Report on the results of the workshop ‘Heavy precipitation events and torrential floods: new risks and options for action in the Rhine catchment area’

4 October 2023, BMUV, Bonn

Workshop of the Working Group ‘High and Low Floods’ with the participation of the Working Groups ‘Ecology’ and ‘Water Quality/Emissions’ of the ICPR

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Summary

At the workshop 'Heavy rain and flash floods: New risks and possible actions in the Rhine basin' on 4 October 2023 at the BMUV in Bonn, the approximately 50 participants were able to deepen their knowledge of these events and their effects in the Rhine basin and exchange their views on the responses of the national states and the ICPR, particularly in the context of implementing the Floods Directive or national strategies. The workshop also provided a framework for an exchange on this topic with the 'Water Quality and Emissions' and 'Ecology' working groups, which will serve in particular as an interdisciplinary contribution to the update of the ICPR climate change adaptation strategy by the end of 2025.

This report provides a summary of the information exchanged during the workshop, as well as recommendations and conclusions that can be incorporated into the work of the ICPR and the states in the Rhine basin.

1. Overview of the workshop

1.1. Background and aim

Heavy rain is defined as intense precipitation falling within a short period of time, often from convective clouds. These events can occur anywhere and may cause rivers to rise rapidly, leading to flooding and often soil erosion. The widespread nature of this risk, which can affect all types of areas, poses an additional challenge when it comes to taking action. Heavy rainfall can trigger two main types of flooding: river flooding and flash floods. The first type involves surface runoff, which leads to local flooding and is often exacerbated by the lack of adequate drainage. It can, but does not have to be associated with a water body and may affect both urban and rural areas. The second type involves an increase in water levels, often without warning, after small-scale, intense rainfall.

Against the background of the implementation of the programme 'Rhine 2040' and the 2nd International Flood Risk Management Plan (IFRMP) Rhine by the states, the update of the ICPR climate change adaptation strategy by 2025, but also in view of the (catastrophic) events of recent years with heavy rainfall and flash floods in the Rhine basin and in view of the expected increase in this type of events due to the consequences of climate change, the ICPR wanted to exchange ideas with various stakeholders from the fields of flood management (WG H, external experts), water protection (WG S) and ecosystems (WG B) in the context of a dedicated workshop.

The aim of the workshop was to analyse the effects of heavy rain and flash floods and to provide guidance for national, cross-border and interdisciplinary measures to manage these risks, particularly in the context of the ICPR.

All information, presentations and background documents for the workshop are available in Appendix 1 or here on the IKSR website.

1.2. Programme

After a welcome and opening by ICPR President Miriam Haritz and the Chair of the WG H, Jan Kruijshoop, the speakers explained the consequences of climate change on the formation of such phenomena (contribution of the ICPR Expert Group HCLIM; see Chapter 2), the problems for water quality and the ecosystem associated with such events, and possible solutions (contributions from WG as and WG B, represented by chairs Friederike Vietoris and Stella Jelden; see Chapter 4). The various national states then presented a broad spectrum of regional impacts and, in particular, mitigation measures that have been taken at different levels (see Chapter 3).

In addition to these presentations, the approximately 50 participants, who mainly came from the countries in the Rhine basin, discussed the following key questions of the workshop intensely with the delegates of the WG H, WG S and WG B as well as the observers of the ICPR in breakout sessions and in plenary:

- What impact does climate change have on the risk of heavy rainfall and flash floods?
- What impact does heavy rain have on water quality and ecology, and how can these impacts be minimised?

- What experience has been gained in the Rhine basin with the management of heavy rainfall and flash floods?
- How can these aspects be integrated into the implementation of the Floods Directive (FD), particularly in connection with the preliminary flood risk assessment (PFRA), the flood hazard maps and flood risk maps, and the flood risk management plans?
- How can these elements be considered in an interdisciplinary way in the ICPR climate change adaptation strategy?

The findings on these key questions of the workshop, which are presented in the following chapters, are based on the presentations and discussions during the workshop.

2. Effects of climate change on the risk of heavy rainfall and flash floods

Climate change causes an intensification and more frequent occurrence of convective precipitation events, which are characterised by substantial amounts within short periods of time and their small-scale occurrence, which favour flash floods. The latest available climate models with high spatial and temporal resolution indicate that these events will become more frequent and more intense (especially in summer) under high-emission scenarios (RCP8.5). A one-hour event with a return period of ten years, for example, may increase in intensity by 10 to 30%. Furthermore, an increase of 25% in days with precipitation of more than 20 mm has been calculated for the Rhine basin by 2071-2100.

Flash floods and severe flooding, as observed in Braunsbach in 2016 and in the Ahr Valley in 2021, will occur more frequently due to the increasing number of heavy rainfall events. This underlines the urgency of adapting spatial planning, risk management and infrastructure to minimise the impact on the population and the economy, but also on the ecosystems in the Rhine basin.

The findings and the need for research into the effects of climate change on these types of events are described in the new ICPR technical report no. 297 (report of Expert Group HCLIM), in particular in chapters 4.4. and 6.2. There, it is recommended to set up convective models with a higher temporal and spatial resolution or to improve existing models so that they can capture and map small-scale intensive precipitation and convective processes that lead to flash floods, among other things.

3. Management of heavy rainfall and flash floods

As the workshop has shown, flooding caused by rain and surface runoff poses a particular challenge. Although significant, they differ from river flooding (which also includes flash floods). Various factors are particularly noteworthy; these include flow velocity, for example in sloping terrain. The distinction between the different forms of flooding can be fluid and gradual.

During the workshop, national and European stakeholders (EU Working Group Floods - WG F, but also the International Commission for the Protection of the Elbe) and participants in flood management projects made it clear that, in the wake of the tragic events of July 2021 in the states in western part of the Rhine basin, numerous measures to prevent and protect against risks associated with heavy rain and flash floods have already been taken or intensified, are planned or have been identified. They can be summarised as follows:

1. **Evaluation and planning in the context of risk management. Improving knowledge and models** (climatological, hydraulic, forecast, digital terrain models, …). It should be noted that the need for climate models has in the meantime been described in ICPR technical report no. 297. **Cartographic recording and assessment of risks** from heavy rain, surface runoff and flash floods. If possible, adaptation of the available information – even on small rivers – after significant events. **Extreme scenarios** – such as those in which the water level of the extreme scenario is exceeded ('real worst case') and where debris accumulations occur at bridges or such as those calculated by the Netherlands after July 2021 ('stress tests', 'water bomb') – are of great importance for assessing and avoiding risks and for preparing for disaster management. These scenarios

provide valuable insights, complement the cartographic documentation, and can be transferred to other regions.

2. **Adaptation of the legal framework and simplified application** of rules and practices in the areas of planning, urban development, agriculture, and architecture that favour the preservation or balanced use of space, the infiltration or retention of rainwater (see Chapter 4), as well as building precautions or protection. This also applies to sensitive facilities such as industrial plants, hospitals, schools, old people's homes, and emergency services buildings. Critical infrastructure, including the sewage system (see Chapter 4), should not be left out either. One example is the insufficiently widespread installation of non-return valves to prevent flooding caused by backflow from the sewage system, which is a major cause of damage.
3. Using the **'window of opportunity' offered by reconstruction after a disaster** to plan or build in a more resilient and sustainable way. Avoiding reconstruction in the same place (as can be observed in parts of the Ahr Valley).
4. **Improving or adapting flood protection** along watercourses at risk, but also in areas where surface water runoff concentrates. Eliminating blockages of debris. Promoting nature-based solutions (see Chapter 4).
5. **Improving awareness, communication, forecasting and warning**. Raising **risk awareness**, communicating about risks and measures (general or individual) plays a key role – especially in the context of disasters (e.g. floods in July 2021). Communication strategies must be formulated at an early stage to involve stakeholders or the population from the beginning (highlighted in the presentation by Austria and the EU WG F). Use or development of **various and specific/adapted communication tools and systems** (in particular cartographic tools, e.g. maps for surface runoff and heavy rain, in Switzerland and Germany), forecasting and early warning (e.g. Vigicrues Flash in France). There are three main types of warning: for large rivers, for small catchment areas and those that come from meteorological services.
6. **Optimisation of disaster management** for these 'new' types of events. A key factor that became apparent during the floods in the Ahr valley is crisis management and preparation for crises. Clearly define and disseminate responsibilities for warning and crisis management (national, regional, and local actors). Develop evacuation and emergency plans to protect the population or sensitive/critical infrastructure.
7. **Coordination** between different actors and services, but also between regions and states (particularly at the EU level) for a **joint response** to hazards caused by severe weather, surface runoff or flash floods.

These measures – which are being quickly expanded in the Rhine basin – aim to reduce the vulnerability of people and ecosystems in the Rhine basin to extreme meteorological and hydrological events, while also promoting resilience and sustainability in the long term.

The presentations at the workshop clearly show that all the states in the Rhine basin take this risk and its expected increase very seriously.

Recommendations: For the national states: Further **implement or further develop** the range of measures listed above. **Within the ICPR**: **Continue the cooperation and cross-border exchange** of good practices. Facilitate the transfer from one region to another. Organise an in-depth exchange on proven communication practices in addition to the **planned meeting between disaster control and the WG H**. In addition: **Provide** participants from the workshop and members of the ICPR **with a collection of relevant cartographic websites or portals** (see appendix 2). If necessary, jointly assess possible risks and measures, and develop or calculate **extreme scenarios or stress tests** for precipitation or flooding in the entire Rhine basin or parts of it.

4. Impacts on water quality and the ecosystem and measures

Heavy rain and flash floods have a **significant impact on water quality and ecosystems in the Rhine basin**. The most important consequences, which were discussed during the workshop, include:

1. As regards **deterioration of water quality**, heavy rain can cause pollutants that have accumulated on urban, agricultural, and industrial land – such as fertilisers, pesticides and herbicides, hydrocarbons, and waste – to be transported, remobilised, and washed out. Examples from regions such as Berlin and along the Rhine show that such pollutants can be detected after heavy rainfall, leading to increased pollution of surface water and, indirectly, groundwater.

   Critical infrastructure such as wastewater treatment plants and sewage systems are particularly susceptible to overloading or even direct damage from flooding during heavy rainfall. An example is the BASF industrial wastewater treatment plant in Rhineland-Palatinate, which has been overloaded several times by flash floods, leading to discharges and the release of biomonitoring warnings.

   There is, however, often a lack of measurement options during heavy rainfall, especially in combined sewage systems. In these systems, rainwater and wastewater are discharged together, which leads to untreated wastewater and remobilised sediments during heavy rainfall, thus affecting water quality.

   Flash floods can also lead to increased water turbidity and microbiological contamination, which can affect ecosystems and drinking water quality. During dry periods, deposits in the sewer network additionally contribute to pollution by being remobilised and overloading wastewater treatment plants. In particular, in small catchment areas, discharges from wastewater treatment plants can account for a significant proportion of total runoff during dry periods, thus deteriorating water quality.

2. Even though the **biocoenoses in rivers are adapted to flooding** and can recover quickly if there are refugia, **heavy rain and flash floods** – which are intensified by climate change and inappropriate spatial planning – **can severely affect aquatic habitats**. These events often cause the pollution of rivers and water bodies, soil erosion and leaching, and the destruction of habitats, particularly through the washing away of sediments, the alteration of banks and the destruction of riparian vegetation. In summer, when thunderstorms occur, the situation is exacerbated by the increase in low water levels and water temperatures, which puts additional stress on populations. Impermeable soils, especially in urban and agricultural areas, restrict the infiltration of water and increase runoff and the risk of mudslides.

The participants of the workshop intensively exchanged views on the measures already taken, possible measures and the development of a coherent and integral approach to this topic. The following section presents the **general recommendations for the ICPR**, while the more **detailed recommendations of the experts** for the protection of water bodies and ecosystems for the experts in flood management can be found in Appendix 3.

Recommendations for the ICPR:

- Thanks to its many years of experience in this field, the ICPR can contribute to strengthening strategies and environmental regulations to **reduce sources of pollution**.
- The ICPR and the responsible stakeholders are called upon to do more to promote **measures to improve the protection of wastewater treatment systems**, to be better able to deal with rainwater and flash floods and to prevent pollution. This also requires better use of synergies between existing EU directives, for example those relating to the protection of critical infrastructure or industrial emissions. Critical infrastructure such as wastewater treatment plants and sewers must not only be protected against flooding and adapted to an increase in extreme weather events, but also evaluated in terms of their ecological impact and cyber risks.
- Regarding the **protection of ecosystems**, the ICPR must continue to promote the preservation or sustainable use of land or soil, the restoration of natural habitats, water retention and storage, agroforestry and reforestation, ecological forestry and agriculture, and the improvement of infiltration capacity in both urban and agricultural areas. In this context, the ICPR must keep an eye on European developments (DG Agriculture, CAP).
- A **holistic and interdisciplinary approach** is needed (*see also the findings of the 2018 ICPR workshop 'Floods/Ecology', ICPR Report No. 260*). It is crucial that the number of existing ICPR working and expert groups is not increased. Instead, the **exchange between groups and disciplines** must be strengthened. Workshops such as this are valuable and should be repeated to promote dialogue. It is necessary to learn from the workshops and exchanges and to improve coordination between sectors. The next ICPR workshop on climate change is seen as an important opportunity to intensify this exchange (see Chapter 6).
- It is recommended that more **no-regret and win-win measures** be implemented, which are effective in the event of frequent heavy rainfall and flooding, but also take account of droughts.
- The stakeholders and the ICPR should work more intensively on the **consolidation of data and maps** to enable an **integrated** and detailed **analysis** of environmental risks. The ICPR could play a role here by providing and combining various national map portals and those of the ICPR/IRBD Rhine (e.g. atlas of floodplains and flood risks on the Rhine – called 'Rhine Atlas' - including potentially environmentally hazardous facilities as well as land use, biotope atlas, numerous maps of the RBPM). In this context, the potential of GIS should be examined for the future. Similarly, the possible use of the ICPR GIS tool 'FloRiAn', which already combines different levels of information and allows calculations, should be examined.

5. Addressing these risks in the national implementation of the Floods Directive, coordinated by the ICPR

Although the topic of pluvial flooding was not one of the priorities in the early years of the Floods Directive, consideration is now being given to harmonising the approach. The EU WG F has organised workshops on this topic. The challenges lie in the **complexity of defining and understanding** the integration of heavy rain into the Floods Directive, as the topic is not yet fully covered by the directive. Although heavy rain causes extensive damage, it is often not considered a 'significant risk' in the sense of the directive. Furthermore, the various terms used in this regard are still insufficiently defined or harmonised. For example: 'heavy rain index maps', 'maps of surface water runoff concentration' and 'risk maps for flash floods'.

Various national approaches to implementing the Floods Directive were explained in detail, particularly during the breakout sessions. Federal states like Germany face additional challenges – like Austria, which is trying to implement harmonised approaches for heavy rain. In Germany, heavy rain events are the subject of a separate regulation, and it is planned to create standardised maps for the whole country by the first quarter of 2024. Luxembourg has already included heavy rain in its hazard and risk maps in the second cycle and added its own strategy for heavy rainfall as an appendix to the FRMP. Some municipalities have already developed concepts, but there is still a need for better data (e.g. to identify hot spots).
The Netherlands plan to include heavy rain in the next cycle of the Floods Directive and to create new flood hazard maps and flood risk maps.

Recommendations: The **harmonisation** of terms and approaches, **communication** within the IRBD Rhine and between river basin districts, the exchange of good practice and the inclusion of small transboundary rivers are essential to **ensure coherent and coordinated implementation**.

Furthermore, the **use of the information** from the workshop and this report will help to ensure that the reports and '**Floods Directive' products of the national states and the ICPR** are adapted for the third cycle of flood risk management:

- **Updating the flood risk assessment and the identification of areas with significant flood risks**: At the national level, it is of crucial importance to review the latest data and models on the events in question in this context. In addition, information on the workshop and/or the topic of heavy rainfall and flash floods will be included in the new national reports to update the areas at risk of flooding and in the report of the IRBD Rhine, which was prepared in coordination with the ICPR WG H (Publication of the reports on the preliminary risk assessment (PFRA) by the end of 2024).
- **Updating the flood hazard and flood risk maps**: Information on these events can be used to update the maps. This would allow for better identification of areas at risk and adaptation of preventive measures. The ICPR's report on the flood hazard and flood risk maps and the Rhine atlas will be updated accordingly by the end of 2025/beginning of 2026.
- **Updating the national flood risk management plans and the IFRMP**: The revision of the FRM plans may include specific measures to reduce the risks associated with heavy rainfall and flash floods. A corresponding text will be included in the 3rd FRMP of the IRBD Rhine.

6. Contribution to the update of the ICPR climate change adaptation strategy

Participants from all sectors engaged in intense discussions about perspectives, challenges, and joint activities in the context of updating the ICPR climate change adaptation strategy by 2025. The cross-sectoral identification of impacts, vulnerabilities, and solutions in the context of climate change-related events carried out in this workshop will facilitate discussions at the 2025 climate change workshop and make it easier to develop the new strategy. This workshop has shown that updating the strategy requires a holistic approach to address the complex challenges posed by the effects of climate change in the Rhine basin, in collaboration with various experts and stakeholders.

Recommendations: Close **interdisciplinary cooperation** between the ICPR groups is of crucial importance for the ICPR's climate change adaptation strategy, to **jointly consider and manage heavy rainfall, flooding, drought and low water**. Mitigation or adaptation measures should be identified that address these various issues and avoid contradictions. It is recommended that **good practice examples** from the member states – particularly from small catchment areas – be included to highlight their added value for ecology and water quality as well as for reducing the effects of floods and low water.

Conclusions and general recommendations

Retrospectively, the workshop was an important forum to clarify the role of the ICPR in relation to the issue of heavy rainfall and flash floods and to bring together stakeholders from the fields of flood management, water protection and ecology to explore concrete strategies and measures and to give recommendations in response to the complex challenges of these events. The fruitful and cooperative exchange laid the foundation for increased future collaboration and enabled the transfer of good practice – on the way to greater resilience in the regions of the Rhine basin.

To mitigate the effects of thunderstorms, heavy rain and flash floods on society, water quality and ecology in the Rhine basin, the implementation of sustainable, integrated, and tailored assessment, prevention, protection, and management measures in cooperation with all stakeholders is of crucial importance. This cross-sectoral approach – which also includes sediment management and the issue of erosion – must be anchored in the next ICPR climate change adaptation strategy.

The exchange of information initiated during the workshop is to be continued within the framework of the coordinated implementation of the Floods Directive, the WFD and the ‘Rhine 2040’ programme. In addition, the results of the workshop will be used in the context of the assessment of flood risks (Floods Directive) in the IRBD Rhine by the end of 2024, and the revision of the flood maps (Rhine Atlas) by the end of 2025. These will contribute to the new ICPR climate change adaptation strategy (see corresponding workshop and the preparatory work of working groups H, B and S) and the first assessment of Rhine 2040, the 3rd FRMP and the 4th RBMP of the IRBD Rhine by the end of 2026.

Annex 1 – Programme of the workshop ‘Heavy rain and flash floods: New risks and possible actions in the Rhine basin‘

The workshop programme and the presentations can be accessed below:

Overview on the workshop on the website of the ICPR

Programme

Presentations and background information

Annex 2 – Relevant websites and mapping services

Switzerland:

- Surface runoff hazard map: https://www.bafu.admin.ch/bafu/de/home/themen/naturgefahren/fachinformationen/naturgefahrensituation-und-raumnutzung/gefahrengrundlagen/oberflaechenabfluss.html
- Publication on rainwater management in urban areas: https://www.bafu.admin.ch/bafu/de/home/themen/klima/publikationen-studien/publikationen/regenwasser-im-siedlungsraum.html
- Cities of tomorrow: the sponge city as a response: https://www.bafu.admin.ch/bafu/de/home/themen/ernaehrung-wohnen-mobilitaet/dossiers/magazin-2022-4-dossier/staedte-von-morgen-die-schwammstadt-als-antwort.html

Austria:

- HORA: hora.gv.at (Water/Surface runoff)
- WISA: https://maps.wisa.bml.gv.at/vorlaeufige-risikobewertung-2018 (Tab Gefahrenhinweiskarte Oberflächenabfluss), will be updated on 22 December 2024 (Publication preliminary risk assessment / areas with potential significant flood risk)
- Leaflet: https://info.bml.gv.at/service/publikationen/wasser/Eigenvorsorge-bei-Oberflaechenabfluss---Ein-Leitfaden-fuer-Planung-Neubau-und-Anpassung.html (new edition covering all flood processes planned for the first quarter of 2025)

France:

- Vigicrues Flash: https://vigicrues-flash.org/?mode=apic&area=fr&res=202410220800
- Heavy rain warnings at municipal level (APIC): https://apic.meteofrance.fr/?mode=vf&area=fr&res=202410220745

Germany:

Baden-Württemberg:

- Flooding BW topic heavy rainfall: https://www.hochwasser.baden-wuerttemberg.de/starkregen
- Municipal heavy rain risk management: https://reginastark.starkregengefahr.de/

Bavaria:

- General: https://www.lfu.bayern.de/wasser/starkregen_und_sturzfluten/index.htm
- Bavaria-wide information map 'Surface runoff and flash flood': https://www.lfu.bayern.de/wasser/starkregen_und_sturzfluten/hinweiskarte/index.htm

Hesse:

- https://www.hlnug.de/themen/klimawandel-und-anpassung/projekte/klimprax-projekte/klimprax-starkregen

Lower Saxony:

- https://www.niedersachsen.de/notfallmonitor/tipps/starkregen/starkregen-223971.html

North Rhine-Westphalia:

- State-wide map of heavy rain hazard: https://flussgebiete.nrw.de/hinweiskarte-starkregengefaehrdung
- A collection of links to maps of the districts and municipalities can be found under the item 'Konzepte vor Ort': https://www.klimaatlas.nrw.de/klima-nrw-pluskarte

Rhineland Palatinate:

- https://wasserportal.rlp-umwelt.de/auskunftssysteme/sturzflutgefahrenkarten

Saarland:

- https://www.saarland.de/mukmav/DE/portale/wasser/informationen/hochwasserschutzimsaarland/starkregenvorsorge/starkregenvorsorge

Thuringia:

- https://hnz.thueringen.de/hw-portal/

Luxembourg:

Websites:

- Crues subites - Administration de la gestion de l'eau - Le gouvernement luxembourgeois
- Anhang-1-Starkregenrisikomanagement-in-Luxemburg.pdf (gouvernement.lu)

Mapping service:

- Geoportal - Home (geoportail.lu) > Thema: Wasser > Hochwasserrisikomanagement-Richtlinie (HWRM-RL) > Starkregen

Netherlands:

- https://www.klimaateffectatlas.nl/nl/waterdiepte-bij-kortdurende-hevige-neerslag
- https://klimaatadaptatienederland.nl/kennisdossiers/wateroverlast/
- https://www.onswater.nl/onderwerpen/hoe-ontstaat-wateroverlast
- https://wachtnietopwater.nl/
- https://overstroomik.nl/
- https://basisinformatie-overstromingen.nl/#/viewer/11
- https://www.jcar-atrace.eu/

Annex 3 – interdisciplinary solutions and recommendations

The **presented and recommended measures**, which emerged from the exchange between the participants, are primarily aimed at integrating cross-sectoral risk factors at different levels (see introductory information in Chapter 4). However, their implementation **continues to be a challenge**: although many measures have already been identified, they are still insufficiently implemented.

1. Cross-sectoral approach and networking

Enhanced co-operation between stakeholders at all levels is necessary to ensure water quality and the protection of ecosystems in the long term.

Recommendations: To develop integrated solutions for problems such as heavy rainfall, flooding and droughts, a cross-sectoral approach is needed that involves and brings together authorities at all levels, spatial planning, urban planning, agriculture, water and risk management. This also applies to cross-border sections or sub-catchments of the Rhine.

2. Water quality and environmental monitoring, early warning systems, crisis management and infrastructure resilience

Monitoring and warning of storms, floods, or pollution, as well as responsiveness and resilience, are still inadequate, leading to an increase in environmental damage.

Recommendations: Water quality and environmental monitoring, as well as early warning systems, should be improved and disaster risk management processes should be strengthened to be better able to respond to the increasingly frequent extreme events. One example of this is the inclusion of protective measures for environmentally hazardous facilities (e.g. industries) and sewage systems in disaster preparedness and management, including the development of appropriate crisis management guidelines. Early warning systems and resilience strategies must be better adapted to the needs and characteristics of sensitive facilities and critical infrastructure.

3. Risk analysis and cartographic instruments/GIS

In many regions, the lack of full-coverage maps makes it difficult to assess environmental risks posed by heavy rainfall and uncontrolled surface water runoff, as well as to determine the ecological potential of certain habitats or areas.

Recommendations: Existing maps, e.g. of surface runoff and flood risk, should be combined with maps of land use, flora and fauna habitats, and critical infrastructure (e.g. environmentally hazardous industries, wastewater treatment plants). This would enable a more precise identification of areas at risk to the environment and of ecological hotspots.

4. Urban water management and wastewater disposal

In view of the increasing frequency of heavy rainfall events and the discharge of untreated wastewater into rivers, improvements in urban wastewater disposal are essential. The separation of rainwater and wastewater systems (e.g. increasingly implemented in the Netherlands) are priority measures to reduce overloading. However, separation systems, which are helpful in the event of small-scale, intensive rainfall, can be insufficient for extreme events, as even with these systems it cannot be guaranteed that untreated surface water will not enter the rivers. New approaches, such as the integration of filter systems, must be investigated to minimise the ecological impact.

Recommendations: Experts in water quality and environmental protection emphasise the importance of integrating wastewater treatment systems more effectively into flood prevention strategies. It is crucial to adapt urban wastewater management infrastructure to the new requirements arising from climate change, in particular more frequent and intense precipitation.

5. Protection of buildings and critical infrastructure

The protection of buildings, industrial plants, or critical infrastructure, particularly regarding substances hazardous to water such as fuel oil, must be improved. In rural areas, there is often no access to alternative energy sources such as natural gas, so that fuel oil tanks must be protected from floating up.

Recommendations: Experts recommend better monitoring and enforcement of existing regulations – particularly those designed to protect against water-polluting substances in floodplains. The relevant measures should be given higher priority to ensure the long-term resilience of buildings and infrastructure and to reduce pollution from accidents.

6. Land preservation, renaturation, retention and infiltration

Given rising temperatures and more frequent heavy rainfall and flash floods, measures to restore and protect wetlands, floodplains, or areas where surface runoff is concentrated, for renaturation and natural retention (e.g. riparian forests) are crucial to strengthen the resilience of ecosystems and create refuges, in addition to improving water quality. Approaches to optimising urban planning, such as the 'Slow Water' programme (Switzerland) or the 'sponge cities' (increasingly common practices in the river basin) aim to improve water storage or infiltration, thereby reducing runoff. For relevant measures in rural and agricultural areas, see also below under 7.

Recommendations: Promoting natural water retention and natural infiltration, appropriate wastewater, and rainwater management in cities (reducing flooding and the discharge of pollutants), and ecological engineering to protect or create habitats that promote biodiversity. Restoration measures could be more strongly promoted after flooding events. Finally, the monitoring of development measures along rivers or the appropriate design of urban and rural areas is of fundamental importance.

7. Agriculture, forestry, and land management

In contrast to conventional agriculture, which applies fertilisers, herbicides, and pesticides – leading to increased soil permeability, soil erosion, more surface runoff, and less groundwater recharge formation – organic and sustainable agricultural, agroforestry and forestry practices lead to a decrease in harmful substances in water and to better storage of surface and groundwater. These sustainable agricultural practices thus limit the negative effects of heavy rainfall events, flooding, and droughts on ecosystems. However, their implementation often remains complex. For example, organic farming and the conversion to more sustainable methods face obstacles because they are difficult to implement on a large scale. Additional incentives are needed here. Subsidies for farmers who reduce the use of harmful pesticides (as in Switzerland) are helpful, but – as the case of nitrogen in the Netherlands shows – are not always sufficient.

Recommendations: The transformation of agriculture and a more sustainable multi-risk soil management were identified as success factors for improving water quality and protecting biodiversity. The challenges lie less in gaps in knowledge than in implementation deficits. There is a desire for interdisciplinary approaches to be more strongly promoted to better support farmers and improve agricultural practices in relation to water management and resilience to storms.