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Conceptual approach for a holistic low-flow risk analysis

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ABSTRACT

The recent drought events highlighted the impacts caused by hydrological drought and low-flow events to society and ecosystems. In Germany, some rivers even dried out during the drought events of 2018, 2019 and 2022 causing massively damages to the ecosystem. Also, the impact on the economy due to restrictions on water use is immense. In this work we present a conceptual approach for a holistic low-flow risk analysis as base for an effective risk management including risk acceptance, transparent evaluation of mitigation measures and communication. The low-flow risk combines probabilities and consequences of low-flow events on a (sub-)catchment scale. However, the risk analysis is based on synthetic long-term time series (continuous risk modelling), as these appear to be more suitable for low-flows than scenario-based simulations, which are well known from flood risk analysis. The holistic approach requires a representation of all relevant processes, starting from weather generation, the hydrological and hydrodynamic response and the consequences to society and ecosystems.

KEYWORDS

Low-flow risk analysis, hydrological drought, drought management, risk analysis

1. INTRODUCTION

The drought events of 2018 and 2019 have shown the massive impact of hydrological drought and the resulting low-flows on water users all over Europe. The drought situation in summer 2022 again provided low water levels with several new negative record values and massive restrictions on water use. In France, the water temperature in some rivers exceeded the specified threshold values, hence nuclear power plants were only allowed to continue using cooling water with special permits tagesschau (2022b). In many parts of Germany private water withdrawal from surface water was prohibited MDR (2022a, 2022b). Shipping on the Rhine was disturbed for several weeks in July and August 2022, leading to disrupted supply chains and higher freight costs tagesschau (2022a). The river Schwarze Elster in southern Brandenburg and the river Dreisam in Baden-Württemberg partly dried out dpa (2022); Bergmann (2022). The ecological losses in these dry sections are massive and full recovering will take years. In other rivers the

high water temperatures lead to a lack of oxygen and cause ecological impact Höger (et al. 2022).
The impact of recent events demonstrates the urgent need for effective low-flow risk management, particularly by an expected future increase of these events due to climate change. All tasks within low-flow risk management are based on a well-founded risk analysis, combining probabilities and impact of low-flow events in a quantitative way. A holistic risk analysis approach is required to represent all relevant processes leading to consequences. The results as risk values support transparently the risk acceptance process and communication task as well as the conceptual design and evaluation of mitigation measures. This includes administrative measures like prioritizing and coordinating of individual water users during low-flow events, measures of storage as adapted reservoir management or constructive measures like low-water channels in a river. Finally, a software tool is required which transfers the application of a low-flow risk analysis to the end-users.

2. METHOD: HOLLISTIC LOW-FLOW RISK APPROACH

The low-flow risk analysis approach focusses on so-called blue-water droughts and their consequences, following the definition in UNESCO (2016) as "unusual and significant deficiency in the water stored in freshwater lakes, rivers, aquifers and wetlands". Rivers and their surrounding areas are target areas. Low water levels and high water temperatures resulting in ecological and economic consequences are analysed.
In the field of flood risk applications, scenario-based calculations are often performed. For example, the relevant parameter for the design of flood protection structures as levees is based on HQ100, a discharge that statistically occurs once in 100 years. Flood hazard maps are calculated for three different scenarios. Due to a relative short duration of flood events between a few days to a few weeks and in general negligible hydrological interaction between temporal distant flood events, a clear distinction of such events is comparatively simple.
However, for low-flow risk modelling, the definition of scenarios is considerably more complex due to their long-term development and occurrence. While in a river flood the hydrological situation of the previous year has just a negligible impact on the characteristics of the flood event, low-flow, in contrast, is a gradual process that develops over weeks, months and years. Thus, hydrological conditions from previous years can be essential for the development of a low-flow event.
Therefore, a long-term simulation approach is proposed for the low-flow risk analysis. The fundamental model concept is adapted from a long-term approach applied in flood risk analysis research, further described in SAIRAM ET AL. (2021). The basic idea consists not on the selection of independent scenarios, it is based on the generation of synthetic long-term timeseries (continuous risk modelling) from several hundred or thousand years, including weather generation, hydrology (Hydrological module), hydrodynamic (Hydrodynamic module) and analysis of consequences (Consequences module, cp. Fig, 1). The risk, finally, is calculated by the sum over the consequences divided by the simulated years (Risk module). This continuous approach makes it possible to fully represent the temporal connected low-flow events with their characteristics and consequences within the risk calculation. Considering low-flow events this approach is clearly advantageous compared to the scenario-based approach.
In the following a short description of the individual modular components of the holistic approach and their connections are given. In a first step a statistical weather generator is applied (cp. Fig. 1) to produce synthetic long time series of relevant weather parameters (like precipitation, temperature etc.) based on the statistical description of the current climate. This generated weather data serves as input data for the hydrological model of a river catchment. The hydrological model calculates the required results, such as runoff and infiltration.

Area-specific influencing factors such as land use, topography and soil type of the area under investigation are considered.

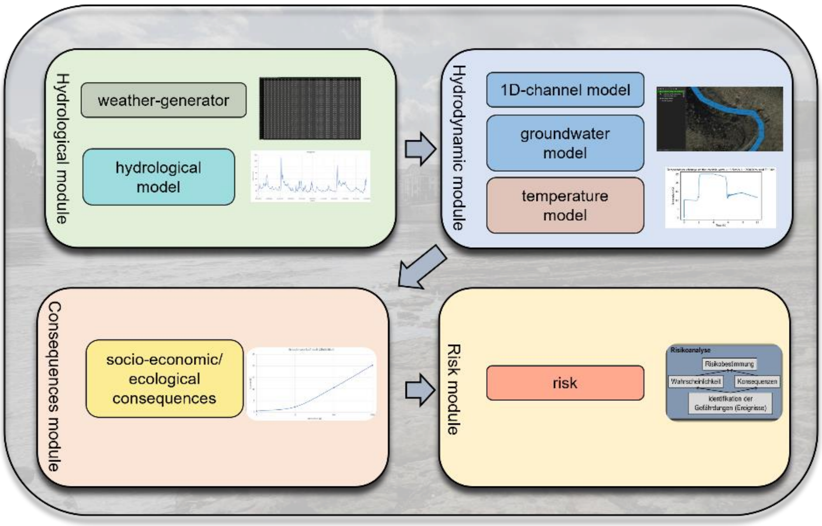

Fig. 1. Conceptual model approach for a holistic low-flow risk analysis

The hydrodynamic module uses the results of the hydrological model as input. It consists of three submodules. The core of the module is the one-dimensional river model, which models e.g. water levels and flow velocities in the river on basis of the diffusive wave approach (a simplification of the St. Venant-equations). In addition to hydrological data, input data such as cross section geometry and friction coefficients are considered. The hydrodynamic module also includes a model of the near-surface groundwater body. It is used to model the groundwater levels in the vicinity of the river. The groundwater model is coupled bidirectionally to the river model. In this way, the interaction of the groundwater and the river through ex- and infiltration can be modelled realistically. Last step in the hydrodynamic analysis of the river is the calculation of water temperature as a possible indicator of water quality. The coupling to the hydrodynamic river model is unidirectional. After its calculation is completed, the results of the river model, especially the flow velocity, are transferred to the temperature model. As further input global radiation and characteristics of anthropogenic inlets are integrated.
Based on the results of the hydrodynamic module, the consequences of low-flow for the different water users and the river ecosystem are quantified. The determination of the consequences is very complex, because the effects are manifold (e.g., Folkens et al. (2022)). The basic principle of the assessment of socio-economic consequences is based on threshold values above which a consequence occurs. As an example, the shipping industry can only operate with reduced freight at defined water levels. The situation is similar for power plants, which are only allowed to draw water for cooling purposes to a limited extent if the water temperature exceeds a certain threshold. A pure monetary evaluation is possible. The ecological consequences are evaluated using fixed empirical values. For example, many fish only can tolerate a water temperature of over 28°C for a short period of time. If for the ecological consequences a monetary assessment is adequate needs to be further developed. As a result, the accumulated sum of damages of the analysed long-term time series - including low flow events - are determined.

3. RESEARCH PROJECT DRYRIVERS

This work is part of the DryRivers research project, which aims to develop a tool for effective low-flow risk management. The tool will be tested in the pilot areas of the river Selke, Rur and a part of the Elbe river. In addition to the risk analysis, mitigation measures and mitigation strategies will be developed. An overview of the project is presented in Bachmann et al. (2022). The project, which is being conducted by interdisciplinary partners from the University of applied sciences Magdeburg-Stendal, RWTH Aachen University, the umweltbüro Essen and LimnoPlan, started in February 2022 and will run until the beginning of 2025.

4. CONCLUSION

Recent drought events highlighted the massive economic and ecological impacts of hydrological drought. Approaches and tools are required to effectively support the management of these extreme events. Thus, we present a holistic risk analysis approach for a basic support of a low-flow risk management. It considers all relevant processes from the weather-generation to consequences to ecosystems and society, mirroring the holistic set-up. The modelling is performed using long-term series, which are more suitable for analysing low-flow events than an event-based approach. In the flowing steps of DRYRIVERS this developed conceptual approach will be implemented in a tool and tested at three river catchments in Germany.

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