit from the measures. Financial compensation of losses due to measures (e.g. losses of investments or economic opportunities) should be considered; at present this often happens insufficiently or too late. 05 10

Compensation of damages *after* floods is another matter where improvements are possible in many regions. This can be arranged through the public sector or the private sector, but clear guidelines are needed in both cases. These are now often lacking, creating uncertainty on the compensation that can be expected, and thereby contributing to a call for a costly (and ultimately unsuccessful) 'zero risk' strategy. That things can be different is shown in Switzerland, where 'community insurance programs' exist which aim at minimising the potential damages. Communities that have adopted such a program have seen their premiums reduced by 50% over the past twenty years - a clear indication that the 'insurance instrument' gives a good incentive to citizens and creates 'flood risk awareness'. This approach is likely to contribute to an increased acceptance of (limited) flooding.



Prognosis for the increase of urbanisation (‘settlement and traffic area’) in much of the German part of the Rhine basin (from Maxau to Lobith) from 1996 to 2010.
(Result of Project 2).



Suggested co-operation structure for integrated flood risk management in the Rhine basin.
(Result of Project 5).

Compensation to regions
In some cases, regions (or municipalities) have a responsibility for the flood risk in another region:

- Some flood risk reduction measures (e.g. flood detention areas) can be more efficient when taken somewhat upstream from the region where flood risk needs to be reduced most.
- Sometimes, regional river management is disadvantageous to other regions: e.g. river regulation may increase downstream flood risk; river blockages may increase upstream flood risk.

In both cases, there is a need for transfer of money between regions - either to take action or as compensation. Means to achieve this are funding of flood protection from a 'central' budget, or direct negotiations between downstream and upstream regions. The current practice of financing flood protection plans and measures provides insufficient incentives for this. Therefore, a fundamental change in the financing of flood protection towards burden compensation between regions and incentives for acting regions or municipalities is necessary. 05

Addressing flood risk in spatial planning: zoning as a regulatory measure

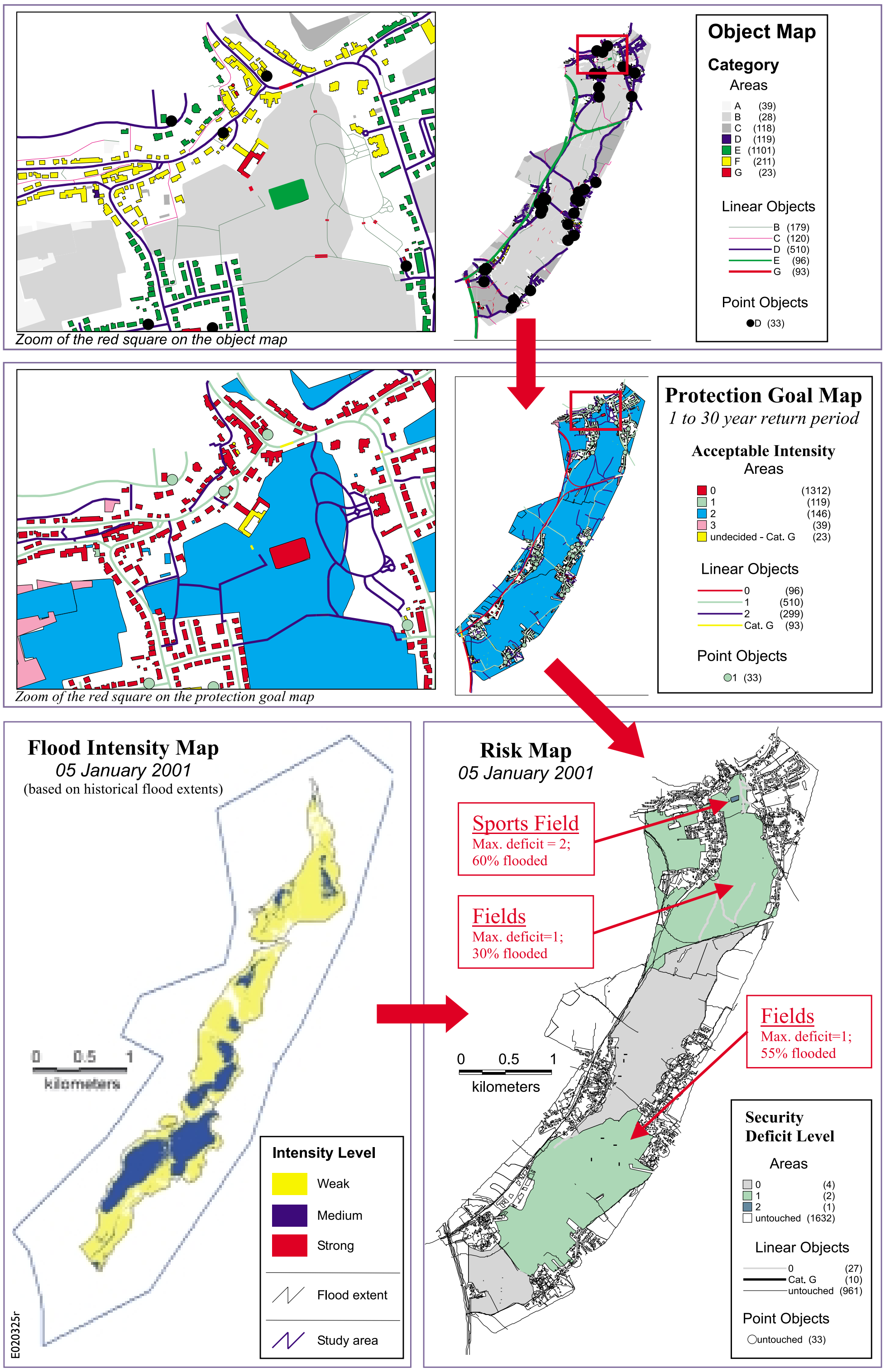
Spatial planning instruments exist in all countries in the Rhine and Meuse basins, but their contribution to flood damage prevention is found to be insufficient. An important reason for this is that organisations responsible for spatial planning and building approval (often at the municipal level) are decisive for successful damage prevention, but they usually give it low priority. As a result, the aim of the Flood Action Plan for the Rhine (by the International Rhine Commission) to reduce the damage potential in areas at risk of flooding is not achieved and the economic damage potential in river valleys and dike-protected areas continues to rise. 05
There are large regional differences in the way spatial planning instruments are used to control economic and demographic developments in potentially flooded areas. These differences result mainly from differences between the national cultures and planning systems, and not so much from differences in physical conditions (flood characteristics, land use etc.). It would be more efficient to optimise spatial planning practices for local or regional physical conditions. 05

The proper use of spatial planning instruments, to ensure that fewer investments will take place in flood-prone areas, can be improved on the basis of risk zoning based on flood hazard maps - a simple and effective tool for communicating spatial planning decisions to everyone involved. 05

Regional and institutional co-operation in flood risk management

Because of the hydrological and ecological links between upstream and downstream areas in a river basin, transboundary co-operation is essential, but it is not necessary to involve the whole catchment area for all questions. A hierarchically layered structure with e.g. 3 levels might provide an adequate framework for such co-operation at different levels. 05

Flood risk management and spatial planning must be much more closely integrated, because otherwise spatial claims, tensions and pressures will increase which is likely to result in higher risks and higher costs. This is especially important in countries/regions where spatial planning and water management are the responsibility of separate organisations (e.g. the Netherlands). 02 05 10 In cases where the responsibility for spatial planning and flood risk management belongs to a single authority, this will often be a planning organisation which may have insufficient knowledge especially in the area of hydraulics, flood hazards, vulnerability etc. - in this case, better information is required among spatial planners. 05
International co-operation should take regional differences into account. Not only the river changes along its course (e.g. it generally becomes more regulated going downstream), but the cultural and economic values attributed to the river and even to its ecological functions are also different. Co-operation will be more successful if the importance of such cultural differences is recognised and respected.



Schematised flood risk analysis for the Livange-Hesperange area in the Alzette river basin, based on historical water levels for the January 5, 2001 flood event (with a 1 to 30 year return period).
(Result of project 3).

6 Concluding remarks

Gaps in knowledge and data

The main aim of IRMA-SPONGE was to develop 'state-of-the-art' methods based on the best available information - and this aim has been achieved. However, for most projects the duration of the program was too limited for extensive new research, and some important gaps in our knowledge and in the data available remain.

Need for inclusion of social and economic sciences

The focus of most projects in IRMA-SPONGE has been on physical (climatic, hydrological and hydraulic) and ecological aspects, and this has resulted mainly in conclusions and recommendations on the *effectiveness* of measures. However, in the reality of flood risk management the public perception of measures is no less important than scientific facts on the effectiveness of these measures. Therefore, for studies on the *feasibility* of measures, and on the best way to implement them, further co-operation should be sought with economists and social scientists.

How to deal with uncertainties?

There will always be uncertainties in the prediction of future developments - not only in climate scenarios but also in the acceptance of risk and in the priorities set by society. Several related knowledge gaps are identified:

- If decision makers would aim to develop integrated flood risk management strategies that can deal with uncertainties, then research should aim at defining integrated and coherent scenarios on which to base such strategies - this calls for further integration of physical, social, economic sciences with environmental sciences.
- If public awareness of uncertainties is raised, an effort should be made to clearly indicate these uncertainties in research results, in a way that the public can understand.
- If uncertainties are to be indicated better in research results, they should be part of the output of hydrological and hydraulic models - this is insufficiently the case at the moment.

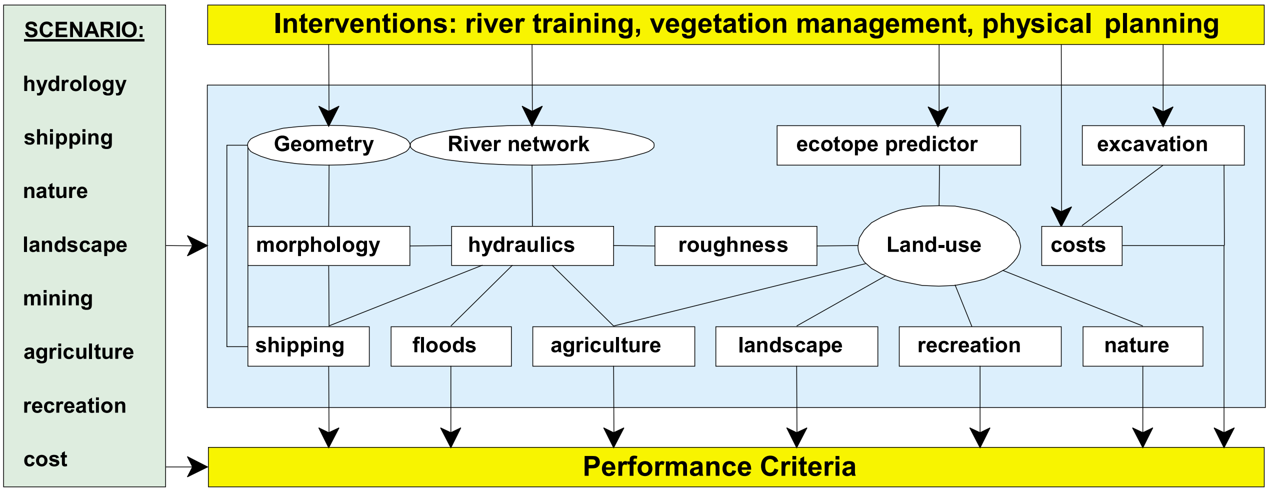
Better data needed for improved flood hazard maps

Flood damage prevention through improved spatial planning of investments (risk zoning) based on flood hazard maps is an effective flood risk management measure. The techniques to develop such maps have developed rapidly in recent years (GIS, tools to predict flood probability, 2D flood models), and it would be technically feasible to develop them for extensive areas along the Rhine and Meuse. However, the availability of highly detailed Digital Elevation Models, needed for this exercise, is insufficient at present. Development of large-scale hazard maps for the Rhine and Meuse basins requires a political decision to develop and make available a basin-wide digital topographic database that is highly detailed and accurate.

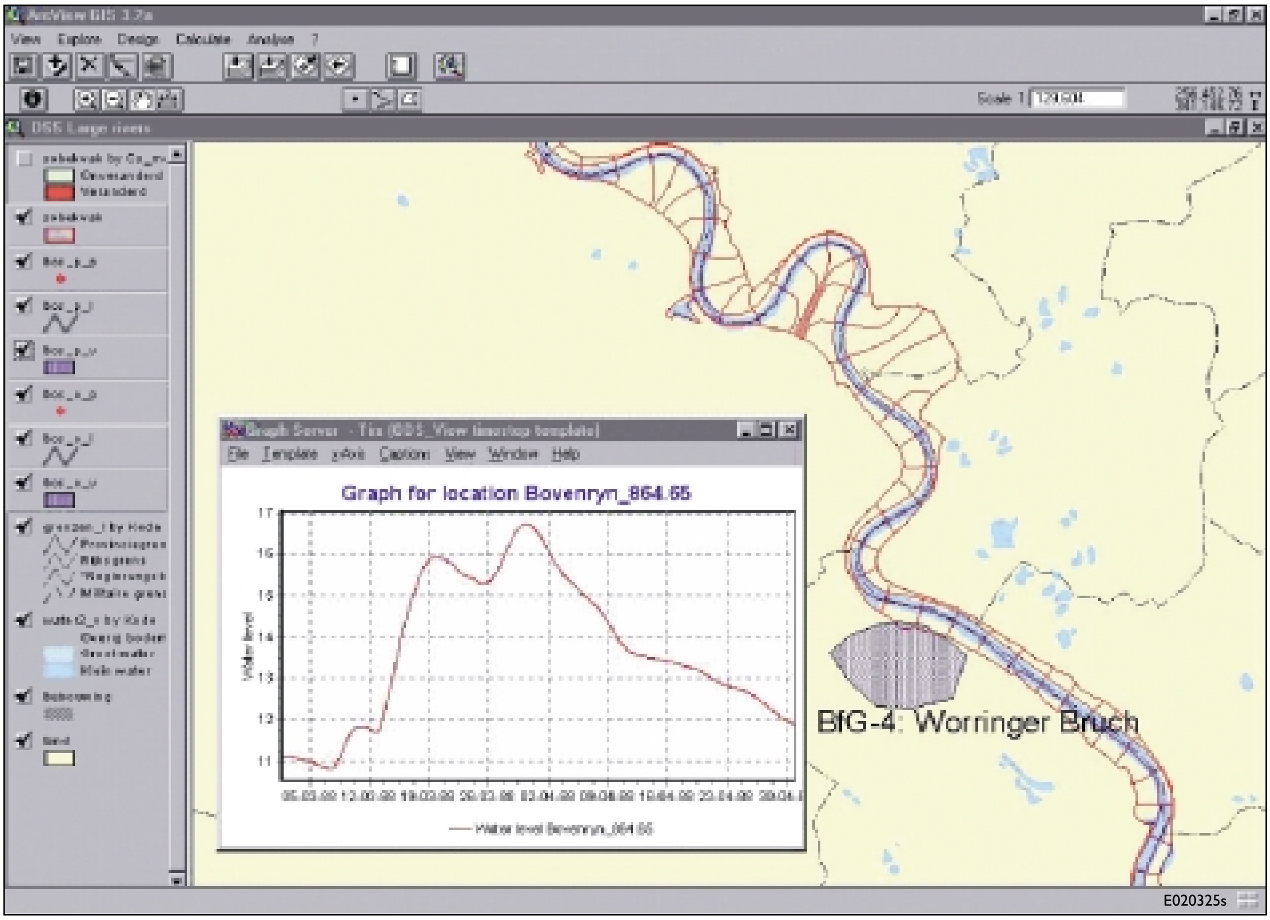
Lessons learnt

The value of centralised program management

The IRMA-SPONGE Umbrella Program was complex in many respects: it was international, co-financed from different sources, multidisciplinary, and a large number of individuals and organisations were involved. In all, research was carried out by more than 50 scientists from 30 institutes, working together in 13 projects. Much of the research dealt with complex and sometimes sensitive issues. Moreover, the period during which all projects were co-ordinated to achieve common goals lasted only 2 years - a very short period for the tasks involved. The fact that these goals were achieved testifies to the very co-operative attitude amongst participants, who agreed that they were helped a lot by the centralised and transparent, albeit sometimes rather strict, program management executed by NCR. The lesson is that such program management is a prerequisite to keep this type of program on track.



Relationships between modules in the STORM-Rhine simulation tool for flood risk management, which allows 'players' to learn about the effects of a wide range of flood risk management measures. (
Result of Project 13).



Interface of the DSS Large Rivers, with the Rine river and a location for a potential detention area, of which the effect on water levels can be calculated.
(Result of Project 4).

Improved understanding amongst scientists
An important goal of the program was to enhance transboundary co-operation amongst scientists, and several initiatives in this direction were taken within IRMA-SPONGE. It was found that not only the practical co-operation could be improved, but also the understanding between scientists: cultural differences between regions also exist in the way issues and research questions were perceived by scientists from different regions. There is not necessarily a single 'best' flood risk management strategy: the perception of issues varies in space and changes in time, and these differences should be bridged, not covered up. The program has invested in building a transboundary, multidisciplinary network of research groups that communicate well. It is suggested that this network should be kept active, extended and exploited further. Certainly, transboundary co-operation between planners and managers requires transboundary understanding, and this is only possible if scientists are co-operating not on an ad-hoc basis, but within a long-term international and interdisciplinary network.

Language differences can lead to differences in understanding
Though all participants in IRMA-SPONGE (from the Dutch, German and French language areas) could communicate very well in English, it appeared that certain English terms were interpreted differently by people from different countries, and sometimes even by people from the same country with different scientific backgrounds. Moreover, in some cases it was difficult to agree on translation of terms for region-specific concepts (e.g. certain measures) into or from Dutch, German or French. It is therefore recommended to 'standardise' terms and concepts at an early stage in programs like IRMA-SPONGE, that are both multidisciplinary and transboundary. The glossary added to this summary aims to contribute to this.

Need for clear target groups for research
In IRMA-SPONGE, scientists have developed methods and tools for decision makers, spatial planners and others that are active in flood risk management. In some cases, however, it is not clear which organisation or person is going to use these results of research and developments. For example: while a DSS or 'communicative Role-play' can clearly have a function in the development of flood risk management strategies and implementation of measures, it is not always clear who should use it, for which purpose and when. If this information would be available, some of the research could be 'targeted' better and research results could be communicated more efficiently.

ANNEX

Abstracts of projects focussing on 'Flood Risk and Hydrology' aspects

Project 1 — DEFLOOD: Development of Methodologies for the Analysis of the Efficiency of Flood Reduction Measures in the Rhine Basin on the Basis of Reference Floods
Keywords: hydrometeorological reference condition, integrated river basin modelling, framework
Objective: to develop procedures for assessment of the effect of decentralised measures on flood generation in large river basins — as the basis for planning instruments. Furthermore, the method developed should allow comparison and evaluation of past and probable future flood events.
Method: Procedures for defining hydrometeorological reference conditions (HRC), using hydrological models, were developed. These conditions are classified on the basis of historical and synthetic time series of precipitation and temperature. In addition, methods are studied for estimation of a maximum possible precipitation distribution. A framework (FIRM-Flood Reduction) was set up for an integrated catchment modelling approach that encompasses the defined HRCs, an integrated river basin modelling component (precipitation-runoff modelling and flood routing tools), and guidelines for incorporating scenario calculations. The River Mosel basin was the pilot study area for demonstrating the methodologies developed.

Project 2 — Integrated management strategies for the Rhine and Meuse rivers
Keywords: land use, climate change, hydrological modelling, uncertainties, perspectives, scenarios.
Objective: to develop a set of integrated water management strategies (and scenarios) for the Rhine and Meuse basins, which consider possible future developments taking into account uncertainties.
Method: a scenario study was carried out in which physical modelling was combined with socio-cultural theory. Existing climate, land use and socio-economic scenarios, as well as flood risk management strategies have been structured using the Perspectives method. This resulted in integrated scenarios for water management, each representing a different view on the future, linked to a specific water management style. Using a suite of existing modelling tools the implications of each scenario for the water systems were evaluated. Finally, the risks, costs and benefits associated with each strategy were evaluated for each scenario.

Project 3 — FRHYMAP — Flood Risk and HYdrological MAPping
Keywords: climate change, hazard, hydraulic model, hydro-climatological atlas, hydrological model, land use change, regionalisation
Objective: improving the understanding of flood genesis, mainly in headwaters, and of the management of floods in the floodplains.
Method: a wide range of issues associated with flooding events, reaching from hydro-climatological causes to socio-economic impacts, were studied. Studies took place in the single, meso-scale, transboundary basin of the Alzette river. Time series analysis was carried out to search for signals of effects of land and climate change in the observed discharge records. The hydrological response of changes in land use on flood generation was simulated with a various hydrological models. Methods were explored for application of local results of hydrological models to larger areas (regionalisation).

Project 12 — Extension of the flood forecasting model FloRIJN
Keywords: river modelling, Flood Early Warning System (FEWS)
Objective: To set up a prototype Flood Early Warning System for the Rhine that forecasts peak discharges at the Lobith gauging station (near the Dutch border) with a 4 days lead time.
Method: The existing forecasting system FloRIJN system was extended in upstream direction and most of the model components were improved significantly. The system can use the historical data on precipitation (for calibration) and precipitation forecasts provided by the German Meteorological survey (DWD). Hydrological models were developed for the main part of the Rhine basin between Basel and Lobith.

Abstracts of projects focussing on 'Flood Protection and Ecology' aspects

Project 6 — Guidelines for rehabilitation and management of floodplains - *ecology and safety combined*
Keywords: floodplains, ecological rehabilitation, plan development.
Objective: to produce guidelines for optimisation of floodplain habitats and ecological infrastructure, while improving flood protection by increasing discharge capacity as a primary goal.
Method: from literature, recent scientific results and practical experience, recommendations were defined for the implementation of measures that might be considered in floodplain rehabilitation projects. This included excavation of stagnant water bodies, construction of secondary channels, lowering of floodplains, removal of minor embankments, grazing, encouragement of the development of natural levees, river dunes and marshes. The planning process is explicitly taken into account and a number points are addressed that need special attention when developing a floodplain management plan.

Project 7 — Cyclic Floodplain Rejuvenation
Keywords: floodplain lowering, vegetation rejuvenation, nature management
***Objective*:** the development of a strategy which will allow both improved flood risk management (by increasing the discharge capacity of the winterbed) and nature restoration.
Method: a cyclic floodplain rejuvenation (CFR) strategy was defined that involves cyclic excavation of the floodplains, (re)construction of the secondary channels and setting back the vegetation succession. This strategy was investigated for a stretch of the Rhine river in the Netherlands, applying a complex of hydrologic, morphologic, vegetation and habitat models and GIS. The long-term impact of the interaction between measures and natural (sedimentation/erosion and ecological) processes on water levels and ecological quality of the floodplains was analysed.

Project 8 — Evaluation of floodplain management strategies: the added value of wetland rehabilitation
Keywords: water retention, nutrient retention, value of water, denitrification, floodplain wetlands.
Objective: to evaluate the beneficial effect of wetlands on flood risk reduction and water quality improvement.
Method: the study consisted of two parts: A) The contribution of floodplain wetlands to flood risk reduction was assessed; it was determined conceptually whether the position of a wetland in the basin — upstream or downstream — will influence the value of the wetlands in terms of reduced flooding damage. B) It was assessed whether increased areas of downstream floodplains — and more specifically rehabilitation of agricultural grasslands into floodplain wetlands — may increase nutrient retention.

Project 9 — Intermeuse: the Meuse reconnected
Keywords: Integrated water management, nature rehabilitation, spatial cohesion, physical habitat evaluation.
***Objective*:** to provide solutions on how optimisation of flood protection along the Meuse can best be combined with sustainable floodplain ecosystem rehabilitation — focussing on spatial planning aspects.
Method: an evaluation method was developed and tested. Two scale levels at which flood protection and floodplain rehabilitation can be integrated were elaborated: global for a river basin or local for a specific site. Ecological aspects studied were spatial cohesion and habitat configuration (global level) and habitat quality (local level). Based on the results of the analyses performed an integration approach was developed that can be used in different parts of the planning cycle: different toolboxes for the planning phase and the actual evaluation, and guidelines of how to use these toolboxes in practice.

Project 11 — BIO-SAFE
Keywords: riverine ecosystems, biodiversity assessment, nature conservation policy and legislation.
Objective: to produce a tool for impact assessment of flood prevention measures on biodiversity in floodplains.
Method: The transnational model BIO-SAFE (Spreadsheet Application For Evaluation of BIOdiversity) for the rivers Rhine and Meuse is a policy and legislation based assessment model that quantifies biodiversity values in river basins for several taxonomic groups on the basis of the policy status of river characteristic species. The model uses data on presence of species and of riverine landscape ecological units (ecotopes) for different spatial scales. It gives information regarding the degree to which floodplain designs or observed (or predicted) trends of floodplain developments meet goals set in (international) agreements.

Abstracts of projects focussing on 'Flood Risk Management and Spatial Planning'

Project 4 — DSS - Large Rivers and analysis of retention options along the lower Rhine river
Keywords: Decision Support System (DSS), flood risk management, detention areas.
Objective: to support decision making regarding flood detention measures along the Lower Rhine river, taking into account hydraulic, landscape- and ecological consequences.
Method: A generic Decision Support System was developed that supports the planning and assessment of river landscapes —with a focus on options for retention and detention areas along the Lower Rhine River. Effects of such options are addressed at the feasibility level, not at detailed design level. Besides 1D and 2D computational modules for hydraulic and ecological impact assessment the DSS also contains an information management system that provides easy access to relevant documentation as well as a database-based system containing results of previous analyses. Special attention was given to the integration of hydrodynamic modelling with ecological and habitat analysis, network evaluation and landscape evaluation.

Project 5 — Spatial planning and supporting instruments for preventive flood management
Keywords: spatial planning, regional planning, hazard zoning, interregional co-operation, burden sharing, information management, risk management, public awareness.
Objective: to produce recommendations for optimising the (use of-) spatial planning instruments for flood risk management purposes, for European, national, regional and local spatial planning authorities.
Method: Two groups of spatial planning instruments were investigated in Switzerland, France, Germany and the Netherlands: zoning instruments (regulative instruments of regional planning, hazard zoning) and supporting soft *instruments* (co-operation, incentives, information management). Similarities and differences were analysed, and recommendations produced for A) better use of existing regulation instruments and B) improvement of regulations.

Project 10 — Living with Floods
Keywords: flood risk management, multiple land use, Rhine River, river basin management, resilience, sustainable development, land use planning.
Objective: to design and evaluate alternative flood risk management strategies for the lower Rhine river which are applicable for the long-term (50-100 years) and better take into account the uncertainties that are inherent to lowland rivers. This by aiming at resilience rather than control (resistance), and by looking specifically at the options for multiple land use.
Method: Two different strategies were elaborated, based on the principle of resilience and living with floods: compartmentalisation for detention and green rivers for discharge. It was found that these alternative strategies have many advantages from a sustainability point of view, although they are difficult to implement.

Project 13 — STORM-Rhine - simulation tool for river management
Keywords: simulation game, role-play, participatory decision-making, river functions, stakeholder interests.
Objective: to produce a simulation game as a tool that can improve understanding of river and floodplain management amongst policy makers and stakeholders along the Lower and Middle Rhine. This by (1) raising awareness of river functions, (2) exploring alternative strategies, (3) showing the links between natural processes, spatial planning, engineering interventions, river functions and stakeholder interests, (4) facilitating the debate between different policy makers and stakeholders from across the basin.
Method: the heart of the tool is the hydraulic module, which calculates representative high- and low water-levels for different hydrological scenarios and influenced by river engineering measures and physical planning in the floodplains. The water levels are translated in flood risks, navigation potential, nature development and land use opportunities in the floodplain. Players of the Role-play represent institutions with interests in different functions (flood protection, navigation, agriculture, urban expansion, mining and nature).

Glossary of technical terms used in the IRMA-SPONGE summary

GLOSSARY of terms related to flood risk management, with translations into Dutch and English

*This glossary explains terms as they are used in this summary, it does not aim to 'standardise' terms. In some cases, more than one explanation or translation is given.**

English	***Dutch***	***German***
alluvial plain: flat area shaped by river processes and formed by river sediments.	alluviale vlakte	alluviales Flachland
attenuation (flood peak-): lowering a flood peak (and lengthening its base).	hoogwatervervlakking	Hochwasserverflachung
basin (river-) (*same as catchment area*): the area from which water runs off to a river.	stroomgebied	Einzugsgebiet
biodiversity: the variability among living organisms; this includes diversity within species, between species and of ecosystems.	biodiversiteit	***Artenvielfalt***
catchment area (river-) (*same as river basin*): the area from which water runs off to a river	stroomgebied	Einzugsgebiet,
channel (river-): main watercourse.	stroomgeul (hoofd-)	Hauptrinne
climate change scenario: prediction of expected long-term developments in climate, i.e. in the average temperature, rainfall and wind speed, and in the variation therein.	klimaatveranderings scenario	Klimaveränderungs-szenario
compartmentalisation (*Dutch concept*): dividing a dike-protected area into smaller protected areas.	compartimentering	Untergliederung
cyclic rejuvenation: periodic floodplain lowering (through excavation), setting back morphological and ecological processes to an earlier stage of development.	cyclische verjonging	zyklische Verjüngung
design discharge: flood discharge for which the river system (channels, dikes, structures) was designed.	onwerpafvoer	Entwurfswassermenge
design flood: flood level for which the river system (channels, dikes, structures) was designed.	ontwerphoogwater	Bemessungshochwasser
detention area (*term used mainly in The Netherlands*): area for controlled storage of floodwater for 'peak shaving', usually in an area surrounded by dikes, with a controlled inlet/outlet for river water. The difference with 'retention' is that detention is more effective in storing water only during peak discharges, without being filled (and losing space for further storage) during early stages of floods, and without releasing water as soon as river levels drop. *Note that the terms detention and retention are sometimes used for the same concept, and that the term 'detention' is not universally accepted.*	detentiegebied	Gebiet zur gesteuerten Retention/Wasserspeicheru ng, (Taschenpolder, Rückhalteraum)
dike relocation: moving a dike away from the river in order to provide more space for the river water during floods.	dijkverlegging	Deichrückverlegung,
discharge (stream-, river-) (*same as flow*): as measured by volume per unit of time.	rivierafvoer, debiet	Abflussmenge
downstream (-area): situated relatively close to the outlet of a river basin.	benedenstrooms	Stromabwärts
ecological infrastructure: system of linkages between habitat patches.	ecologische infrastructuur	Ökologische Infrastruktur
ecotope: spatial ecological unit with (more or less-) uniform abiotic site conditions - location of an ecosystem.	ecotoop	Ökotop
evacuation scheme: plan for the combination of actions needed for evacuation (warning, communication, transport etc.).	evacuatieplan	Evakuierungsplan
flood (1): high river discharge.	hoogwaterafvoer	Hochwasserabfluß
flood (2): high water level.	hoogwater	Hochwasser
flood (3): inundation of land.	overstroming	Überschwemmung
flood damage: damage to investments (buildings, infrastructure, goods), production and intangibles (without direct monetary value: life, cultural and ecological assets).	overstromingsschade	Hochwasserschaden
flood control (-measure): *usually understood as* a set of actions aiming to limit the (potentially) flooded area as much as possible.	hoogwaterbeheersing	technischer Hochwasserschutz
flood discharge: flow during a flood event.	hoogwater afvoer	Hochwasserabfluß
flood early warning system (FEWS): suite of systems designed to provide a warning of flood levels well before they occur: A) flood forecasting system, B) warning system	hoogwater waarschuwingssysteem	Hochwasserwarnsystem
flood flow (*same as* flood discharge): flow during a flood event.	hoogwater afvoer	Hochwasserabfluß
flood forecasting system: suite of models designed to provide an early prediction of flood discharges: A) hydrological models	hoogwater voorspellings	Hochwasservorhersage-

English	***Dutch***	***German***
(converting precipitation to discharge); B) hydraulic models (predicting channel discharge and wave propagation).	systeem	system
flood hazard map: map with the predicted or documented extent of flooding, with or without an indication of the flood probability.	kaart van overstroombaar gebied	Karte der überschwemmungs-gefährdeten Bereiche.
flood level: water level during a flood.	hoogwaterstand	Hochwasserstand
flood peak: highest water level during a flood.	hoogwaterpiek	Hochwasserspitze
flood peak shaving: storing only the top of a flood wave, by 'detention' (or 'controlled retention'). Flood water is not allowed in the storage area until water levels are high. The effect it that the flood peak is lowered more than in the case on 'attenuation' in 'retention areas'.	aftopping van hoogwaterpiek	'Abschneiden' der Spitze der Abflusswelle
floodplain: part of alluvial plain (formed by river sediments) which is still regularly flooded.	uiterwaard, overstromingsvlakte	Flussvorland
flood prevention: actions to prevent the genesis of an extreme discharge peak.	voorkoming van hoogwaterafvoer	Hochwasserprävention
flood protection (-measure): to protect a certain area from inundation (using dikes etc).	hoogwaterkering, bescherming tegen hoogwater	Hochwasserschutz
flood risk: function of both probability of flooding, and potential damage due to flooding *(this is* ***not*** *the probability or 'danger' of flooding!)*	overstromingsrisico	Hochwasserrisiko
flood risk management: totality of actions involved in reducing the flood risk - the aim can be to reduce the probability, the damage, or both.	hoogwater risico beheer	Management des Hochwasserrisikos
flood risk zoning: delineation of areas with different possibilities and limitations for investments, based on flood hazard maps.	hoogwater risico …?	Risikozonierung
flood routing: calculation (or modelling) of the movement (propagation) of a flood wave through the river channel.	hoogwaterberekening	Hochwasserberechnung
flood wave: high water volume moving downstream through a river channel.	hoogwatergolf	Hochwasserwelle
flow (stream-, river-): A) *same as* discharge, as measured by volume per unit of time, B): movement of water *(not used in this summary).*	A) afvoer B) stroming	A) Abfluß(-menge), B) Strömung
FRM: abbreviation for flood risk management	-	-
green river (*Dutch concept*): an additional channel (constructed through presently dike-protected area) which increases the discharge capacity of the river system during high waters.	groene rivier	'Grüne Flüsse', Umflußkanal
habitat: natural environment of an organism. Also: the set of (riverine) ecotopes that a species can utilise during the various stages of its life cycle.	habitat, leefgebied	Habitat
hazard (flood-): specific natural event, such as a flood, with the potential to cause damage characterised by a certain probability of occurrence and an intensity.	(overstromings-)gevaar	(Überschwemmungs-) Gefahr
headwater: source area for a stream, i.e. highest area in a river basin.	brongebied	Quellgebiet
hydrological model: model that simulates the conversion of precipitation into channel flow (there are several fundamentally different types).	hydrologisch model	Hydrologisches Modell
hydraulic model: model which simulates water movement through a channel.	hydraulisch model	Hydraulisches Modell
inundation: flooding of land with water.	overstroming	Überschwemmung
measure (flood risk management-): measure that can be used as part of FRM.	maatregel	Maßnahme
modelling (hydrological-, hydraulic-, habitat-): simulation of natural processes and conditions, using a computer program	modelleren	Modellierung

English	***Dutch***	***German***
nature rehabilitation: allowing or enhancing natural processes.	natuurherstel	Renaturierung
peak flow / flow peak: highest discharge during a flood.	piekafvoer	Spitzenabfluß
precipitation: rainfall plus snowfall.	neerslag	Niederschlag
resilience (-flood risk strategy): consistent set of measures aiming to minimise the effects of floods, rather than to control (resist) them.	veerkracht	Dehnfähigkeit
retention (flood water-): temporary, uncontrolled, storage of flood waters, in a basin (sometimes a wetland) which is open towards the river. *Note that this term is not universally accepted, e.g. in 'Anglosaxon' areas it can be understood as 'seasonal storage of water', and in Europe it is sometimes used for what is called 'detention' in this summary.*	retentie	Retention
retention area: area in which water is stored.	retentiegebied	Retentionsgebiet
river regulation: adapting (e.g. straightening, widening, deepening) a river (or part of it).	rivierregulatie	Flußregulierung
runoff: the part of precipitation that appears as streamflow.	afstroming	Abfluß
scenario (flood risk-): a sequence of expected *autonomous* events which have an impact on flood risk but can not (at the moment) be influenced directly by flood risk management (though FRM aims to respond to scenarios with strategies). Events shaping scenarios may be: (A) 'natural' (e.g. climate change), (B) caused indirectly by human intervention (e.g. land use change in the catchment), (C) the direct result of social changes (e.g. trends in valuation of flood losses), (D) or result from economic changes (e.g. progressive investments in floodplains).	scenario	Szenario
Side channel: secondary channel through the floodplain.	nevengeul	Seitenrinne
spatial planning: decisions and regulations aiming to regulate and optimise the use of space for different functions.	ruimtelijke ordening	Raumplanung,
stakeholders: parties with a direct interest (stake) in an issue.	belanghebbenden	Interessengruppen
strategy (flood risk management-): consistent set of measures, developed to achieve a certain goal - often responding to a scenario.	strategie	Strategie
sustainable flood risk management strategy: strategy which aims to A) be effective in the long term, and B) can be combined ('integrated') with other functions - usually summarised as economic, social and ecological development.	duurzaam	nachhaltig
uncertainty analysis: determining the accuracy of a (modelling) result. A measure of the accuracy is needed to judge the fitness of a value as a basis for making decisions.	onzekerheidsanalyse	Unsicherheitsanalyse
upstream (-area): situated relatively close to highest parts of a river basin.	bovenstrooms	stromaufwärts
winterbed (*Dutch term, sometimes same as major bed or floodplain*): area between the dikes, across a river, consisting of the channel plus the floodplains.	winterbed, hoogwaterbed	Hochwasserbett Flußbett,

*A requirement for improved basin-wide flood risk management is good communication between experts and decision makers. For this, it is necessary that they understand each other's technical terms. In IRMA-SPONGE, it was found that this is not always the case, for a number of reasons:
Some concepts are only used in certain languages and are hard to translate - 'literal' translations often have a very different meaning.
Even within languages, experts from different backgrounds often understand a word in different ways.
'Flood Risk Management' is a relatively new and very wide (multidisciplinary) field of expertise. New concepts and terms are continuously evolving.

This glossary aims to make sure the main concepts used in the IRMA-SPONGE summary report can be understood by all readers. It does not aim to 'standardise' terms in flood risk management (though there is certainly a need for this), but only to explain the terms as they are used in this Report - it is therefore possible that more accurate or comprehensive explanations exist. The full explanation of terms is given only in English. In Dutch and German, only the translation of the word is given; a French version is being developed. Explanations and translations are based on A) technical dictionaries, B) the understanding of the author, C) contributions by IRMA-SPONGE participants.

The Netherlands Centre for River Studies (NCR) is a collaboration of the major developers and users of expertise in the Netherlands in the area of rivers, viz. the universities of Delft, Utrecht, Nijmegen and Twente, IHE, ALTERRA, TNO-NITG, RIZA and WL | Delft Hydraulics.

NCR's goal is to build a joint knowledge base on rivers in the Netherlands and to promote co-operation between the most important scientific institutes in the field of river studies in the Netherlands. This co-operation will also strengthen the national and international position of Dutch scientific research and education.

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