SYSTEM RISK ETN

Policy Brief

Advanced tools for implementing a systems approach to large-scale flood risk assessment and management

Coping with the complexity of flood risk systems in devising risk reduction strategies is a key challenge in flood risk assessment and management.

A systems approach accounts for the complexity of the flood risk system, including interactions, feedbacks, and dynamic changes along the flood risk chain and should be applied for large-scale flood risk management planning. Research from the European Training Network System-Risk shows how flood risk assessment and management could benefit from the use of advanced models, tools and datasets.

KEY MESSAGES

- Accounting for system behaviour disentangles complex flooding phenomena.
- Spatial consistency and exploring unprecedented scenarios improve large-scale risk assessments.
- Big data: exploiting large data volumes leads to new insights for risk mapping.

This policy brief was compiled by adelphi based on the research work done by the Early Stage Researchers within the context of the European Training Network System-Risk with special contributions by Bruno Merz, Kai Schröter (GFZ German Research Centre for Geosciences), Attilio Castellarin (University of Bologna), Karin de Bruijn (Deltares) and Sally Priest (Middlesex University).

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Introduction

The EU Floods Directive (2007) stimulated major changes in flood hazard mapping and risk management practice in Europe. Nevertheless, river floods continue to cause major damage all over Europe. Policy-makers and flood risk managers need better methods for risk mapping and risk assessment in order to produce comprehensive and spatially consistent flood risk management plans and successfully manage risk portfolios.

Flood risk modelling is a complex task, as risk depends on a number of interrelated factors, which often change over time. Current flood risk models are usually limited to certain areas and focus on individual factors. Expanding the spatial scope and degree of complexity of risk models is not straightforward and requires considerable computational resources.

Adopting a systems approach can help remedy these drawbacks. How so? The Marie-Skłodowska-Curie European Training Network "System-Risk" funded the development of 15 doctoral research projects on "A systems approach to large-scale flood risk assessment and management". This comprises of the development of advanced models and tools for implementing a systems approach.

They include, for instance, adopting a broader perspective on flood risk drivers and examine the interactions and feedbacks that shape system behaviour. It also allows flood risk drivers to change over time. Finally, System-Risk research aims to simplify the use of large data volumes to support risk assessment and management.

Policy makers and practitioners will benefit from adopting a systems approach, as it gives them a more comprehensive view of flood risk systems.

Implementing a systems approach: better assessing and managing risk

Accounting for system behaviour unravels complex flooding phenomena

Changes in flood risk systems are difficult to quantify and account for. If, for instance, a levee breaches, the likelihood for flooding of downstream communities may decrease, because large amounts of floodwater leave the river and relieve the load downstream. Another example are flood protection measures, such as embankments, which reduce the room for the river, induce higher water levels, and may shift the risk of flooding downstream. Understanding these interactions is crucial for risk planners to assess flood risk realistically and draft reliable risk management plans. They need to take into account the entire flood risk system of which the simulation with available models is costly regarding time and computational resources. In practice, applying such complex models is often not feasible.

In order to remedy this deficiency, System-Risk developed several approaches to bridge the gap between complexity and applicability. One of these approaches consists of a simplified levee-breach model for large river systems to represent the upstream-downstream effects of levee breaches. This allows the faster set-up of more realistic flood scenarios, which is extremely valuable for emergency planning and risk assessment. Another approach looked into embanked river behaviour (1)[1]. Under the solidarity principle of the EU Floods Directive, understanding the effects embankments have in terms of shifting risks and being able to swiftly visualise these effects is of advantage when planning new measures such as levee

[1] With this number, you can find further information about the developed approaches on the last page of the briefing.

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strengthening. Another method developed by System-Risk focuses on the assessment of vulnerability of the population affected by flooding (2). It quantifies the effects of private precautionary measures on flood losses (many models ignore this factor). Including the effect of private precaution decreases the common over-estimation of risk for well-prepared communities and vice-versa. This kind of information is useful for insurers, as they can provide more customised products and adjust their pricing accordingly.

Summing up, the systems approach can sharpen our view on flood risk by allowing to:

- Model levee breaches and their downstream effects, and in turn, provide more realistic flood scenarios,
- Quantify effects and spatial interactions of embankments, which permits cost-effective investments and reveals redistributions of risk,
- Account for changes in vulnerability by including private precaution into loss modelling.

Spatial consistency and exploring unprecedented scenarios improve large-scale risk assessments

Flood risk assessment and management often build on local-scale hazard and risk mapping approaches. Piecing together these local results for large-scale risk assessments falls short in consistently representing the spatial variability of floods and their consequences. Yet, certain purposes, such as strategic planning or estimating worst-case scenarios at the national level, require spatially coherent risk estimates. It is thus necessary to assess floods over large regions with risk drivers changing over time.

System-Risk developed a stochastic weather generator, which provides high-resolution weather events, which can be further processed with hydrological models to produce scenarios of hypothetical floods (3) including hitherto unobserved extremes. This forms the basis for spatially coherent large-scale hazard and risk scenarios, as well as for the development of comprehensive trans-boundary risk management plans. "Future Weather" techniques, i.e. running numerical weather prediction models in hypothetical climate settings, allow exploring scenarios, which may lead to unprecedented compound events. An example is the occurrence of a storm surge or snowmelt in superposition with heavy rainfall also in the context of future climate risks (4). This approach refines traditional climate change scenarios and decreases the chances of surprising events for flood risk management.

In summary, these novel approaches allow to:

- Produce spatially coherent flood scenarios for large-scale hazard and risk assessments for improved flood risk management plans,
- Simulate unprecedented compound events and prepare decision makers for events never experienced to date.

Big data: exploiting large data volumes leads to new insights for risk mapping

Large-scale flood hazard mapping and flood risk assessment require the preparation and processing of large data sets, which is a time- and resource-consuming enterprise. It demands the setup and execution of complex mathematical models (hydrological and hydrodynamic), which is not always feasible in practice. System-Risk developed the "LFPtoolbox", i.e. automated input data processing tools for efficient large-scale flood inundation modelling (5). These tools made it possible to simulate the river hydraulic and inundation processes in almost 300 European river basins for a period covering the last 26 years at daily time steps and high spatial detail (90 m resolution). Aggregation of data on such scales is useful to gain a better understanding of the nature of past flood events, as demonstrated for the case of Europe. It also

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supports the identification of future flood-prone areas and the assessment of the effectiveness of flood protection measures. Another System-Risk example for innovative large-scale flood hazard mapping is the web-application "Smart-FLOOD" which allows the swift mapping of flood-prone areas at high spatial resolution using hydro-geomorphic properties and the integration of big data (6).

The computational efficiency of this approach opens up new potential to explore flood risk systems and helps stakeholders in deriving strategies for risk reduction. Both approaches give new insights for risk mapping and enhance the capability to:

- Efficiently process big data sets,
- Produce high-resolution flood hazard maps on large scales.

Contributions of System-Risk

System-Risk provided novel tools for implementing the systems approach in flood risk assessment and management. They allow:

- Considering upstream-downstream interactions within river systems, for instance due to levee breaches,
- Taking into account temporal changes in risk, such as the effect of private precaution on flood losses,
- Processing big data volumes and simulating large-scale yet high-resolution flood scenarios and unprecedented compound events.

Flood risk managers and private stakeholders can profit from the System-Risk approach, as it provides methods and tools for flood hazard and risk assessments that are spatially coherent, consider interactions and cover large spatial scales. Drafting and simulating unprecedented compound events may inform about unforeseen consequences.

Related links:

(1) Curran, A., Bruijn, K. M. D. and Kok, M.: *Influence of water level duration on dike breach triggering, focusing on system behaviour hazard analyses in lowland rivers*, Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 0(0), 1–15, doi:10.1080/17499518.2018.1542498, 2018.

(2) Sairam, N., Schröter, K., Lüdtke, S., Merz, B. and Kreibich, H.: *Quantifying Flood Vulnerability Reduction via Private Precaution*, Earth's Future, 7(3), 235–249, doi:10.1029/2018EF000994, 2019.

(3) Diederen, D., Liu, Y., Gouldby, B., Diermanse, F. and Vorogushyn, S.: *Stochastic generation of spatially coherent river discharge peaks for continental event-based flood risk assessment*, Natural Hazards and Earth System Sciences, 19(5), 1041–1053, doi:https://doi.org/10.5194/nhess-19-1041-2019, 2019.

(4) Khanal, S., Ridder, N., de Vries, H., Terink, W. and van den Hurk, B.: *Storm Surge and Extreme River Discharge: A Compound Event Analysis Using Ensemble Impact Modeling*, Front. Earth Sci., 7, doi:10.3389/feart.2019.00224, 2019.

(5) Sosa, J., Sampson, C., Smith, A., Neal, J. and Bates, P.: *A toolbox to quickly prepare flood inundation models for LISFLOOD-FP simulations*, Environmental Modelling & Software, 123, 104561, doi:10.1016/j.envsoft.2019.104561, 2020.

(6) Tavares da Costa, R., Manfreda, S., Luzzi, V., Samela, C., Mazzoli, P., Castellarin, A. and Bagli, S.: *A web application for hydrogeomorphic flood hazard mapping*, Environmental Modelling & Software, 118, 172–186, https://doi.org/10.1016/j.envsoft.2019.04.010, 2019.

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