DELIVERABLE D.T3.1.1

Forecast-System for the Rur-Reservoir-System

EMFloodResilience

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Legal Disclaimer

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1 Executive Summary

A proper forecast of discharge downstream the Norther-Eifel-Reservoir-System depends on knowledge of future reservoir releases. The operation of the reservoirs is complex and cannot be implemented in common hydrologic models. A special system to forecast reservoir releases, based on operation plans, is set up and brought into constant pilot operation, able to deliver discharge forecasts to the downstream forecast models of the State Agency for Nature, Environment, and Consumer Protection North Rhine-Westphalia (LANUV NRW) and Waterschap Limburg (WL). The forecasting system was established using a specific reservoir model and a simple hydrologic model. It provides new forecast information in hourly time steps.

2 Zusammenfassung

Eine gute Abflussvorhersage stromabwärts des Talsperrensystems der Nordeifel hängt von der Kenntnis über zukünftige Abgabemengen der Talsperren ab. Der Betrieb der Talsperren ist komplex und kann in üblichen hydrologischen Modellen nicht abgebildet werden. Auf der Grundlalge der gültigen Betriebspläne wurde ein spezielles System zur Vorhersage der Abgabemengen aus den Talsperren aufgebaut. Dieses System befindet sich aktuell in ständigem Pilotbetrieb. Es liefert Abflussvorhersagen, die von den flussabwärts gelegenen Vorhersagemodelle der Landesanstalt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (LANUV NRW) und des Waterschaps Limburg (WL) verwendet werden können. Das Vorhersagesystem wurde mit einem spezifischen Talsperrenmodell und einem einfachen hydrologischen Modell aufgebaut und liefert stündlich neue Vorhersageinformationen.

3 Introduction

3.1 Identification of hydrological and meterological system

The lowland and low mountain range catchment area of the Rur (2372 km²) is located in the very west of Germany with parts in Belgium and the Netherlands in maritime climates with an annual precipitation range from 600 to 1300 mm. The Norther Eifel Reservoir-System consists of nine reservoirs (Figure 1). This changes about one third of the Rur catchment to a complex hydrologic system which controls approximately half of the discharge of the Rur:

Three reservoirs exclusively serve as drinking water reservoirs (Dreilägerbach-, Kall- and Perlenbach-Reservoir) and are operated by water supply companies. Drinking water for the Aachen region is received from a chain of reservoirs which connects the Dreilägerbach-Reservoir to the Kall-Reservoir and the Upper lake of the Rur-Reservoir. This allows the provision of water for the drinking water production even in dry seasons. In very dry times the chain of supply can be extended by a transition from the Urft-Reservoir. The operation of the reservoirs used for drinking water has a minor hydrologic effect downstream.

Six reservoirs are operated by the WVER, whereof the Wehebachtalsperre serves for drinking water supply and flood control. The remaining five Reservoirs form the Rur-Reservoir-System, a jointly managed dam system which objectives are flood control, the supply of drinking water and low water enrichment. Downstream of the Obermaubach storage basin, a discharge of at least 5 m³/s ensures the supply of industrial water for the industries located along the Rur river. The releases from the reservoirs are controlled, based on operational plans. These operational plans (for the Olef-Reservoir itself and conjoined for all reservoirs together) have been approved by the district government and are optimized based on simulations using a model of the reservoir rules (in TALSIM) and time series spanning more than 100 years. The released water at the dam sites is used for hydropower generation.

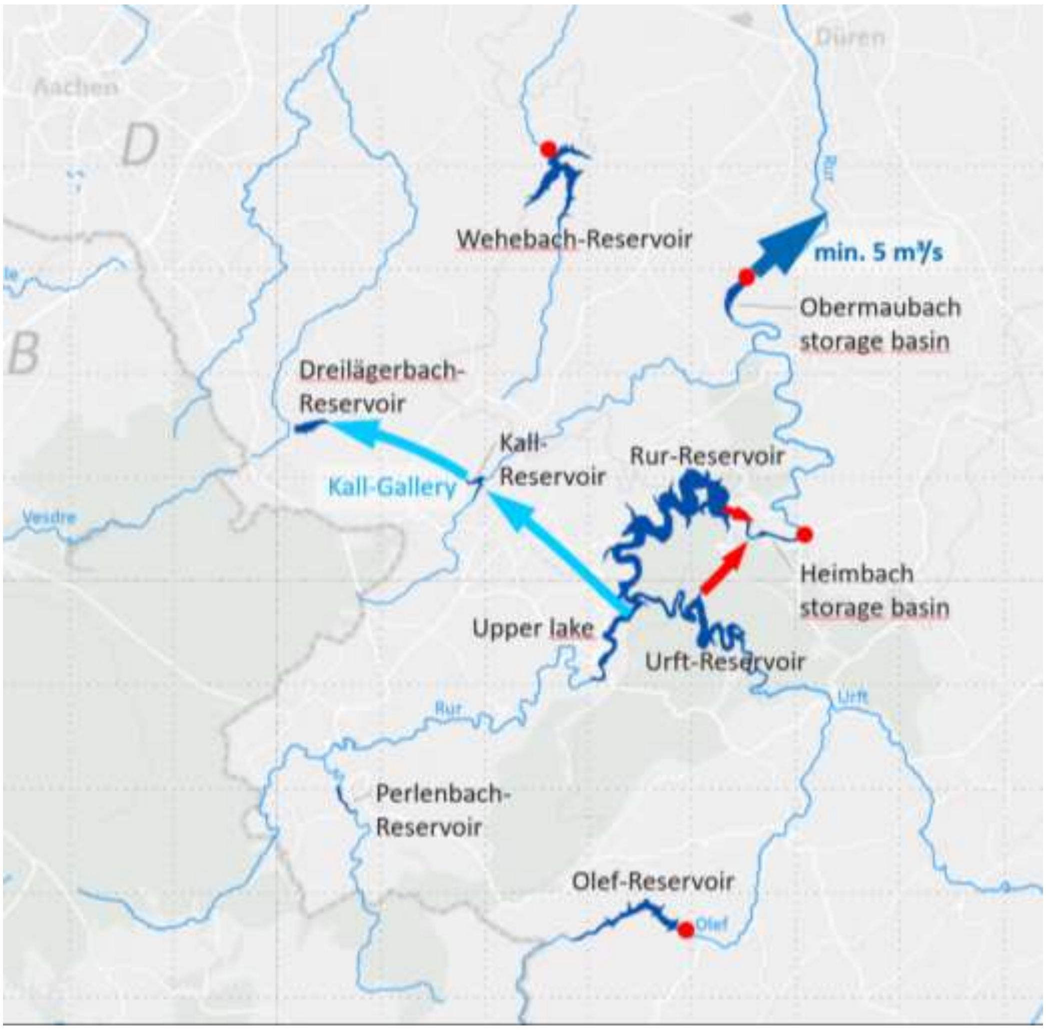

Figure 1: Overview of the Northern-Eifel Reservoir-System

The discharge from the reservoir-system is officially released from the Obermaubach storage basin only for small discharges, while large discharges are released at the Heimbach storage basin. During mean flood events, the Rur river distributes about 3 % to the discharge of the Meuse downstream of Roermond, whereas in times of low flow the ratio of the Rur is about 30 %. This exceptional hydrologic behaviour is originated in the operation of the Rur-Reservoir-System (low water enrichment and flood control).

3.2 Needs downstream

Waterschap Limburg and LANUV NRW each operate different forecast models for the Rur river to provide discharge predictions and flood warnings. A proper forecast downstream discharge depends on knowledge of present and future reservoir releases. Because the operation of the reservoirs is complex and depends on operation plans and service requirements (temporarily building sites and maintenance) it cannot be implemented in common hydrologic models or derived systems (e.g. AI). It's best to obtain information about future releases from the point of best knowledge, the operator of the reservoir system (WVER).

Today, a manual timeseries of known or planned changes of the reservoirs' releases is provided to the downstream forecast models. Because this forecast is handmade, it is based on individual hydrological assessment and cannot provide different scenarios or ensembles, which are commonly used in contemporary forecast modeling.

Ensembles of different forecast products would help to enable improving the quality of the downstream prediction of the discharge in the Rur river and allow a fully automatic chain of models for the provision of flood warnings.

3.3 Data and equipment to use for forecast system

A proper forecast of downstream discharge depends on knowledge of the future reservoir releases. The operation of the reservoirs is complex and cannot be implemented in common hydrologic models. A model of the reservoir operation rules of the Rur-Reservoir-System, set up in the software TALSIM [2], is developed and used over more than 15 years to optimize and demonstrate the effectiveness of the reservoir regulations.

In 2008, a collaboration between the German Weather Service (DWD) and water boards in North Rhine-Westphalia (the so-called radar-cooperation) started an initiative to use radar data and forecasts for water management applications. Today, the State Agency for Nature, Environment, and Consumer Protection North Rhine-Westphalia (LANUV NRW) also participates in the cooperation, which jointly organizes the exchange of measurement and forecast data, as well as operates Delft-FEWS systems for the efficient provision of the collected data. In addition to the measurement data from terrestrial rain gauges and rain radars, numerous forecast products are made available (e.g. Radvor-op, ICON-D2/-EPS, ICON-EU/-EPS, ICON-GME).

4 Adjustment of the information-products

4.1 Meetings

In advance of setting up the model, two online meetings were conducted with Waterschap Limburg (WL), Service Public de Wallonie (SPW), Delft University of Technology (TU Delft), the German Weather service (DWD) and the State Agency for Nature, Environment, and Consumer Protection North Rhine-Westphalia (LANUV NRW). The valuable and available meteorologic and forecast-products were upraised and analysed (see apendizes 8.1 and 8.2). Knowledge about available measured and forecast data was shared and new contacts between the participants and to potential data providers were established.

4.2 Identification of valuable and available meteorologic forecast-products

As a result of the meetings, it was found that a big variety of measured data is available in the international catchment of the reservoirs. The ability of timely delivery of measured data is developing, but not yet comprehensively satisfying for forecasting purposes. The next step agreed upon, was to establish data exchange between the involved organizations without claiming real-time data, and then gradually improve data timeliness

Especially in forecast data, many new producs are in development (see also WP 4). The results come to late for this project, but the products have to be kept in mind for further development of the forecast system in the future.

4.3 Information-products demanded from a forecast-system for the Rur-reservoir-system

The three organisations that are interested in forecasts information of the Rur-Reservoir-System, have specific requirements. These requirements are very likely to change in the future due to technological developments in downstream forecasting systems (e.g. hydrologic models, use of artificial intelligence).

Waterschap Limburg is interested in measured and forecast data at the storage basin in Obermaubach and the discharge gauge Rur-Zerkall (5,5 km upstream Obermaubach). The demands of TU Delft extend across measured data and forecast data of all discharge gauges and discharge of catchments upstream of the reservoirs and on reservoir data (e.g. storage volume, water level). LANUV demands measured data and forecast of discharge downstream the storage basins in Heimbach and Obermaubach (the official release points of the reservoir-system).

In a first step, the transfer of the information-data will be provided via FTP or via the server of the radar-corporation, where it is computed. Subsequently other transfer methods like WISKI-exchange, KIWIS (WISKI-API), or FTPS will be established.

4.4 Used input data for the forecast-system

Because the timely delivery of measured data is not entirely satisfying, in the first step, the forecast-system for the reservoirs will base on available and well-established rain-radar and forecast-data provided by the German Weather Service (DWD). A blend of real-time data of rain-radars, nowcasts from rain radar and forecast models (ICON-EU-EPS) will be used as input for the hydrological forecasting models.

5 Setup of the forecast-system

5.1 Setup of a Forecast-System for the Rur-Reservoir-System

The forecast-system for the Northern-Eifel-Reservoir-System consists of a hydrologic model of the catchments upstream of the reservoirs, connected with a model of the reservoir operation, including all operation rules [2]. A Delft-FEWS-platform [1] provides hydrological data and meteorological (forecast-) data to the hydrologic model and receives and distributes calculated forecast-data of the reservoir-system to the interested organizations (see Figure 2). The forecast-system will be put into continuous (test) operation and provides forecast information in an hourly timestep.

5.2 Delft-FEWS

As data hub for all data types of needed-data and to trigger and control the model calculations a FEWS-platform [1] was set up. The system was built in an existing FEWS-System that is used within the framework of the radar-cooperation (DWD, waterboards, LANUV). This simplified the access to data already provided and used for other purposes. For extended utility, the forecasting system can also be used to calculate the reservoir’s release with precipitation scenarios.

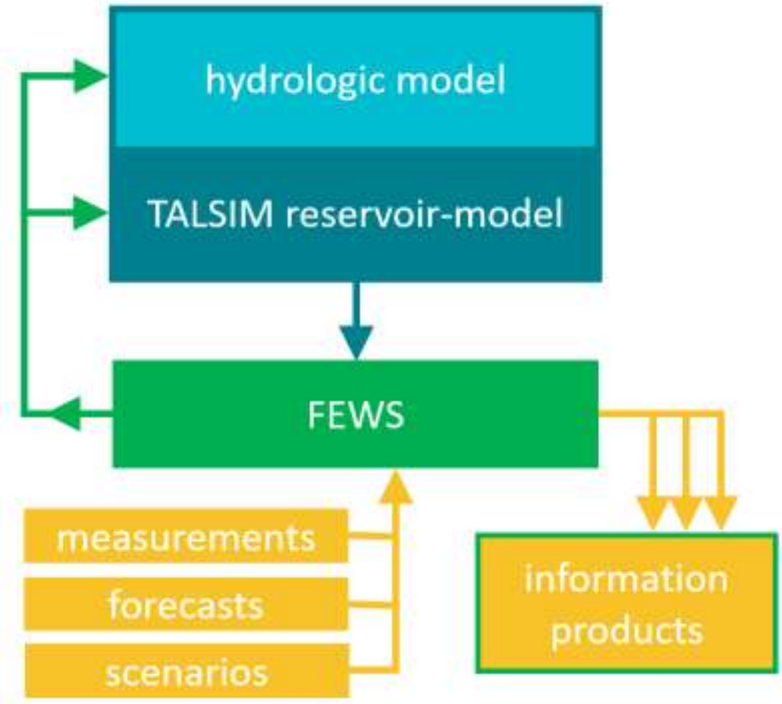

Figure 2: Schematic of the Forecast-System for the Rur Reservoir-System

5.3 Reservoir Model

The already existig reservoir-operation-model for the Northern-Eifel-Reservoir-System is represented in the TALSIM software [2]. The software can depict complex, interdependent, and seasonally varying control rules and calculate the response of the reservoir-system to inflow variations. Therefor the characteristics and controling devices of the reservoirs and the connecting elements (e.g. transition) are included.

The reservoir-operation-model was set up to optimize and demonstrate the effectiveness of the operational plans based on simulations for a time period of more than 100 years and for climate scenarios.

To use the TALSIM-model for the Rur-Reservoirs for this project a FEWS-adapter was already available from the contractor who was tasked with connecting the models into FEWS (Hydrotec, Aachen).

5.4 Hydrologic Modelling

In the first phase of the project, discussions lead to a request by LANUV to use the hydologic models, developed for flood-warnings in North-Rhine-Westphalia. These flood forecast models run on the software LARSIM [3]. Because some discharge gauges for flood warning are located upstream of the reservoirs, a significant advantage would be a homogeneous basis of information regarding discharge values. Unfortunately, this idea could not be implemented. In mid-2023, it became apparent that due to ongoing revisions of the hydrological model and issues with the FEWS adapter for compatible LARSIM versions, an implementation within the project's runtime was no longer attainable.

An alternative approach was sought to achieve the project's goal on time: The solution found, is to utilize the hydrological modeling component implemented in TALSIM, which has not been used so far, to simulate the inflow to the reservoir system. Extending the existing reservoir-operation-model with incorporated simple hydrologic models of the catchments of the reservoirs has the advantages that one edge of data-transmission is eliminated because hydrology and reservoir management are included in one model. Additionally, the same FEWS adapter for TALSIM as originally planned can be used.

The hydrologic model was set up by SYDRO Consult with 84 sub-catchments to represent all catchments of the reservoirs, of discharge gauges or sub-catchments with different hydrological characteristics (see Figure 3). A 200m-grid elevation model (official DGM200 dataset) and the BK50 soil data was used for basic parameters. Landuse was derived from ATKIS and Corine datasets. The sealing parameters were extracted from the high-resolution layer Imperviousness, a dataset of the Copernicus Land Monitoring.

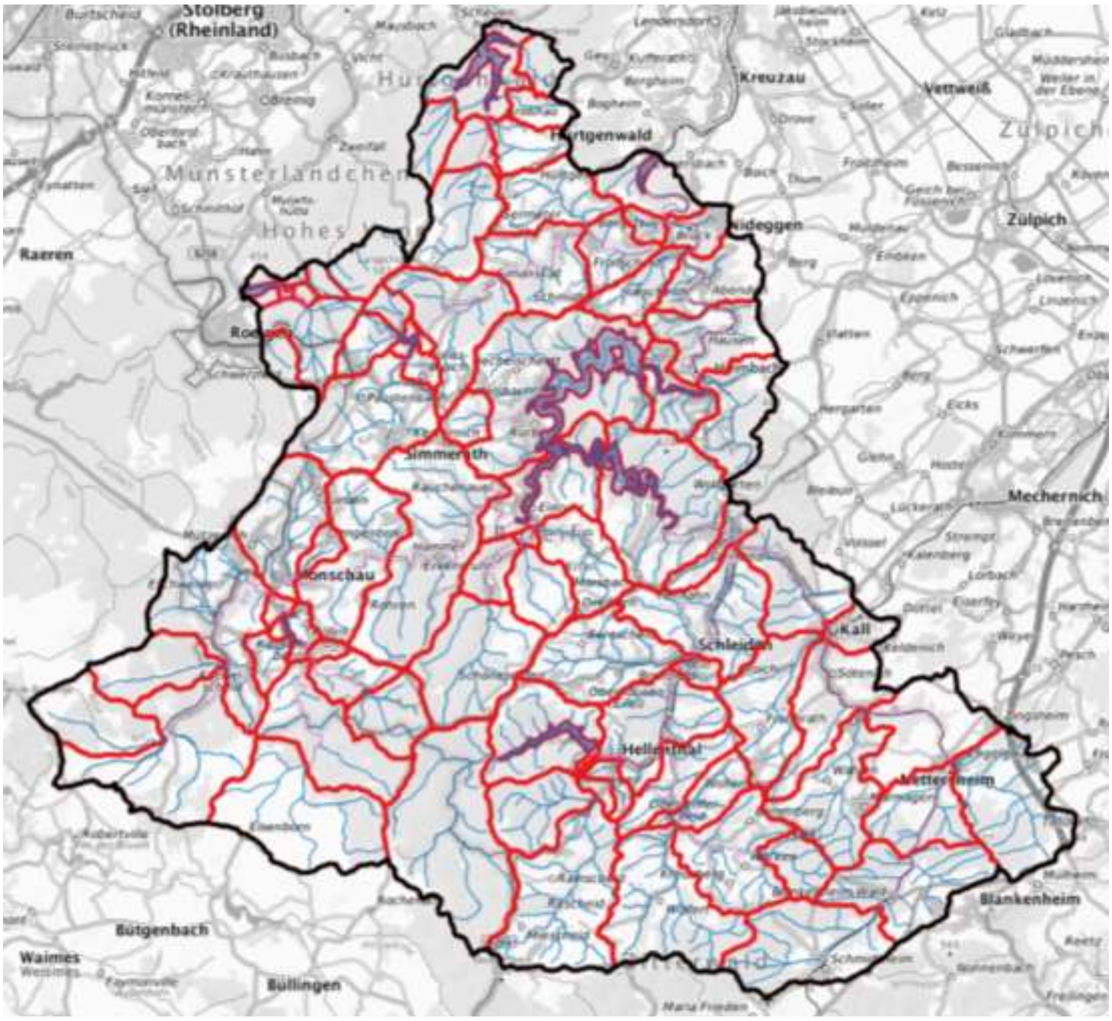

Figure 3: Catchment delineation of the hydrologic model

For the calibration of the model precipitation data from dx-offline (a composite of recalibrated radar data annually generated for the radar-cooperation of DWD, waterboards and LANUV) was used. The evaporation was derived from two meteorologic stations of the DWD (Kall-Sistig and Nideggen-Schmidt). Discharge data at gauges from LANUV and WVER was used. The generated hourly discharge is especially calibrated on discharge volumes at the inflow-gauges of the reservoirs and based on Nash-Sutcliffe-Efficiency (NSE) as well as visual checks.

Table 1: Nash-Shutcliff-Efficiency after first calibration phase

Hydro-logisches Jahr	Nash-Sutcliff-Efficiency						
	Urft Gemünd	Olef Stauwurzel	Rur Dedenborn	Rur Erkensruhr	Weißer Wehebach	Kall Zufluss	DLB Zufluss
2012	0.8	0.6	0.8	0.7	0.8	0.8	0.7
2013	0.7	0.5	0.7	0.4	0.3	0.7	0.4
2014	0.0	0.5	0.6	-0.4	0.5	0.2	0.6
2015	0.7	0.6	0.8	0.5	0.7	0.6	0.6
2016	0.7	0.6	0.8	0.6	0.6	0.6	0.5
2017	0.6	0.4	0.6	0.4	0.4	0.0	0.5
2018	0.6	0.6	0.7	0.5	0.5	0.7	0.4
2019	0.8	0.6	0.8	0.7	0.6	0.7	0.6
2020	0.8	0.6	0.8	0.6	0.6	0.6	0.6

Due to the limited time available time for setup and calibration of the hydrologic model, the current mapping quality does not yet meet our usual quality standards. , the calibration is ongoing and will continue until satisfactory results are achieved.

The current status of the calibration has been incorporated into the forecasting system, providing first forecast information on the reservoir’s release.

5.5 Performance

A forecast for the reservoirs' discharge is calculated every hour. The calculation takes less than 10 minutes for a forecast period of 5 days and 40 ensemble members (ICON-EU forecast, DWD). During periods of moderate precipitation, the ensemble members yield results with minimal variation. In uncertain weather conditions with heavy rainfall, the reservoir system shows a wide variety of discharge reactions (see below)

6 Forecast information

6.1 Information Products

The forecast information about the delivery of the Rur-Reservoir-System from storage basin Heimbach (for large winter discharge) and downstream storage basin Obermaubach (for small discharges and the minimum discharge of 5 m³/s) is currently provided as a CSV-file with forecast timeseries of 40 ensemble members simulated with the ICON-EU precipitation forecast. A recalculation of the discharge forecast is provided every hour.

As an example, Figure 4 illustrates the result of the forecast simulations for the reservoir-system's discharge at the storage basin Heimbach on December 19, 2023, as seen on the FEWS interface. Due to an approaching rainy and occasionally showery phase with predicted precipitation up to 80 mm in 5 days, releases are (delayed due to an increase in the reservoir levels) resulting in higher forecasted discharges.

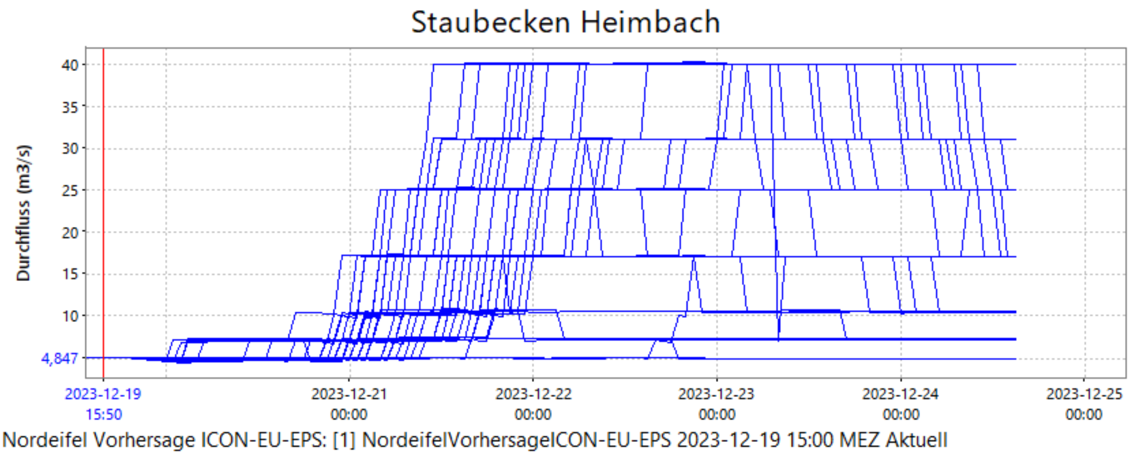

Figure 4: Prediced discharge timeseries at Heimbach (ICON-EU 2023-12-19 15:00)

To get a better idea of the discharge forecasts Figure 5 shows the simulation results at two specific time points. The reservoir system's response varies due to the diverse amounts of forecasted precipitation. For ensemble members with large predicted precipitation heights, the reservoirs are filling rapidly and the release is increased due to the operation rules (to maintain flood protection capacity in the reservoirs for significant events). For members with low predicted precipitation heights, the response of the reservoir system is slight, and there is minimal change in the discharge of the reservoir system. Understandably, the average and the median of the discharges moves upward with the increasing duration of rainfall.

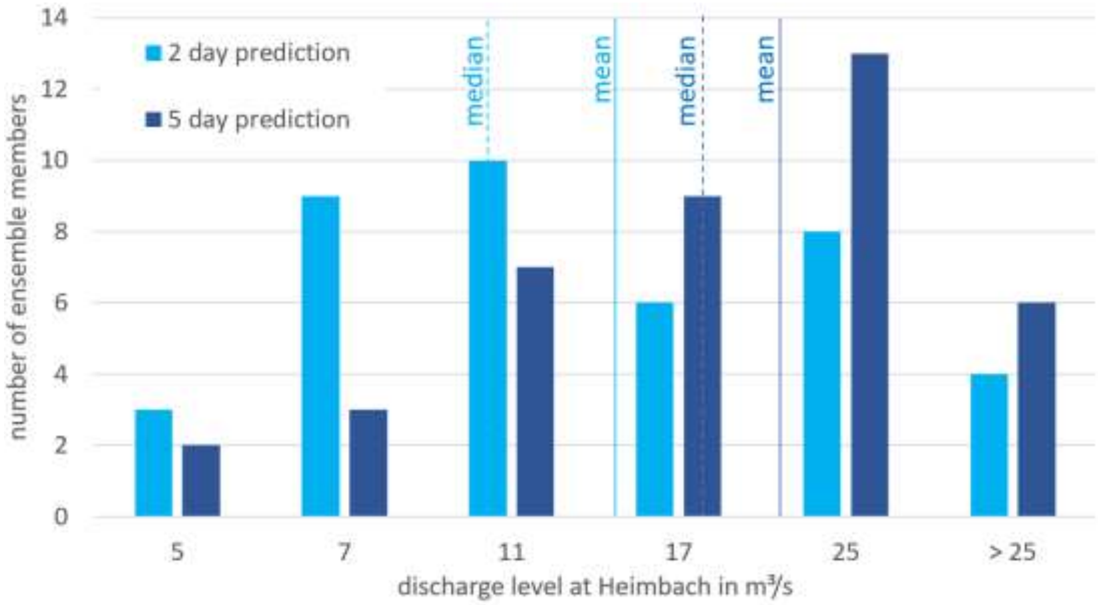

Figure 5: Distribution of discharge levels for a 2-day and a 5-day prediction at Heimbach (ICON-EU 2023-12-19 15:00)

To simplify data usage, additional delivery of statistical parameters, such as mean, median, and quantiles, is planned.

6.2 Data transfer

To initiate, the model output is accessible via FTP. Access to the FTP directory has been provided for LANUV, WL, and TU Delft.

The information products are not yet incorporated as input data in the forecast systems for the Rur river (WL and LANUV)

6.3 Feedback

The application to the hydrologic forecast-models for the Rur downstream of the reservoirs has not been tested so far. The forecast information is attainable, readable and can be interpreted.

Waterschap Limburg and LANUV want to test the provided forecast data of the reservoirs discharge delivery in the upcoming year 2024. A brief query on assessments of the usability of the product (see apendizes 8.3 to 8.5) yielded some new insights into improving the system and linking it with other forecast systems. The use of distribution parameters (percentiles) for input to the receiving systems could make it easier to include this input into the systems (e.g. AI-Systems). The calculation of the statistical values should be done by the recipient of the forecasted reservoir discharges to meet specific needs; thus, it is interesting to receive several ensemble members of the forecast.

New precipitation forecast products of KNMI and DWD shoud be tested on both systems. A uniform basis of precipitation forecast data facilitates meaningful integration of the systems.

7 Conclusion and outlook

The forecast system for the Rur-Reservoir-System is operational and consistently delivers hourly forecasts for reservoir releases. Currently, a five-day forecast is generated based on the ICON-EU rainfall predictions. The forecast for the reservoirs' discharge downstream of the storage basins Heimbach and Obermaubach is provided to downstream users via FTP.

The WVER is committed to continuing the operation of the forecast system and further developing it with self-funding. Ongoing improvements in the forecast system's quality and adjustments of the information products for downstream models will persist until the goal of automatic integration into downstream users' forecast systems (e.g., flood warnings) and a propper support for reservoir operation is achieved. To achieve this, the use of different forecast products and input data will be explored. In further development, options for data provision will be tested and expanded, guided by user requirements.

During project meetings and assemblies within the context of EMfloodResilience, several ideas for the use and enhancement of the forecast system were discussed:

- Application and testing of existing and upcoming rainfall forecast products will provide further insights to enhance the information received by the forecast system for the reservoirs. As the Rur watershed is located in a border area and flows into the Meuse, Dutch and German forecast products are available for this area and can be used and compared.
- Variant sets of forecast simulations with different limitations in operation (maintain a low water level due to a construction site) or starting values (e.g. soil moisture) will offer a better understanding of the variation and uncertainty of prediction results.
- For catastrophic rain events, like in July 2021, which cannot be reproduced by hydrologic models with commonly calibrated parameters (e.g., overland runoff), specially adapted hydrologic models can serve as a fallback system to provide reasonable forecasts even for such situations.
- Simulating scenarios or scenario sets (e.g., KNMI's long-term synthetic weather data from WP5 D.T5.4.1) can support the understanding and design of reservoir operation rules or downstream flood control measures. Climate scenarios can help increase resilience to climate changes.
- An additional delivery of statistical parameters such as mean, median, and quantiles could simplify the usage of the forecasted discharges.

References

[1] Detares: Delft-FEWS, https://oss.deltares.nl/web/delft-fews/ and https://publicwiki.deltares.nl Used version: Delft-FEWS stable 2022.02119774

[2] SYDRO Consult: TALSIM, http://www.talsim.de

[3] Ludwig, K., Bremicker, M. (Eds.) (2006): The Water Balance Model LARSIM. Freiburger Schriften zur Hydrologie, Band 22 Institut für Hydrologie der Universität Freiburg. and larsim.sourceforge.net

8 Appendices

Brief Minutes of the preparatory sessions for coordinating information products in 2022 and sessions for presenting the results in 2023.

8.1 First meeting on 21.09.2022

<table>
<tr><td colspan="2">Online-Meeting (gotomeeting) 21.09.2022 from 14:00 to 16:00</td></tr>
<tr><td colspan="2">Participants: Claudia Glase (DWD), Sabine Bartussek (WL), Gijs van den Munckhof (WL), Angela Klein (TU Delft), Athanasios Tsiokanos (TU Delft), Remko Uijlenhoet (TU Delft), Christell Dere (SPW), Claudia Rabisch (WVER), Christof Homann (WVER)</td></tr>
<tr><td>Welcome of the participants and brief introduction round of the attendees</td><td>all</td></tr>
<tr><td>Short introduction to the structure and the regulations of the Northern-Eifel-Reservoir-System and the hydrologic system.</td><td>WVER</td></tr>
<tr><td>Presentation of the planned steps to setup a forecast-system for the Rur-Reservoir-System (1. agreed information products, 2. forecast-system, 3. application of information).</td><td>WVER</td></tr>
<tr><td>Discussion on the forecast-system, available input data, data transfer and forecast information:
Following measured data that can be provided:
• DWD: Precipitation, air temperature, rain-radar (mainly on german territory, e.g. Radolan, RW, all official products available)
• KNMI: Precipitation, air temperature, rain-radar about 100 km to the east beyond the german border,
• EmfloodResilience WP4- will provide further rain-radar-data
• WL: Precipitation and Discharge (some gauges on german terretory, downstream the reservoirs)
• SPW: Precipitation and further meteologic data, real-time data is still challenging (some stations with delay), hourly delivery possible, Delivery to LANUV could be used by WVER. Two other organisations measure rain and temperature in Belgium (real-time data?).
• WVER: Precipitation (SPI, continuously calculated), discharge, air temperature, real-time data still challenging
• No reliable continuous data for soil moisture available. Hint: Soil-moisture models are provided by the Forschungszentrum Jülich (project Tereno), some data (real-time?) can be provided by WL (Peter Hulst)
Forecast data:
• DWD:
    ○ Rain-radar-nowcast Radvor RQ: every hour, +2 h
    ○ COSMO-LEPS2: every 3 hours, +27 h (+ 45 h)
    ○ ICON-D2 (-EPS): every 3 hours, +48 h (best for convective precipitation)
    ○ ICON-EU (-EPS): every 3 hours, +30 h (+120 h) (best for longrun precipitation)
    ○ SNOW4: every 6 hours, +72 h
• KNMI: Reference to a direct inquiry (Hubert Konij), several products in development, short-term-forecast data from WP 4 in EMfloodResilience could be used after project (2024).
Data transfer can be carried out via:</td><td>all</td></tr>
</table>

• DWD: Preferably over the server of the radar-coorporation of DWD, waterboards of Northrhine-Wetphalia and LANUV • WL: Preferably over FTP • SPW: WISKI-exchange (zrxp), FTP, KIWIS (WISKI-API) possible in future • WVER: WISKI-exchange, KIWIS (WISKI-API) and server of the radar-coorporation	

Information needed by the forecast-models downstream the reservoirs:
• WL:
  ○ Measured data and forecast data at the storage basin in Obermaubach and the discharge-gauge Rur-Zerkall (5,5 km upstream of Obermaubach)
• TU Delft:
  ○ Measured data and forecast data of the discharge of catchments and reservoirs
General agreement of the participants to intensify data exchange among the organisations in the three countries and to use cross-border projects for the implementation. Central data exchange platform can not be established in the short time of this project, but should be moved foreward by the states organisations.	

8.2 Second meeting on 13.10.2022

Online-Meeting (gotomeeting 383-953-469) 13.10.2022 from 14:00 to 15:30	
Participants: Isabel Menzer (LANUV), Sebastian Hansmann (LANUV), Hanna Fuchs (WVER), Claudia Rabisch (WVER), Christof Homann (WVER)	
Welcome of the participants and brief introduction round of the attendees	all
Short introduction to the structure and the regulations of the Northern-Eifel-Reservoir-System and the hydrologic system.	WVER
Presentation of the planned steps to setup a forecast-system for the Rur-Reservoir-System (1. agreed information products, 2. forecast-system, 3. application of information).	WVER
Discussion on the forecast-system, available input data, data transfer and forecast information: • Because the state agency is in charge of flood warning and official statements regarding (low-water) discharges it should be tried, to use the hydrological model of the state. This wouldt give the advantage to base on an identical (sub-)model and to deal with the same calculations results regarding the forecasts. The hydrologic model is available and there is a converter to FEWS that could be used with few adjustments. • The part of the states hydrologic model upstream of the reservoirs will need max. two minutes to calculate for 62 ensemble members (Mosmix, ICON and COSMO). It could be used free of licence. The hydrologic modell does not use a infiltration module by now and some parameters (e.g. sealing) are derived from areal datasets and are not calibrated. Data transfer can be carried out via: • FTP, WISKI-exchange, KIWIS (WISKI-API) or over the server of the radar-coorporation of DWD, waterboards of Northrhine-Wetphalia and LANUV Information needed by the forecast-model downstream the reservoirs: • Measured data and forecast of discharge downstream the storage basins Heimbach and Obermaubach.	all

8.3 Telephone conversation on 19.12.2023

Telephone call 19.12.2021 15:19 Gijs van den Munckhof (WL) and Christof Homann (WVER)	
Test of provided data as input in AI in the next year	
Statitic values (like percentiles) would be more suitable as input data for hydrologic AI-model.	

8.4 Telephone conversation on 21.12.2023

Telephone call 21.12.2021 12:09 Marc Scheibel (LANUV) and Christof Homann (WVER)	
The provided data will be tested as input data for the hydrologic model of the LANUV (flood-forecast).	

8.5 Telephone conversation on 21.12.2023

Telephone call 21.12.2021 13:11 Sabine Bartusseck (WL) and Christof Homann (WVER)	
The provided data is readable and can be interpreted.	
It would be preferable to use the FEWS-XML format for data exchange, as both the AI Forecast system of WL and the Reservoir Forecast system are operating on FEWS systems.	
To have a better adaption to the application goals, the calculation of statistical parameters shoud be done by the user of the data. The delivery of serveral ensembles can be very interesting.	
New forecast products of KNMI and DWD shoud be tested on both systems. A uniform forecast basis would be very helpful.	