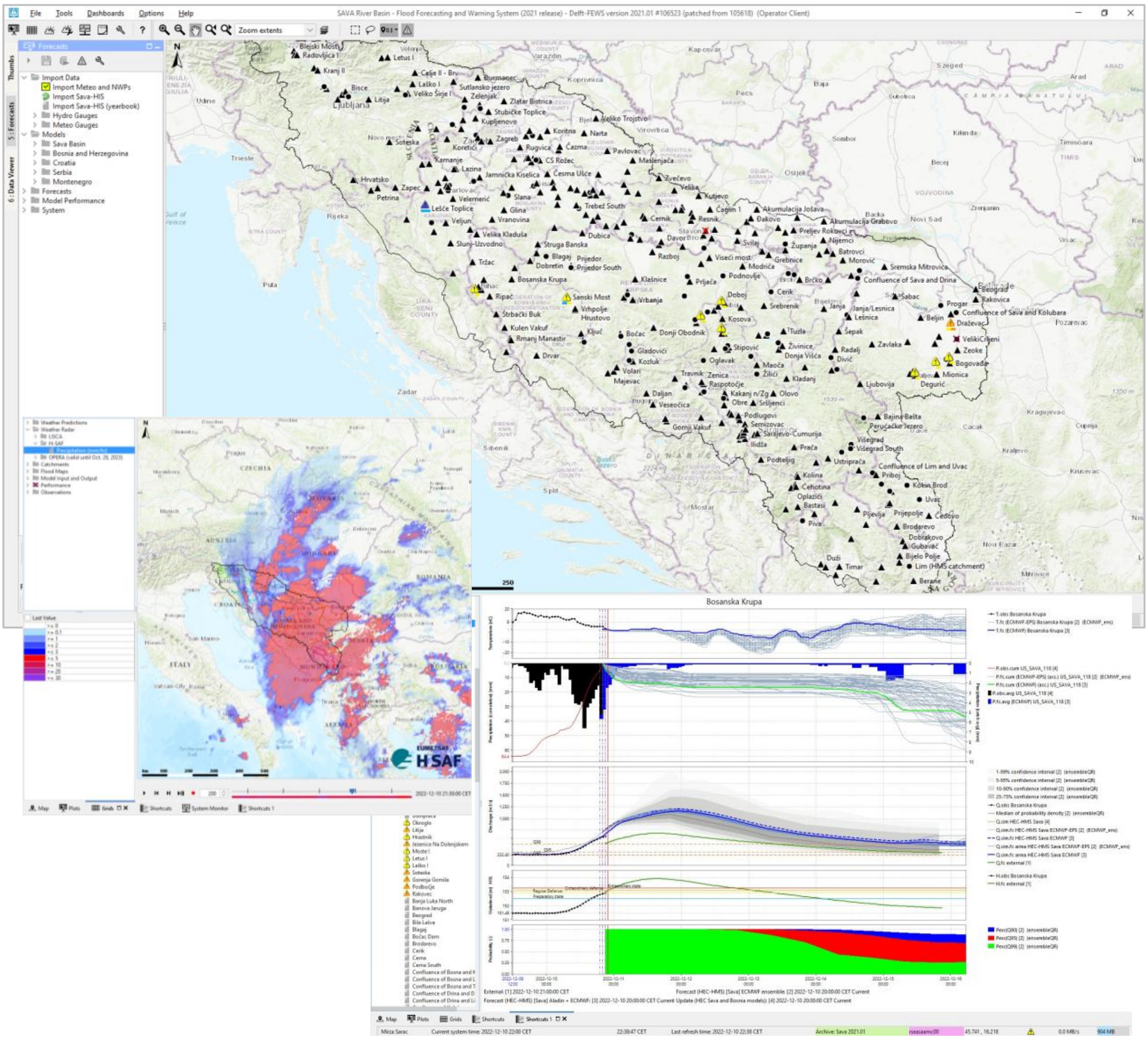
INTERNATIONAL SAVA RIVER BASIN COMMISSION

Terms of Reference

for

Technical Assistance for the improvement, extension and operationalization of flood and low-flow forecasting and warning system in the Sava River basin



May 2024

PROJECT:	SAVA AND DRINA RIVER CORRIDORS INTEGRATED DEVELOPMENT PROGRAM (SDIP)-Phase I, Part 4 – Regional Cooperation
IMPLEMENTING AGENCY:	International Sava River Basin Commission (ISRBC)
ACTIVITY:	Technical Assistance for the improvement, extension and operationalization of flood and low-flow forecasting and warning system in the Sava River basin
REFERENCE NUMBER	HR-ISRBC-343725-CS-QCBS

ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
COSMO	Consortium for Small-scale Modeling
DHI MIKE	Danish Hydraulic Institute’s Modelling Integrated in a Knowledge Environment
DWD	Deutscher Wetterdienst (National Meteorological Service of Germany)
ECMWF	European Centre for Medium-Range Weather Forecasts
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
H-SAF	Satellite Application Facility on Support to Operational Hydrology and Water Management
FASRB	Framework Agreement on the Sava River Basin
FEWS	Flood Early Warning System
FFWS	Flood Forecasting and Warning System
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HEC-RTS	Hydrologic Engineering Center's Real Time Simulation
HIS	Hydrologic Information System
H&H	Hydrological and hydraulic
IFI	International Financial Institution
ISRBC	International Sava River Basin Commission
LiDAR	Light Detection and Ranging
NWP	Numerical Weather Prediction
OC	Operator Client
OGC	Open Geospatial Consortium
REST	Representational State Transfer
SOAP	Simple Object Access Protocol
SDIP	Sava and Drina Rivers Corridors Integrated Development Program
SSD	System for Spatial Data Discovery
WML	Water Markup Language
WMO	World Meteorological Organization
WMS-T	Web Map Service - Time
XML	Extensible Markup Language

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1. Background

This assignment is a part of the *regional component* of the *Sava and Drina Rivers Corridors Integrated Development Program* (SDIP) - *Phase I* which aims at strengthening transboundary water cooperation and improving navigability and flood protection in the Sava River basin.

The assignment aims to reduce vulnerability to floods and droughts in the Sava River basin by focusing on integrated water resources management through transboundary cooperation in flood and low-flow monitoring, forecasting, and early warning systems, thereby making the countries more resilient to extreme events. While activities connected to water-related risks, including forecasting and warning, have predominantly addressed flood conditions, the forthcoming instruments and capacities are also expected to improve the ability to mitigate the negative impacts of low-flow conditions. The assignment will incorporate forecasting and warning capabilities to better predict floods and low-flow events, as well as support the development of vulnerability assessments, consequences analysis, and adaptation planning scenarios.

1.1. Sava River basin characteristics

The Sava River basin covers an area of approximately 97,200 km^2. Encompassing substantial portions of Bosnia and Herzegovina, Croatia, Montenegro, Serbia, and Slovenia, the Sava River basin constitutes 12% of the Danube River basin area, making it the second-largest sub-basin of the Danube (Figure 1).

Figure 1. Sava River basin overview

The Sava River is the largest tributary by discharge to the Danube River, with an average discharge of about 1,700 m^3/s, which accounts for almost 30% of the Danube's total discharge at their confluence in Belgrade. The Sava River is formed by two mountainous streams: the Sava Dolinka and the Sava Bohinjka. From the confluence of these headwaters in Radovljica (SI), the Sava River is 945 km long. It flows in a northwest-southeast direction through Slovenia, Croatia, Bosnia and Herzegovina, and Serbia. A schematic longitudinal profile of the Sava River and some of its main tributaries is shown in the following figure.

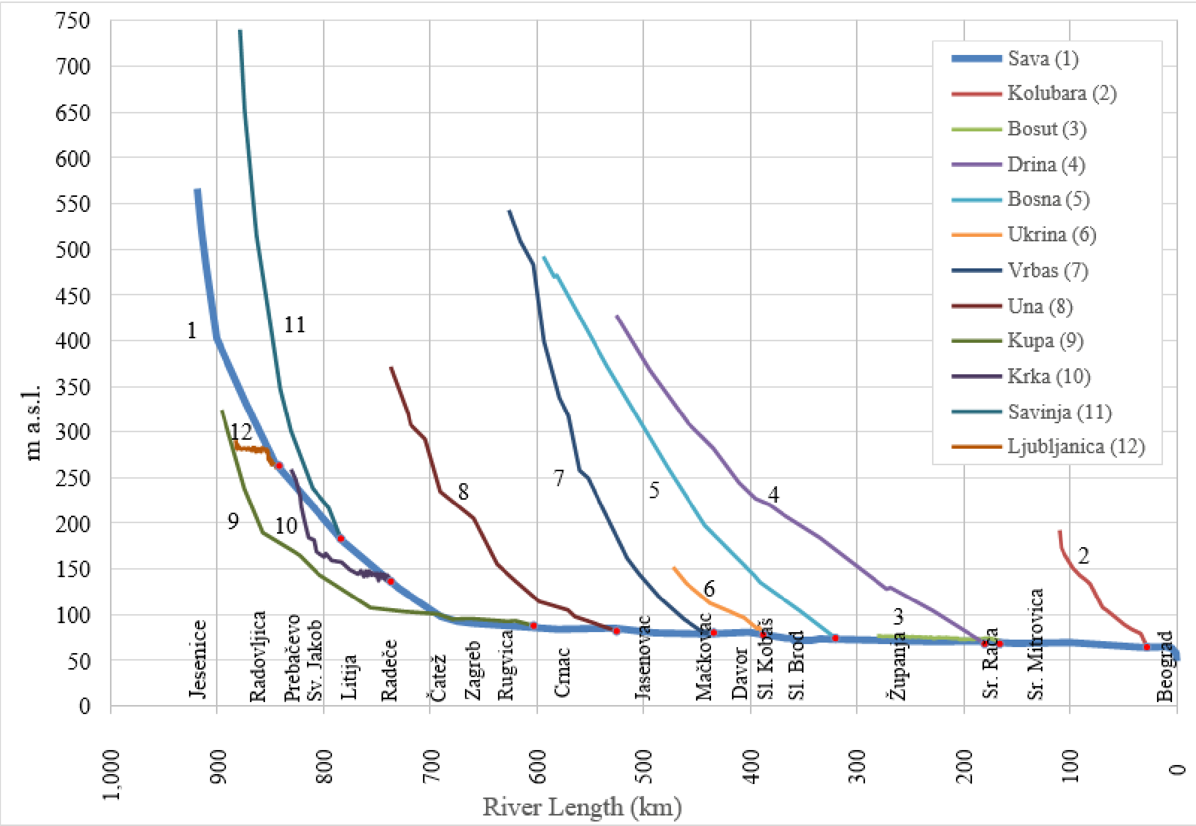

Figure 2. Schematic longitudinal profiles of the Sava River and its main tributaries

A detailed elaboration of the main characteristics of the Sava River basin is provided in the 2nd Sava River basin analysis report prepared in 2016.

1.2. Legal framework for cooperation in the Sava River basin

In 2001, the four riparian countries of the Sava River basin (at the time, Slovenia, Croatia, Bosnia and Herzegovina, and the former Federal Republic of Yugoslavia) aiming at cooperation for the sustainable basin-wide water resources management, entered into a process known as the Sava River Basin Initiative. The basic idea of the Sava Initiative was to establish an appropriate institutional framework for transboundary cooperation, to ensure sustainable use, protection, and management of water resources in the Sava River basin and ultimately enhance living conditions and raise the standard of population in the region. The process was successfully finalized in 2002 by signing the Framework Agreement on the Sava River Basin (FASRB). The FASRB calls, among others, for cooperation among the Parties[1] toward three main goals: (a) establishment of an international regime of navigation on the Sava River and its navigable tributaries; (b) establishment of sustainable water management; and (c) undertaking of measures to prevent or limit hazards and reduce and eliminate adverse consequences, including those from floods, ice hazards, droughts, and incidents involving substances hazardous to water. To facilitate the implementation of FASRB, the International Sava River Basin Commission (ISRBC; Sava Commission) was established in 2005. Since then, ISRBC has coordinated the development and implementation of joint and /or integrated plans on the management of the water resources of the Sava River basin, preparation of the development programs, establishment of integrated information systems, harmonization of the activities with national and international organizations and the development of protocols for regulating specific aspects of the FASRB implementation.

[1]Slovenia, Croatia, Bosnia and Herzegovina and Serbia. Montenegro cooperates on a technical level with the Parties based on a Memorandum of Understanding on cooperation between ISRBC and Montenegro, signed in Belgrade on December 9, 2013.

1.3. Regulatory framework for cooperation and key results of interest for Assignment

As one of the main objectives of the FASRB, the work of the Sava Commission has consistently focused on implementing measures to prevent or mitigate hazards, as well as to reduce and eliminate harmful consequences, including those caused by floods and hydrological droughts. Collaboration between the Sava countries in flood protection was further strengthened by signing the *Protocol on Flood Protection to FASRB*[2] in 2010. The Protocol has been in force since 2015, following ratification in all member countries of the Sava Commission. The Protocol formalizes a firm commitment of the Parties to further deepen cooperation in the implementation of joint activities aimed at improving flood management in the Sava River basin, through the Sava Commission, including, inter alia, the development of the joint Flood Risk Management Plan, improvement the exchange of hydrometeorological data and the establishment of a flood forecasting and warning system.

The preparation of a regulatory basis for data and information exchange in the Sava River basin started back in 2012, in collaboration with the World Meteorological Organization (WMO). Unfortunately, the catastrophic flood of May 2014 showed that the lack of timely information on the hydrological situation in the basin was one of the main obstacles in effective flood defense and demonstrated the urgent need for a more efficient exchange of hydrological and meteorological data among the cooperating countries. Consequently, the *Policy on the Exchange of Hydrological and Meteorological Data and Information in the Sava River Basin*[3] was signed in July 2014 by relevant organizations of the Parties to the FASRB and Montenegro (national/entity hydro-meteorological services and water agencies). This Policy serves as a regulatory framework for exchanging meteorological and hydrological data and information.

That was also a prerequisite for establishing the ***Sava Hydrologic Information System*** **(Sava HIS) in 2015**. Since then, the Sava HIS[4], hosted by ISRBC, **has provided tools for collecting, storing, analyzing, and reporting hydrometeorological data.** These tools are utilized in decision-making processes not only in flood risk management but also in all aspects of water resources management in the basin.

A further major step in supporting the five riparian countries in making balanced decisions in flood-related emergencies was the establishment of the ***Sava Flood Forecasting and Warning System*** **(Sava FFWS), which has been fully operational since October 2018.** The system is jointly operated and maintained by Bosnia and Herzegovina, Croatia, Serbia, Slovenia, and Montenegro with the coordination and support of ISRBC. To ensure the smooth operation of the Sava FFWS, its regular maintenance and performance control, the training of engaged personnel, and the long-term sustainability of the system, in July 2020 the Sava countries (and ISRBC) signed the *Memorandum on cooperation concerning regular functioning and maintenance of the Sava FFWS*[5] (Sava FFWS MoU). The Sava FFWS MoU regulates the rights and obligations of all institutions involved in the operation and the use of the system.

1.4. Current status of the Sava FFWS

1.4.1. Organizational aspect of the system

The Sava FFWS is a unique regional hydrological prognostic system. Based on the agreement of the cooperating countries, it is physically located at five hosting locations, specifically, one primary server and three backup servers are located within the competent institutions in the four countries sharing the Sava River basin, while a part of the system is located at the ISRBC headquarters. Since its establishment, the Sava FFWS has been regularly used by relevant national organizations (10 institutions from 5 countries responsible for flood forecasting), while ISRBC monitors its functionality

[2] The integral text of the Protocol is available here: https://www.savacommission.org/UserDocsImages/05_documents_publications/basic_documents/protocol_on_flood_protection_to_the_fasrb.pdf
[3] dataexchangepolicy_en.pdf (savacommission.org)
[4] https://savahis.org
[5] The integral text of the Sava FFWS MoU is available here: Sava FFWS MoU

and coordinates activities related to its regular operation, maintenance, and further development. The complete list of institutions and their roles in the system is given in Table 1.

Table 1. List of the Sava FFWS hosting and users' organizations

Country	Institution	Role
Slovenia	Slovenian Environment Agency (ARSO)	Host of the primary server and user
Croatia	Croatian Meteorological and Hydrological Service (DHMZ)	Host of the 3rd backup and user
	Hrvatske vode (Hvode)	User
Bosnia and Herzegovina	Federal Hydrometeorological Service (FHMZ)	User
	Sava River Watershed Agency (AVP Sava)	Host of the 2nd backup and user
	Republika Srpska Hydro-Meteorological Service (RHMZRS)	User
	Public Institution "Vode Srpske" (JUVS)	User
Serbia	Republic Hydrometeorological Service of Serbia (RHMZ)	Host of the 1st backup & test system and User
	Public Water Management Company "Srbijavode" (Svode)	User
Montenegro	Institute of Hydrometeorology and Seismology (ZHMS)	User
	International Sava River Basin Commission (ISRBC)	Host of the archive and web server and Coordinator

By the Sava FFWS MoU, international bodies have been established with tasks and competencies aimed at securing regular maintenance, functioning and further system development. The organizational scheme of the Sava FFWS international bodies is shown in Figure 3. below. Their roles and responsibilities are detailed in the memorandum.

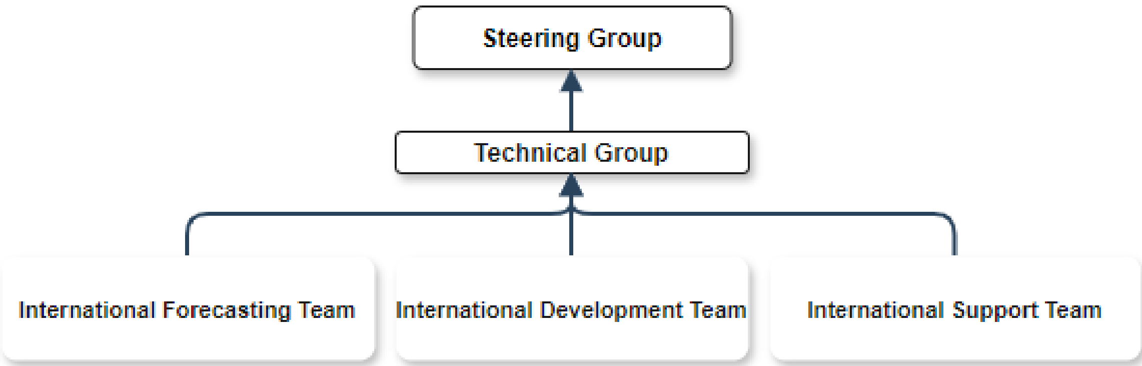

Figure 3. Sava FFWS international bodies

Working together at the international level through the Sava FFWS significantly improves understanding and knowledge transfer among cooperating institutions while maintaining countries' autonomy in monitoring, modeling, forecasting, and warning.

1.4.2. Technical capabilities of the system

The Sava FFWS is a client-server application, based on the Delft-FEWS[6] platform. Delft-FEWS is open source software that provides the architecture and modular framework necessary to address specific needs and challenges faced by the Sava countries. This concept is particularly important for the cooperating countries and their responsible organizations, as they have independently developed various models that are easily 'plugged' into a common forecasting platform. Since the Sava FFWS is designed as an open and flexible platform, it also allows the integration of a wide range of external data and models. Currently, it integrates the following components:

- Sava HIS, as a data hub for the collection of real-time hydrological and meteorological data,
- various Numerical Weather Prediction (NWP) models,
- weather radar and satellite imagery,
- outputs of the existing national forecasting systems,

[6] https://oss.deltares.nl/web/delft-fews/

- different hydrological and hydraulic (H&H) simulation models.

A schematic overview of the Sava FFWS is depicted in Figure 4 below.

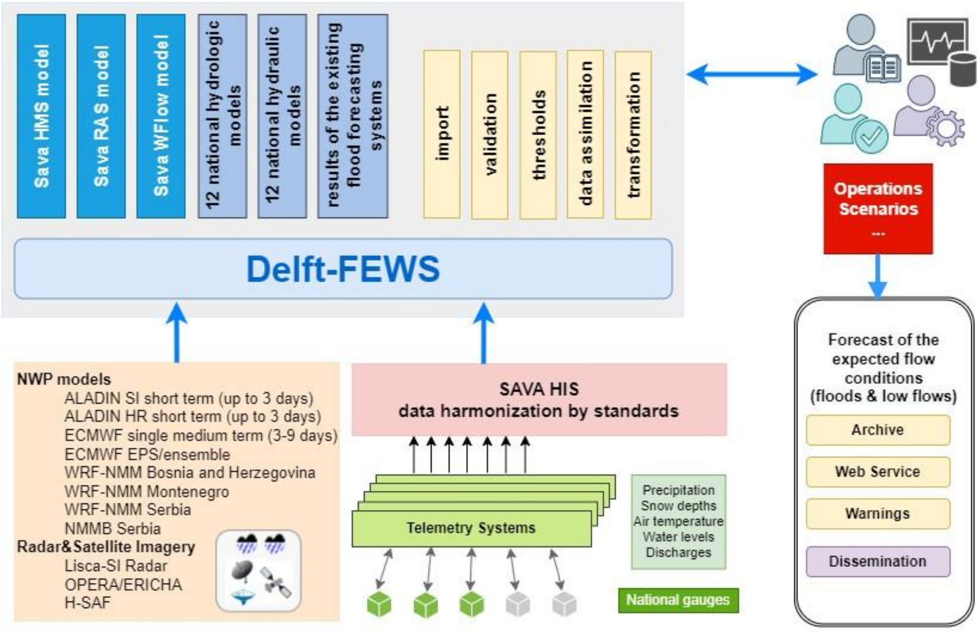

Figure 4. Sava FFWS schematic overview

Currently, 12 hydrological and 12 hydraulic models, developed in individual countries, covering some subbasins and rivers or specific river sections, are integrated into the Sava FFWS. The Sava FFWS also integrates the HEC[7]-HMS Sava hydrological and the HEC-RAS Sava hydraulic models, developed within the frame of work of ISRBC, which represent the backbone of the prognostic platform. The HEC-HMS Sava covers the entire area of the Sava River basin, while the HEC-RAS Sava model covers a large part of the main reach of the Sava River, spanning approximately 725 km. It also covers larger or smaller sections of the main Sava tributaries.

Another hydrological model that was developed during the establishment of the Sava FFWS is the distributed WFlow[8] Sava hydrological model. The WFlow Sava model has a catchment-wide coverage within the area of Bosnia and Herzegovina, Serbia, and Montenegro while accommodating the model flow boundaries from the area of Croatia as external inputs. As part of this assignment, the model will be expanded to encompass the entire Sava River basin..

Further details about the system, and the existing monitoring, modeling and forecasting tools integrated under the Sava FFWS can be found in APPENDIX A – Existing monitoring, modeling and forecasting tools.

So far, the Sava FFWS has proven to be an efficient prognostic system, fulfilling the main objective that it was designed for – flood forecasting. However, further improvements are necessary, especially considering the following: The system is technically capable of forecasting low-flow conditions but its reliability in predicting low flows (and hydrological droughts) is not yet satisfactory, and therefore, for now, it cannot function as a forecasting tool for such conditions. The situation is similar in the entire Danube River basin. There are several drought monitoring (and risk estimation) tools in the region (see EU Interreg Danube Drought Strategy), but the forecasting and early warning systems for low flows, as a basis for hydrological drought analysis, are lacking in most countries. There is no clear inter-institutional scheme of data, responsibility, and communication flow – thus a weak response before and

[7] www.hec.usace.army.mil

[8] www.deltares.nl/en/software-and-data/products/wflow-catchment-hydrology

during drought results in the lack of proactive drought management. As for the countries sharing the Sava River basin, that is planned to change with this assignment, since the operational framework of data and models allows the use and further extension of the system for non-flooding situations. Furthermore, from the time the Sava FFWS was put into operational use, the creation of new and more precise geometric input data allows for a further enhancement of H&H simulation models. A major improvement of the warning capabilities and related communication of warnings to all kinds of extreme situations is also planned in the frame of this assignment. Details of the objectives and related tasks are given in Sections 2 and 3.

2. Objectives of the Assignment

The **main goal of this assignment is to improve the forecasting of flood and low-flow events and related warning procedures in the Sava River basin to better inform decision-making on the management of hydroclimatic risks across water-related sectors**, thereby reducing the risks of loss of human life, damage to property, environment, cultural heritage, and economy, and to increase the resilience of the entire society, considering the current climate variability and future climate change impacts.

The assignment will place a major focus on improving, upgrading and upscaling the existing Sava FFWS and procedures and technical capacities to better inform decision-making processes. The five **major expected outcomes** of the assignment, are:

1 **Improved and upgraded modeling tools.**

Through this activity, NWP and H&H models will be enhanced, leading to improved reliability in operational forecasting for both high and low flows.

2 **Improved and upgraded low-flow forecasting capabilities.**

This outcome will provide the Sava countries with more reliable low-flow forecasting capabilities, under the existing common platform to better inform all water users in the basin (navigation, agriculture, hydropower, environment, etc.).

3 **Further developed and enhanced flood and low-flow warning system.**

The national forecasting and warning procedures of the Sava countries, as well as their data exchange and the warning capabilities within the common forecasting system, will be assessed. From this assessment, recommendations for improvements to enhance warning procedures in each national flood and low-flow warning authority of the Sava countries will be drawn. Based on these recommendations, innovative flood and low-flow warning products and services, including a web dissemination platform, will be developed.

4 **Well-trained staff of the Sava FFWS user organizations.**

This outcome will be measured by the availability of better-trained staff to operate the Sava FFWS and to make informed decisions during regular and emergency conditions.

5 **Recommendations for future developments of the forecasting system.**

This outcome will serve as guidelines for further investments in development after the assignment is completed.

The results of the assignment should optimize the operational work of hydrological forecasting offices within national meteorological and hydrological services, as well as water agencies in the Sava countries (i.e. the Sava FFWS user organizations).

Along with the Sava FFWS user organizations, the following main stakeholder groups will be addressed: national and local authorities for emergency management and civil protection as well as specific user sectors such as agriculture, hydropower and environment. Further, since inland navigation is one of the primary sectors of cooperation within ISRBC, special emphasis should be placed on meeting the specific needs of this sector. To enable reliable forecasting for inland navigation, meaning medium- and long-range planning timescale, setting up seasonal hydrological forecast (ensemble) models, and establishing a computational framework for seasonal water level calculations (seasonal forecast) will be required.

The outcome should include the calculation of water depths (for relevant navigable river stretches) and the calculation of actual and forecasted bridge clearances. Since navigation is particularly sensitive to the reliability of water level forecasts during low-flow periods, the confidence bands of the forecasts should be narrow.

In general, this assignment will contribute to improving regional capacity for flood and low-flow forecasting and warning in a changing climate, resulting in improvements across the entire disaster management cycle, encompassing prevention, preparedness, response and recovery.

The functionalities required for the joint flood and low-flow forecasting and warning platform should comply with the following specifications that are more specifically elaborated in Section 3:

Use and upgrade of the existing forecasting platform: The assignment should leverage the knowledge, best practices, and tools available within the operational Sava FFWS. The existing platform is based on the Delft-FEWS 2023.02 which allows a uniform presentation of the outputs from a wide variety of data and model products and still leaves it open for the user organizations to maintain and further develop their forecasting systems, in parallel. These functionalities should be maintained after all required interventions.

- The platform must support forecasting of a broad spectrum of simulations, including "gradually varying" for flood and low flows, as well as "flash" for flood situations.
- The platform should allow for a combined simulation of different hydrological conditions or be customizable and divided into components, such as a dashboard for flood forecasting and a separate one for low-flow forecasting.
- The system should support running "what-if" scenarios for individual Sava basin countries, including the operation of reservoirs and flood gates.
- All data sources and models should be connected through standard adapters, which will be delivered to the client along with detailed descriptions to facilitate future extensions of the system with new or modified data sources and models.
- The system should maintain sufficient capacity to handle the increased number of adapters and data connections. Both the existing flood forecasting system and the improved low-flow forecasting component should remain open to allow the integration of additional data and models.
- Upon completion of all planned improvements and developments, the Delft-FEWS software and all its components should be upgraded to the latest version.

Improvement of the meteorological and hydrological real-time data as well as weather forecasts: Out of all available data from meteorological and hydrological stations within the Sava HIS-RT[9], only about 60% currently provide real-time inputs to the Sava FFWS models, while many new gauging stations were installed and became operational after the initial establishment of the system. Also, there are several NWP models in the region, most of which focus on a specific country. Integrating knowledge from all existing models would lead to better basin-wide weather forecasting products. Alternatively, a "model mixing algorithm" could be implemented to combine results from multiple NWP models. This technique involves using data and outputs from different NWP models to create a consensus forecast that takes into account the strengths and weaknesses of each model. Additionally, specific improvements which would further enhance forecasting capabilities must include:

- Enhancing the initial state by improving Quantitative Precipitation Estimate (QPE) and meteorological forecast by improving Quantitative Precipitation Forecast (QPF).
- Improving telemetry connections of air temperature observing stations to Sava HIS-RT, particularly those relevant to snow conditions.
- Integrating NWP models for medium/seasonal term (weeks, months) and long term (years, decades) relevant for low-flow forecasting.
- Integrating new products recently developed at the country level, such as Croatia RADAR composite image.

[9] A special real-time version of the Sava HIS - Sava HIS-RT (details in Appendix A)

Improvement of the existing Sava basin-wide hydrological models and the Sava River hydraulic model, contributing to flood and low-flow forecasting: The hydrological models, namely HEC-HMS Sava and Wflow Sava, along with the HEC-RAS Sava hydraulic model, serve as the backbone of the FFWS system and should enable simulation of both flood and low-flow situations. For areas where other hydrological models are available or under development, their outputs will also be integrated and compared within the open forecasting platform to provide alternative forecasts. This comparative analysis will help in understanding uncertainties associated with the forecasts, similar to the use of ensemble simulations in forecasting.

The functionalities required for these models should comply with the following specifications:

- Models and corresponding system functionalities should be capable of representing both flood and low-flow conditions.
- They should be well suited to represent hydrological processes for the particular conditions prevailing in the Sava River basin, such as those requiring parameter estimation for karstic formations and snow coverage.
- Formulation of hydrological processes should allow for realistic behavior under different hydrological conditions, e.g. increased subsurface runoff fraction during floods but also in the low-flow periods for which models have not been calibrated.
- For parameter definition, models should be capable of directly utilizing information from GIS layers related to land use, soil characteristics, digital elevation models (DEMs), river networks, etc.
- Models should provide reasonable simulation results for ungauged subbasins.
- Models should be capable of generating results at basin scale within 30 minutes time-step for flood simulations and other applicable for low flows (days, weeks, months, seasons, years).

Enhancement of warning procedures: Issuing warnings for floods and low flows is a national responsibility. Further enhancing the efficiency of warning processes in the Sava River basin should be explored through a proposal of common, innovative, tailor-made warning products and services. This proposal should be based on the outputs of the common forecasting system, as well as other relevant sources, and include a proposal for transboundary harmonization of national warning procedures, along with an appropriate roadmap. An efficient warning process in the basin is one of the basic measures for climate variability and climate change adaptation. The proposed outputs should also improve the timely dissemination of relevant information to users and lead to shorter response times of risk management authorities and civil protection actions in the field during floods. Additionally, they should support making informed operational decisions related to navigation on the Sava River.

Other key requirements include:

- Introducing and testing Common Alert Protocol (CAP) standards.
- Utilizing existing institutional portals in the Sava countries.
- Assessment of the establishment of a new common regional forecasting portal and warning subscription system for efficient dissemination of the warnings.
- Developing concrete proposals for the procedures of transboundary exchange of warnings and their harmonization.

Note: The Sava FFWS must continue to function smoothly and uninterrupted during the implementation of this assignment. It is the Consultant’s responsibility to manage cyber security risks related to the proposed consulting services.

3. Scope of Services, Tasks and Expected Deliverables

The list of tasks presented hereunder in this ToR shall not be considered exhaustive. The tasks will be confirmed based on the Inception Report and it will be subject to further amendments based on insights into the progress. Therefore, it is the responsibility of the Consultant to proactively reassess the requested services, to fulfil the stated objectives of the assignment.

The five major expected outputs, described above, require the following sets of actions:

1. **Identification, acquisition, assessment, and storing of all data, models, and other information relevant to the Assignment,** such as

- Spatial data sets such as land cover/land use maps, soil and soil moisture maps, river catchment delineations, river networks, flood maps, etc.
- Numerical weather prediction models (e.g. DWD products, COSMO, ECMWF-14 days, ECMWF-6 weeks), weather radar images (e.g. Croatia RADAR composite image), satellite images, etc.
- Meteorological data (temperature, rainfall, snow), in particular from all recently established gauging stations that are not currently available in Sava HIS.
- Hydrological data from recently established gauging stations that are not yet available in Sava HIS, including rating curves.
- Relevant data on flood and low-flow threshold levels, pumping station data, as well as data on reservoirs (operation rules, water levels and turbine and spillway flows) obtained from reservoir operators or other available sources (like the Global Water Watch system).
- Recently developed simulation systems (e.g. HEC-RTS Drina system, DHI MIKE Bosna-Ukrina-Tinja-Brka system), including their quality indicators of calibration and validation, and suitability for forecasting purposes, etc.
- Recently developed/upgraded numerical H&H models of interest.
- Digital terrain models (DTMs), newer cross-sectional geometric data, bathymetric data, and information on hydraulic structures and bridges on the Sava River and its main tributaries.
- Other (unspecified) information and data relevant to the assignment.

2. Development of high-resolution NWP models, satellite, and radar composite image

- Improve short-term weather (rainfall and air temperature) forecasts in the whole Sava River basin by either integrating knowledge of the existing local NWP models into a basin-wide NWP model or by using a model mixing algorithm to obtain a more reliable forecast for a specific area or period.
- Improve accuracy of the short (2 to 6 hours) lead-time rainfall forecasts by using radar (e.g. Croatia RADAR composite image) and/or satellite data and developing a radar/satellite-based composite image that covers the whole Sava basin. Such input should improve forecasts during severe weather conditions like thunderstorms, which, inter alia, result in flash floods in small river basins.
- Improve data assimilation of distributed state variables (such as snow-related data and soil moisture) from available radar and satellite information including filling data gaps. The methodology for filling data gaps should be approved by ISRBC.
- Integrate medium/seasonal and long-range weather (e.g. rainfall, air temperature, other necessary parameters) forecasts that will be used for low-flow forecasting.

3. Improvement of the existing H&H models

- The performance of the existing H&H models should be reevaluated with the main goal of reducing the number of workflows. Based on the evaluation it is expected that some models will be removed (e.g. hydraulic models of short stretches of the Sava tributaries), and some replaced with newer versions (e.g. MIKE Sava, MIKE Vrbas).
- All recently developed models in the riparian countries should be evaluated and integrated into the Sava FFWS if their performance meets the given criteria (e.g. models integrated into the prognostic systems HEC-RTS Drina, MIKE Bosna-Ukrina-Tinja-Brka).
- All meteorological and hydrological real-time data from gauging stations currently available in the Sava HIS and newly installed ones in the Sava countries should be reanalyzed, integrated, and linked to the models (especially to the so-called backbone models). Based on the available data from all gauging stations, periods of calibration and verification should be defined.
- Improve the performance and accuracy of the Wflow Sava model by:

- including all currently available meteorological stations and radar composite images in the meteorological component of the model as well as real-time data on reservoir water levels and turbine flow.
- updating the soil and land use maps currently being utilized in the model with the latest ones from publicly available sources; enabling satellite-based soil moisture map that can be used for data assimilation and interpretation of model results by forecasters.
- extending the model to the entire Sava River basin area and implementing the model parameters, based on new DEMs, land use data and soil maps; estimating sensitivity of the main hydrological parameters in the model.
- calibrating all sub-catchments, so that the model can be used reliably in operational forecasting;
- validating the model to ensure that it is accurate and useful for its intended purpose.
- connecting the Wflow Sava to the HEC-RAS Sava and other integrated hydraulic models, as needed.

➢ Enhance the performance of the HEC-HMS Sava model by:
  - including all currently available meteorological stations and radar composite images in the meteorological component of the model as well as real-time data on reservoir water levels and turbine flow.
  - analyzing and applying the most suitable rainfall-runoff method for each subbasin element (loss, transform, baseflow, snowmelt, routing). Special attention should be paid to snowmelt modeling (Snow Water Equivalent).
  - calibrating the HEC-HMS Sava model for a long period that includes both high and low flows.
  - validating the model to ensure that it is accurate and useful for its intended purpose.
  - including the reservoir add-ons recently developed (e.g. for the Drina River HEC-ResSim).
  - connecting the HEC-HMS Sava to the HEC-RAS Sava and other integrated hydraulic models, as needed.

➢ Enhance the performance of the HEC-RAS Sava model by:
  - improving the existing HEC-RAS digital terrain model using collected bathymetric data (for the Sava River channel), cross-sections of the Sava River and its main tributaries as well as by extending it by adding the terrain representation of floodplains along the main Sava tributaries produced after 2017 (based on the LiDAR surveying).
  - preparing a new/updated HEC-RAS model geometry by:
    - extending the model by adding the Sava River section upstream of hydrological station Čatež to Radovljica (from rkm 736 to rkm 945 – i.e. confluence of the Sava Dolinka and Sava Bohinjka).
    - refining the Sava River geometry using the updated HEC-RAS digital terrain model;
    - refining the geometry of the Sava tributaries using new cross-section data and digital terrain model, and extending the geometry upstream where new data are collected;
    - adding/updating bridges in the model (based on the collected information) or based on a new survey of the bridges on the navigable part of the Sava River where the data is missing).
  - refining or adding new data on hydraulic structures in the HEC-RAS model.
  - calibration of the HEC-RAS model against the range of flows (low and high flow conditions) to improve the accuracy of simulations made over a wide range of conditions.
  - verification of the HEC-RAS model (acceptability of the model depends on whether it fulfils its purpose in serving as a decision support tool)
  - developing an HEC-RAS 2D model of the navigational part of the Sava River, if necessary (to be decided during the Inception Phase).

➢ Enhance the current capabilities of the models to enable efficient running and display of ensemble forecasts in the system. This involves combining probabilities (probabilistic forecasting) with model performance information to better address uncertainty.

- Develop criteria and performance indicators for the forecasting system based on calculable categories such as the probability of detection, critical success index, false alarm rate, and bias ratio between predicted and observed flood events. Utilizing performance data, the system should be capable of identifying well-performing model outputs, thereby providing a consistent view of reliability, suitable for sharing online. Additionally, the system should be able to generate confidence bands /expected performance at various lead times to provide users with information suitable for i.e. online forecast sharing.
- Improve the existing Ensemble Kalman Filter (EnKF) approach to assimilate observations in the forecasted variable(s) and implement it in the simulation models.
- Develop the artificial intelligence/machine learning capabilities, e.g. neural network-based forecasting using the observed data, or similar that should be proposed by the Consultant and approved by the ISRBC coordinating body.
- All newly developed or improved models will be adapted for integration into a common Sava FFWS platform using the newest Delft-FEWS adapters.

4. Implementation of the low-flow forecasting into the existing common platform

- Analyze and, if necessary, redefine the use of the existing system architecture based on all available and new data that will be integrated, including medium/seasonal and long-range weather prediction models, meteorological and hydrological data, hydrological models, and appropriate hydraulic models.
- Establish connections to the low-flow forecasting for all components defined in the system architecture, including those for manually transmitted data inputs; develop required adaptors for components that do not yet have them.
- Provide automatic and manual data quality control functionality, filling data gaps when and where needed and preprocessing of data.
- Implement NWP products and related sources for the medium/seasonal term (weeks, months) and the long-range term (year) to be able to forecast low-flow and dry periods.
- Extend hydrological/hydraulic simulation models to represent low-flow conditions and include reservoir operation for principal reservoirs in the basin, based upon predefined or ad hoc modified operation rules. Also, features for the optimization of reservoir operations and flood gates should be included.
- Utilize the HEC-HMS and Wflow Sava models to provide low-flow forecasting capabilities to enable accurate information for the inland navigation sector and hydrological drought analysis. Extend the models to include forecasts of different hydrological variables.
- Based on different hydrological variables, compute low-flow indicators relevant to users, primarily in the navigation sector (e.g. Standardized Precipitation Index - SPI; Standardized Water-level Index - SWI, Streamflow Drought Index - SDI, Standardized Runoff Index - SRI, etc.). Indicators should be determined in collaboration with selected users and sectors.
- Implement low-flow forecasting procedures, including the definition of river cross sections where low-flow forecast is needed, particularly for navigation purposes, the type of variable(s) to be forecasted (water level/water depths), and relevant forecasting lead time.
- Implement support for computing performance indicators to automatically quantify input data and forecast accuracies, as required. Additionally, ensure the system provides the functionality of supporting hindcasting, reanalysis of events, and supporting external data users and developers to expand community research on low flows and hydrological drought analysis.
- Provide telemetry connections of the system and web connections for retrieving all required input data to the low-flow forecasting component.

5. Development of efficient flood and low-flow forecasting and warning procedures and establishment of an internal web dissemination platform

- Determine basin-wide forecast locations that trigger emergency management operations, including the type of information that will be used (e.g. observed/forecasted rainfall accumulations, water levels, flows).
- Define, for each location and type of data, the following information: forecast threshold levels (utilizing all known threshold levels and deriving thresholds for other locations), forecast lead time, and, in case of probabilistic forecasts, exceedance probability. Also define how parameters related to threshold crossings are generated (e.g. model(s) and/or meteorological forecast applied, based on statistical analysis).
- Define the forecasting products to be provided, service delivery frequencies, formats, mechanisms, reliability, and availability according to national warning procedures and through the implementation of the Common Alert Protocol (CAP) standard.
- Provide internal tool(s) – web dissemination platform(s), for collecting forecasts and/or issuing warnings (e.g. ARSO VodePro), in full agreement with the requirements of each country's representatives and based on existing procedures, where exist. Define message formats and web connections for disseminating forecasts and warnings via intranet and internet, to meet the needs of all internal users.

  The web dissemination platform should be designed first, in such a way that it supports the use and adheres to existing functionalities within the Sava FFWS, that are integrated as the backend part of the existing platform (Master Controller and Forecasting Shells). It should be based on the Delft-FEWS Web OC application (v.2023.02) and the available web services (PI REST, PI SOAP, WMS-T, WaterML, SSD, Digital Delta, Umaquo), and it should have the capability to limit and/or extend the number of users. The solution should refrain from introducing new technologies into the existing technological framework, thereby averting any increase in maintenance complexity. The backend process that will prepare the appropriate static files and that should support the easy addition of a new model group or model domain and offer it to the user via the web application will be created using the standard scripting language and will be installed on the existing Sava FFWS hosting servers.

  Dissemination of forecasts and warnings should be enabled using the web dissemination platform, Delft-FEWS OC, e-mail, SMS, and mobile phone apps, and will be defined and customized for different end-users as will be decided by the participating countries.

  Procedures and functionalities for the timely transmission of data and forecasts to navigation companies, shipmasters, and waterways administration should also be developed.
- Provide an automatic triggering tool (e.g. ARSO SAP), as a part of the internal web dissemination platform, for continuous evaluation of measured and forecasted meteorological and hydrological parameters at very short intervals. In comparison with thresholds, the tool should serve to trigger a warning (by e-mail, SMS, or mobile phone apps, including a graphical presentation) to the duty forecasters, indicating the need for continuous monitoring of an event.

6. Test and operationalize the use of common flood and low-flow forecasting and warning system

- Conduct successive testing of new or improved system functionalities on the test platform (RHMZ), both in hindcast and daily operations.
- Provide the installation of the tested system on the operational platform in each of the hosting organizations.
- Establish the chaining of data-models-forecast-warning scenarios for floods and low flows within the common platform.
- Test the system in the operational environment with the active participation of the main stakeholders.
- Hand over the system to the users.

7. Inventory of needs and recommendations on the use and future improvements of the system

- ➢ Conduct an inventory and assessment and propose potential improvements for the following:
  1. Hardware and software installed in the hosting organizations and ISRBC. Prepare technical specifications and cost estimates for additional hardware and/or software acquisition.
  2. Personnel in the hosting and user organizations. Propose capacity-building and institutional strengthening measures as necessary, considering the use, operation and maintenance of the system and models.
  3. Communication requirements for connecting to monitoring devices and requirements related to dissemination of forecasts and warnings within each and between the Sava countries.
  4. Maintenance services requirements. Specify expected maintenance costs and service fees.
- ➢ Additionally, the following is requested:

i. Identify and assess any remaining data and information gaps related to the common forecasting and warning system for the Sava River basin, including cost estimates.
ii. Provide recommendations for follow-up activities.
iii. Provide a proposal for the development of the rapid impact assessment due to flooding. This assessment should include impacts linked to risk receptors as defined in the EU Floods Directive (human health, environment, culture heritage and economy) as well as to the accessibility to key points of interest (e.g. hospitals).
iv. Propose and develop a set of scenarios depicting potential future conditions that would allow an assessment of the system performance. This would be discussed and agreed with ISRBC during the implementation of the assignment.

8. Training, capacity building and communication activities

8.1. Training and capacity building

An essential component of the assignment is the provision of training for key stakeholders (staff of user organizations, ISRBC and other key stakeholders' representatives). These courses should provide participants with the necessary skills to effectively use the system. The training sessions should cover various topics such as system installation and configuration; development, calibration, and verification of models; execution of models and interpretation of the results; tailoring of outputs within the internal web application; generation and issuance of alerts/notifications, etc. Additionally, the training will incorporate an analysis of user experiences gathered during the system's testing phases. The Consultant will organize at least 3 training sessions, each lasting 5 days. The Consultant shall prepare a detailed proposal of the training program, aligned with the project's implementation phases. The program will be refined based on the analysis of the key stakeholders, further detailed, and approved by ISRBC during the Inception Phase.

In principle, the courses will be conducted in person with an estimated attendance of 20 participants per course. The Consultant will cover the costs of travel, meals, and accommodation for training participants. Per diems may not be paid to participants when meals and accommodation are to be provided. The Consultant is also responsible for providing a suitable meeting room equipped with modern technical amenities, including excellent sound systems, quality lighting, a projector, screen, and high-speed internet.

For national experts who will not be able to attend the training sessions in person, access should be provided through a web application, such as MS Teams, Webex, etc.

Training materials such as agendas, descriptions of specific topics, presentations, modeling examples, etc., will be distributed to participants at least one week before each course.

Additionally, the Consultant should establish an online platform, such as SharePoint, for registered users, which will ensure continuous communication between users and the Consultant. This may include a forum that allows for easy discussion about different categories (i.e. how to…, models, bugs). It also may include all documentation produced during the project implementation, to update all beneficiaries with the latest information.

During the operational testing phase, a webinar should be organized for all users of the system. The primary objective of this webinar is to provide users with the opportunity to directly pose specific questions to the Consultant, facilitating the exchange of insights among users and enabling the transfer of knowledge and expertise in utilizing the system and forecasting procedures.

8.2. Project events

In the course of the assignment, the Consultant shall organize the following events with the participation of key stakeholders:

i. Kick-off meeting during the Inception Phase (months 1-2) to present the planned project activities and gather feedback from participants.
ii. Intermediate workshop scheduled after the completion of installation (months 16-17) to exchange experiences with system users.
iii. Final conference scheduled after the submission of the draft Final Report (month 20) to present the system and gather feedback from participants for final adjustments before handing over the system.

The events will be essentially organized in a hybrid format. The Consultant should provide an adequate meeting room, equipped with modern technical equipment, which includes excellent sound systems, quality lighting, projector, screen, and high-speed internet. The costs of refreshments and meals for in-person participants will be borne by the Consultant. The estimated number of participants attending the events in person is the following: 30 at the kick-off meeting, 30 at the intermediate workshop and 40 at the final conference.

For each event, the Consultant should prepare an agenda with background information and draft documents and presentations with critical issues to be discussed. The Consultant shall arrange translations/interpretation, moderate the events, and produce the minutes.

8.3. Communication activities

During the implementation of the assignment, the Consultant will, on an ad hoc basis, prepare appropriate materials for public release, which may include short videos, press releases, and news for the web and social media, in English and one of the official languages of the Parties to the FASRB.

Note: All stakeholders' engagement activities should continuously incorporate in the reporting progress on the SDIP indicator: flood monitoring and forecasting system upgraded in a participatory manner, publicly disclosed and adjusted based on citizen engagement. The indicator should measure the progress in upgrading the flood monitoring and forecasting system in a participatory manner that actively engages stakeholders not only in the formulation but in providing feedback on the system, and that will therefore provide timely, accurate and user-friendly flood forecasting. The level and quality of participation should be measured through beneficiary assessments to be undertaken during project implementation at mid-term and again before project closure.

4. Deliverables/Specific outputs

The following should be delivered to the Client:

1. Improved and upgraded modeling tools, integrated into the existing common platform, tested and put in operation for flood and low-flow forecasting.
2. A robust and resilient operational low-flow forecasting system covering the entire Sava River basin, tested thoroughly, installed, and integrated into the existing common platform, with independent access available in each country.
3. Further developed and enhanced flood and low-flow forecasting and warning system, including the installation of an operational and well-tested web dissemination platform.

4. Appropriately trained staff in all countries to ensure continued use and improvement after operationalization and handover. Staff should be capable to independently implement extensions, updates and/or replacements of forecasting system components, as well as further development of forecast and warning reports.
5. A report outlining the operation and maintenance costs required as well as recommended investments and efforts that will lead to future improvement of the quality of the forecasting system.

The documentation delivered to the Client upon taking over the system should encompass the following:

- System Description: Detailed description of the forecasting system functionalities and features, including information on models, algorithms, and methodologies used for forecasting.
- System Configuration: Detailed overview of system configuration, including settings, parameters, and system management procedures.
- Technical Specifications: Hardware and software specifications used in the system, including compatibility information and system operation requirements.
- User Manuals: Practical guides and instructions for using the system, including steps for startup, data input, forecast generation, and result interpretation.
- Security Guidelines: Guidelines and recommendations for the safe use of the system, including procedures for data protection and access.
- Maintenance and Support: Information on system maintenance, including maintenance routines, user support, and contact details for technical assistance.
- Upgrade Procedures: Guidelines and instructions for system upgrades, including information on available upgrades and procedures for installation.
- Testing Documentation: System testing reports, including test results, conclusions, and recommendations for improvements.
- Emergency and Operation Manuals: Guidelines for emergency response, including procedures for responding to flood and drought events and managing crises, in addition to operating rules for low-flow conditions in the navigation sector, among others.
- Training Documentation: Training reports, including participants, topics, training duration, and achieved results.

The main deliverables specified in this Section will be detailed and possibly amended in the Inception Phase.

5. Reporting Requirements and Time Schedule for Deliverables

Month*	Report	Main Deliverable	Indicator
2	Draft Inception Report		
3	Inception Report	Report	The report, including a description of the detailed approach, working methodology and action plan aimed to achieve the assignment's objectives
7	Draft Interim Report 1		
8	Interim Report 1	Prerelease 0.1	The initial version of the system installed on the testing platform. Models upgraded, calibrated, and verified.
11	Draft Interim Report 2		
12	Interim Report 2	Prerelease 0.2	The system enhanced and upgraded by implementing a low-flow forecasting system/component.
16	Draft Interim Report 3		
17	Interim Report 3	Prerelease 0.3	All components/functionalities of the system implemented.
20	Draft Final Report	Release 1.0	The system tested and implemented on the operational platform.
23	Final Report	Release 2.0	Final release – delivered to the Client, along with all necessary documentation.

* from the commencement of the assignment

Each report shall consist of a narrative section and a financial section. The financial section must contain details of the time inputs of the experts and the provision for expenditure verification. Draft reports must be provided along with the corresponding invoice to ISRBC (e-mail: isrbc@savacommission.org). The ISRBC coordinating body will review the report and provide the Consultant with its comments/approval. The Consultant shall present the final version within 21 days from the date it receives the comments from ISRBC. The approved reports will serve as the basis for payments.

Reports shall be provided in English with summaries in one of the official languages of the Parties to the FASRB. One original and two hard copies of each report are to be submitted for comments and approval. All documents, i.e. (draft) reports, records of informative data, spatial information such as maps, and training material are to be made available in electronic form. Each version of a complete forecasting system (Prerelease 0.1 to Release 2.0), including corresponding models, should be available online and also prepared and submitted on a digital media (memory stick).

In addition to the aforementioned reports, the Consultant is obligated to prepare brief periodic progress reports, generally on a monthly basis. Periodic reports shall be prepared in English.

Note: As the stakeholders' network is rather complex (e.g. representatives of five countries and various sectors), the inception phase is crucial for the assignment, planned for three months. During this phase, the stakeholder list may be updated. The requested outputs and services will be (re)analyzed, confirmed by the key stakeholders and afterwards approved by the coordinating body to be established by ISRBC.

6. Logistics, Team Composition & Qualification Requirements

6.1. Logistic Requirements

To ensure smooth execution of the assignment, the Consultant will:

- Establish one or more offices in the Sava region, including all equipment necessary for the project, which will remain its property at the end of the assignment.
- Establish a mechanism to ensure continuous and unrestricted communication with ISRBC, as well as with relevant stakeholders in the countries of the Sava River basin.
- Conduct a brief identification and analysis of key stakeholders relevant to the assignment - potential customers of the forecasting and warning information as a final result of the system (e.g. national authorities responsible for inland navigation, flood and drought management, reservoir operations and water utilities, emergency management services, as well as relevant regional organizations, e.g. Drought Management Centre for Southeastern Europe – DMCSEE). These customers should be engaged during specific periods of the assignment and should provide feedback, especially on the type and reliability of the forecasts and warnings that could be provided by the system for decision-making.
- In cooperation with ISRBC, propose and support the establishment of a project coordination platform (Steering Committee, Working Groups, etc.), respecting the existing cooperating structure among the participating countries established under ISRBC. Tasks will include the delineation of the ToRs for the different groups that comprise the coordination platform, in addition to its operating rules, among others.
- Organize meetings in and among countries and/or between sectors (with the support of ISRBC when and where necessary) and prepare for each meeting the following: (i) agenda, (ii) a brief description of critical issues to be discussed, (iii) minutes, including agreed actions, deadlines, and responsibilities.

Note: The Consultant's team needs to possess adequate proficiency in the official languages of the FASRB Parties to ensure fluid communication and engagement with national entities in the countries of the Sava River basin during the contract implementation.

6.2. Consultant Qualification

- The core business of the Consultant should comprise the development and configuring of hydrological forecasting and warning systems, including mathematical modeling of meteorological and hydrological conditions, and river hydraulics.
- The Consultant should prove extensive experience in similar work with a proven record of scope, complexity, and value. Relevant similar experience should be specifically outlined and may include, among others:

  i. Experience in developing hydrological forecasting and warning systems based on the Delft-FEWS configuration, including familiarity with related naming conventions, XML schemas, and workflows.

  ii. Experience in meteorology, weather forecasting, and remote sensing, which encompasses satellite and radar imagery analysis.

  iii. Experience in hydrology, hydrological and hydraulic modeling, as well as expertise in model calibration and verification processes.

  iv. Experience in flood and low-flow management relevant to emergency services, inland navigation, and hydrological drought analysis.

v. Experience in IT/GIS, data management, data exchange protocols, dissemination strategies, and statistical analysis.

- The Consultant must demonstrate evidence of at least fifteen (15) years of general experience in performing assignments related to flood forecasting, low-flow forecasting, hydrological and hydraulic modeling, as well as analysis and management of hydrologic time-series data.
- The Consultant must show evidence of required competence and adequacy to successfully complete the assignment and must have specific in-depth and recent experience in at least two (2) similar assignments in the last ten (10) years, where the Consultant acted as a Lead Consultant, with a proven record of scope, complexity, and value. The Consultant's specific experience in developing large-scale flood and low-flow forecasting systems within the past 5 years will be an additional advantage. References for the listed assignments should be provided.
- Experience in similar projects in the Sava region will be considered an added advantage.
- Experience with projects funded by donors such as the World Bank and other IFIs, the EU or similar entities will be considered an added advantage.
- The Consultant must demonstrate solid technical and managerial capabilities of the firm providing only the structure of the organization, general qualifications, and availability of appropriate skills of key experts[10].

The shortlisting criteria are:

a) Overall experience relevant to the assignment –	*35%*
b) Similar contracts to demonstrate specific experience –	*50%*
c) Firm Organization and availability of key experts –	*15%*
Total weight:	*100%*

6.3. Team Composition

The Consultant will ensure that appropriately qualified experts for each of the tasks described in Section 3. (scope of services for each activity) and the necessary equipment are available to complete the activities required and to achieve the overall and specific objectives of this project in terms of time, costs, and quality.

For this assignment, the Consultant should field a well-balanced team of international and local experts with the following aggregate abilities, by specialist position:

Key Expert 1: Technical Team Leader - TTL
A technical team leader responsible for establishing a forecasting system should possess a combination of qualifications and skills relevant to hydrology, forecasting, project management, and team leadership.
Key qualifications include:

- Education: Advanced university degree (master's or equivalent) in water resources engineering, hydro-technical engineering, environmental engineering, hydrology, or another field relevant to the assignment.
- Professional Experience: At least 15 years of extensive practical experience in implementing similar systems and projects.
- Project Management: Documented experience in leading international and multidisciplinary technical projects, including planning, budgeting, scheduling, and resource allocation. TTL should have strong project management skills and leadership abilities to ensure the successful implementation of the forecasting system within specified timelines and budgets.

[10] *No need to provide CVs of key experts. The key and non-key experts will be evaluated at the next stages of the procurement procedure.*

- Communication Skills: Excellent communication skills to liaise with stakeholders, clients, and team members. TTL should be able to convey complex technical concepts clearly and understandably and facilitate effective communication within the team.
- Technical Skills and Expertise: Proficiency in using the Delft-FEWS software platform for hydrological modeling, forecasting and warning, with hands-on experience in configuring, calibrating, and validating models within the Delft-FEWS environment.
- Language: Excellent command of written and spoken English.
- Regulatory Knowledge: Familiarity with relevant EU policies, regulations, standards, and guidelines related to flood and drought management, and civil protection mechanisms will be an advantage
- Previous experience in the Sava basin region will be an advantage.

Key Expert 2: Senior hydrologic expert

A senior hydrologic expert should possess a combination of qualifications and skills tailored to this specific task. Key qualifications include:

- Education: Advanced university degree (master's or equivalent) in hydrology, or another field relevant to the position.
- Professional Experience: At least 15 years of extensive experience which includes: hydrological analysis and data interpretation; assessing flood hazards, risks, and vulnerabilities; assessing droughts using standardized (precipitation and streamflow) indices, etc., with a proven track record of successful related projects.
- Technical Skills: In-depth knowledge of hydrological forecasting techniques, including both deterministic and probabilistic methods, and proficiency in hydrological modeling software, statistical analysis tools, and Geographic Information Systems (GIS); Familiarity with remote sensing techniques and satellite imagery analysis for monitoring hydrological conditions, vegetation health, land surface temperature, and other indicators of drought and flood risk; Familiarity with the design and implementation of flood and low-flow warning systems, including the integration of hydrological models with real-time monitoring data and forecast information.
- Knowledge of Regulations: Familiarity with relevant national and international regulations related to water management.
- Communication Skills: Ability to effectively communicate complex hydrological concepts to diverse audiences, including policymakers, stakeholders, and the public.
- Collaboration Skills: Ability to collaborate with experts from various disciplines, including hydrology, climatology, meteorology, geography, ecology, engineering, economics, and social sciences, to address complex water-related challenges associated with floods and low flows.
- Language: Excellent command of written and spoken English.

Key expert 3: Senior hydrologic modeler

A senior hydrologic expert should possess a combination of qualifications and skills tailored to this specific task, which should collectively enable a senior hydrologic modeler to play a crucial role in the establishment of a flood and low-flow forecasting and warning system, ensuring its accuracy, reliability, and effectiveness in mitigating risks and protecting communities and infrastructure.

Key qualifications include:

- Education: Advanced university degree (master's or equivalent) in hydrology, water resources engineering, environmental engineering, or a related field with a focus on hydrological modeling.
- Professional Experience: At least 10 years of extensive experience in hydrological modeling, including the development, calibration, and validation of hydrological models with a proven track record of successful related projects.
- Technical Skills: Expertise in hydrological modeling software, such as HEC-HMS, WFLOW, or similar tools; Proficiency in using the Delft-FEWS software platform for hydrological modeling and forecasting with hands-on experience in configuring, calibrating, and validating hydrological models within the Delft-FEWS environment; Ability to develop and customize hydrological models to suit the specific requirements of the forecasting and warning system, including parameterization, model calibration, and uncertainty analysis.

- Communication Skills: Effective communication skills to collaborate with interdisciplinary teams, present modeling results to stakeholders, and convey complex technical concepts clearly and understandably.
- Language: Excellent command of written and spoken English.

Key expert 4: Senior hydraulic modeler

A senior hydraulic modeler involved in establishing a flood and low-flow forecasting and warning system should possess a combination of qualifications and skills relevant to hydraulic modeling, flood forecasting, and warning systems. Key qualifications include:

- Education: Advanced university degree (master's or equivalent) in water resources engineering, environmental engineering, or a related field with a focus on hydraulic modeling.
- Professional Experience: At least 10 years of extensive experience in hydraulic modeling, including the development, calibration, and validation of hydraulic models with a proven track record of successful projects related to flood and low-flow forecasting.
- Technical Skills: Expertise in hydraulic modeling software, such as HEC-RAS, MIKE 11, or similar tools; Proficiency in using the Delft-FEWS software platform for hydraulic modeling and forecasting with hands-on experience in configuring, calibrating, and validating hydraulic models within the Delft-FEWS environment, Proficiency in GIS software and statistical analysis tools for data processing and model input preparation; Familiarity with the design and implementation of warning systems, including the integration of hydraulic models with real-time monitoring data and forecast information within the Delft-FEWS platform.
- Communication Skills: Effective communication skills to collaborate with interdisciplinary teams, present modeling results to stakeholders, and provide guidance and support to team members working on the forecasting and warning system within the Delft-FEWS platform.
- Regulatory Knowledge: Familiarity with relevant regulations, standards, and guidelines related to flood and drought management, emergency response, and public safety.
- Language: Excellent command of written and spoken English.

Key expert 5: Senior ICT expert

A senior ICT expert involved in establishing a flood and low-flow forecasting and warning system should possess a combination of qualifications and skills relevant to information technology, data management, and system integration. Key qualifications include:

- Education: Advanced university degree (master's or equivalent) in computer science, information technology, software engineering, or a related field.
- Professional Experience: At least 10 years of extensive experience in IT project management, software development, and system integration with a proven track record of successfully implementing IT solutions for complex projects, preferably in the domain of hydrology or water resources management.
- Technical Skills: Proficiency in programming languages commonly used in software development, such as Java, Python, C++, or JavaScript; working knowledge of PostgreSQL; In-depth knowledge of the Delft-FEWS platform's architecture, functionalities, and capabilities; expertise in developing custom modules, plugins, or workflows within the Delft-FEWS platform to enhance its functionality and address specific forecasting requirements; technical expertise to implement complex algorithms, data processing logic, and visualization features tailored to the needs of the system; experience in developing user interfaces and web applications for data visualization, decision support, and alerting purposes, etc.
- Communication Skills: Effective communication skills to collaborate with interdisciplinary teams, present technical concepts to non-technical stakeholders, and provide user support and training.
- Language: Excellent command of written and spoken English.

<u>Pool of other international and/or local experts, such as:</u>

- Meteorologist(s);
- Climatologist(s);
- Hydrologic modeler(s);
- Hydraulic modeler(s);
- Flood management specialist(s);

- Drought management specialist(s);
- Inland navigation expert(s);
- Environmental/Natural resource management expert;
- ICT specialist(s): database administrator; system integrator, network engineer, cyber security expert, etc.
- GIS expert(s);
- Geodetic expert(s);
- Stakeholder involvement/Public communications expert.

Special requirements

The Consultant should ensure that the consortium brings in substantial local expertise to address the specific needs of the Sava countries and secure future support from consultants based in the Sava River basin. The list of non-key experts shall be approved with the approval of the Inception Report, i.e., when the scope and set-up of the assignment will be (re)defined and approved by the ISRBC coordinating body.

Estimated input per expert

Experts	Number of days
K1- Technical Team Leader - TTL	125
K2 - Senior hydrologic expert	110
K3 - Senior hydrologic modeler	90
K4 - Senior hydraulic modeler	90
K5 - Senior ICT expert	85
Non-key experts	606
TOTAL	**1106**

7. Client's Input and Counterpart Personnel

The work on the assignment will be overseen and coordinated by ISRBC. Existing system users, specifically organizations responsible for hydrological forecasting from all participating countries, will be involved (see Table 1), through ISRBC. These organizations, as the main users of the system, will be actively engaged throughout the assignment period and will assist in the collection of data, models, and other relevant information. Although the collection of data is the responsibility of the Consultant, ISRBC and the main users of the system will also facilitate communication with other potential data providers in the riparian countries (e.g. national authorities responsible for inland navigation, reservoir operators, water utilities, and institutes).

Additionally, ISRBC shall:

- Establish and facilitate the work of the project coordinating bodies.
- Facilitate contacts with the stakeholders and assist in the collection and valorization of comments when necessary.
- Provide support in organizing project events and training courses.
- Make available all publications of interest in electronic form.
- Provide related GIS data in its native format.
- Make available all internally upgraded H&H models.

8. Working languages

The working language would be English.

9. Duration of the Assignment

The requested services are to be rendered within a maximum of **23 months.** The intended commencement date is September 2024, but the actual date will be defined with the Contract signature. The Consultant will perform the services in line with a detailed schedule submitted as part of the proposal, subject to changes during negotiations to accommodate the Client's comments and requirements.

10.Selection process

The Consultant will be selected under the provisions of the World Bank Procurement Regulations for IPF Borrowers (Procurement Regulations), in investment project financing Goods, Works, Non-Consulting and Consulting Services November 2020, based on the method of Quality and Cost Based Selection (QCBS) Lump Sum Contract

APPENDIX A – Existing monitoring, modeling and forecasting tools

The Sava FFWS is in line with the long-term activities carried out by the World Meteorological Organization (WMO), specifically the "Early Warnings for All" initiative as a groundbreaking effort to ensure everyone on Earth is protected from hazardous weather, water, or climate events through life-saving early warning systems by the end of 2027. Another activity is WMO's Hydrological Status and Outlook System (HydroSOS), aimed to strengthen country capacity across the hydrological value chain, to help produce standardized information on the current state of the water resources and forecast the situation for the next days or months.

Components of the Sava FFWS

The Sava FFWS, operationally running on the Delft-FEWS software (current version 2023.02), consists of several components that can be separated into two groups: server-side and client-side components. The client application is installed in all user organizations. The diagram below schematically illustrates a single client connection to all available server systems.

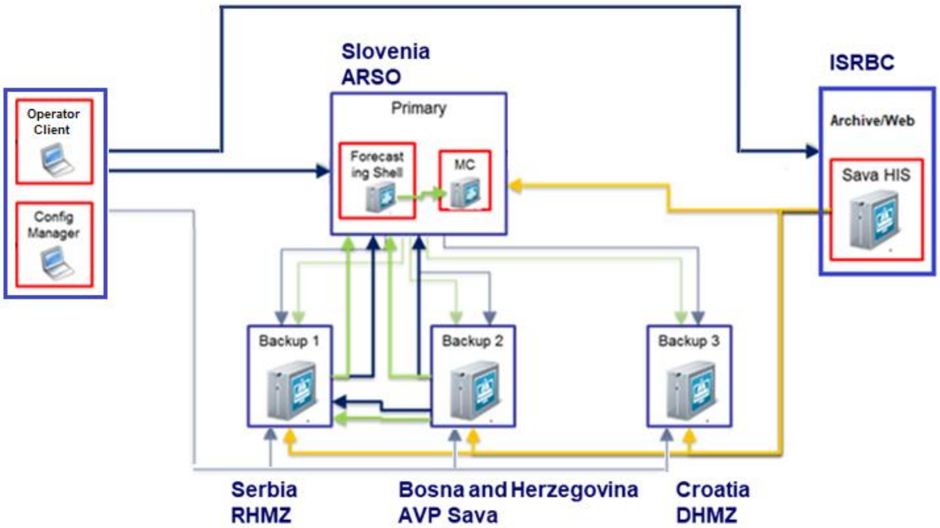

Figure A.1. Components in the Sava FFWS client-server application

On the server side, the main component is the Delft-FEWS Master Controller (MC). This is the agent that monitors the status of all components and distributes tasks to the Delft-FEWS Forecasting Shell Servers (FSS). Actual tasks, such as importing data or running models, are executed on FSS. The system uses a central database which is PostgreSQL.

On the client side (a laptop or PC where the users use the system), the Delft-FEWS Operator Client (OC) is utilized. This is a thick-client, Java-based application that connects to the MC through HTTPS over the internet. Additionally, a web portal is available that can be easily accessed via any web browser.

The Sava FFWS consists of four servers connected via MC-MC synchronization. The MC-MC synchronization is a “pull” process, where time series data configured for synchronization are pulled from one MC to the others. Through this synchronization, each MC possesses the details of all scheduled tasks. The data (time series, configuration, states, etc.) are continuously synchronized between the two systems.

The primary server system is located in Slovenia and three backups are located in Serbia, Bosnia and Herzegovina, and Croatia. There is also a ‘hidden’ host in ISRBC, where one MC is installed, that continuously synchronizes with other MCs, and, in addition, hosts archive and web services. The existing platform allows a uniform presentation of outputs from a wide variety of data and model products and remains open for Sava FFWS user organizations to maintain and further develop their forecasting systems, in parallel.

The system enables data validation and serial and spatial interpolation of incoming data, using data validation rules, as well as data transformation to prepare inputs required for forecasting models, such as aggregating precipitation from distributed point sources, from radar, and numerical weather models, as input to precipitation-runoff modeling and reporting. Predictive uncertainty analysis is also implemented, along with the data assimilation techniques applied to connected models through a feedback mechanism aimed at minimizing discrepancies between observed and forecasted data.

Dissemination of forecasts and other available data through the Web OC, as well as through WMS-T/PI REST/PI SOAP/UmAquo SOAP/WaterML and some other web services, is also implemented.

Meteorological and hydrological data

Sava HIS is the main source of hydrological and meteorological data within the Sava FFWS. The Sava HIS database model for storing hydrological and meteorological real-time and processed data has been designed and structured following the OGC WaterML 2.0 and INSPIRE Directive requirements. Sava HIS contains both real-time and processed hydrological and meteorological data and metadata, including daily time series and statistics from historical data (Hydrological Yearbooks) as well as monthly/yearly time series from discharge measurements. It also contains spatial data (Lat, Lon coordinates of the location of the measuring stations), general data and metadata (organization, type, identifier), and attributes of measuring data (data type, units, methods, accuracy, censoring, data quality). It is hosted by ISRBC, but its special real-time version - Sava HIS-RT, serving as a data hub of Sava FFWS, is installed at the primary server location -ARSO (Slovenia).

299 hydrological stations are currently available in Sava HIS-RT and in operational use in the Sava FFWS (Figure A.2). Of the existing 299 stations, 243 provide information on water level and 136 on discharge in real-time. Sava HIS-RT is also the most important source of meteorological data (rainfall and air temperature). In total, 212 meteorological stations have been implemented in the Sava FFWS so far (Figure A.3), with plans to establish more soon.

Table A.1. Stations with the hourly (real-time) data available in the Sava HIS-RT / Sava FFWS

	BA	HR	ME	RS	SI	Totals
Hydrological stations	104	125	13	31	26	299
Meteorological stations	66	49	5	14	78	212

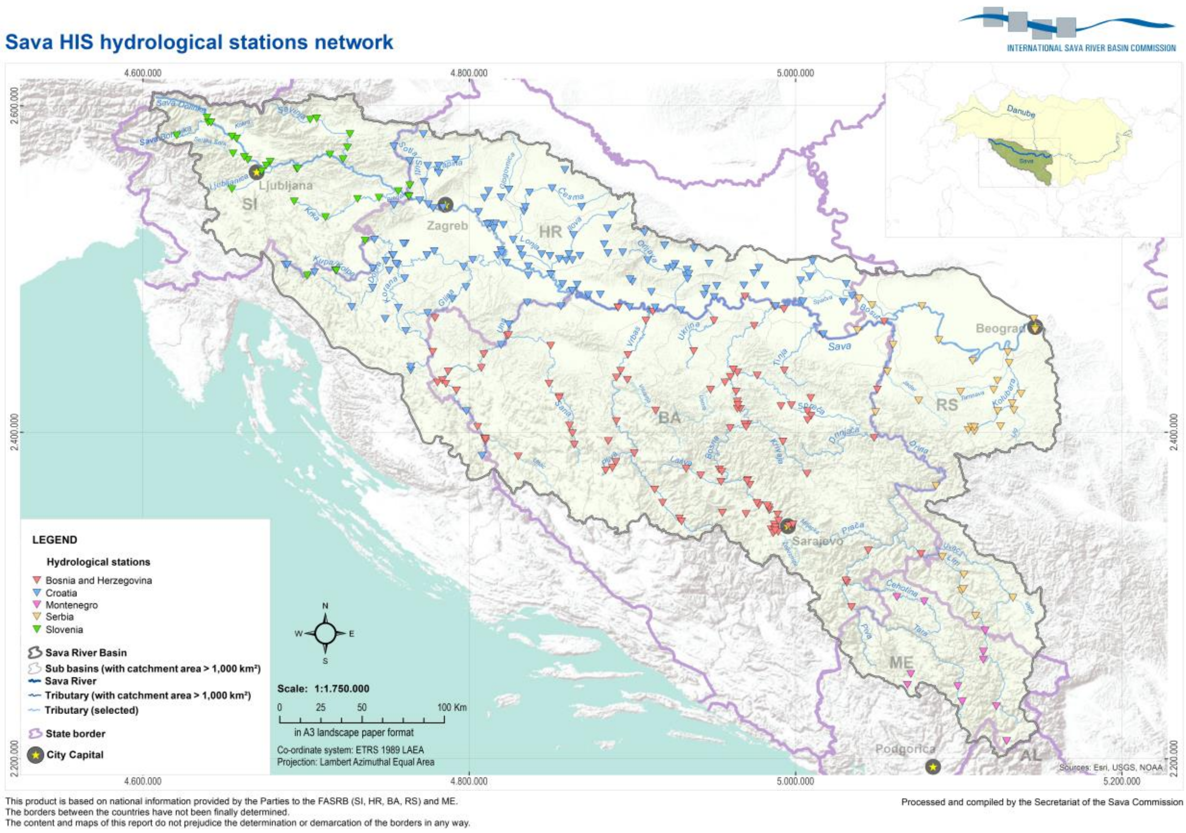

Figure A.2. Map of hydrological stations available in the Sava HIS-RT / Sava FFWS

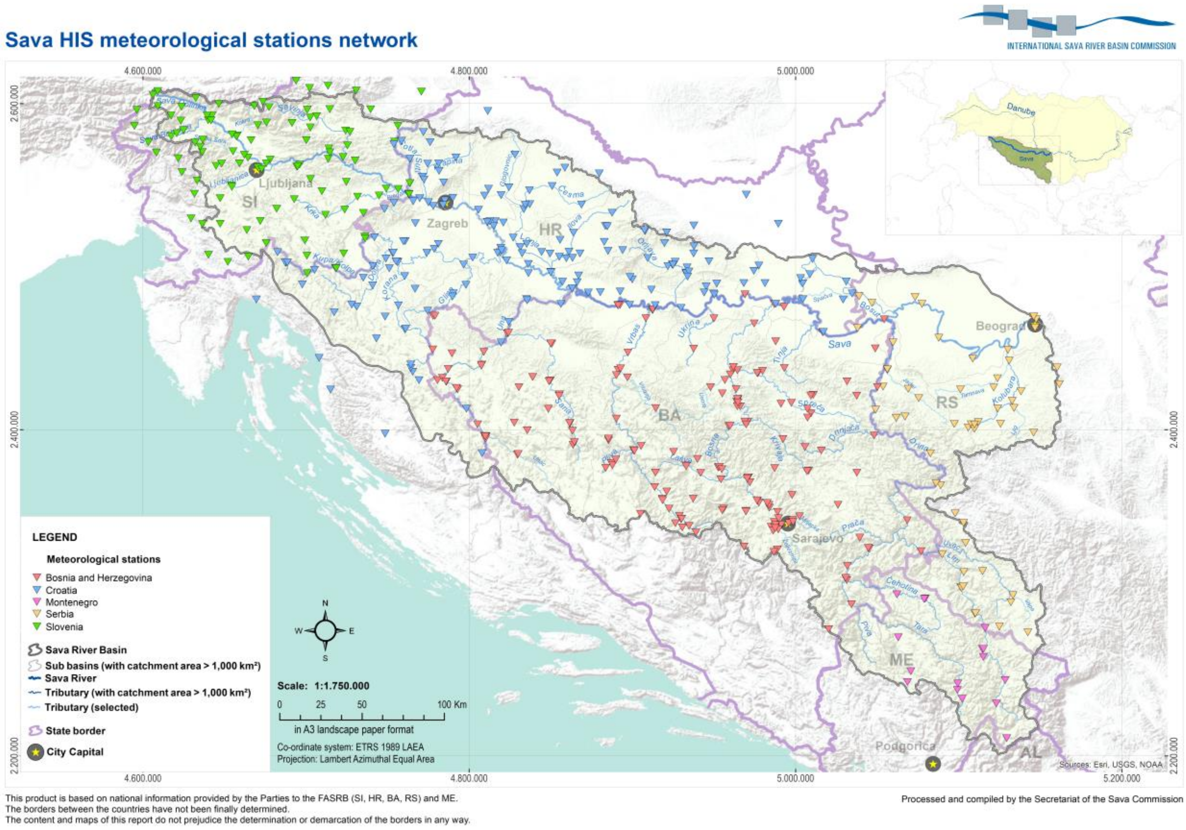

Figure A.3. Map of meteorological stations available in the Sava HIS-RT / Sava FFWS

Existing numerical weather prediction models, radar and satellite imagery

Within the Sava FFWS, nine NWP models (Table A2.) are currently in use as meteorological inputs for hydrological models. The rationale for relatively many NWP models is the fact that the countries use different models. From experience gained so far, it can be concluded that all these models perform quite well, as far as can be expected in general from such models. The general issue with these models is that they are updated only every 6-12 hours.

Table A.2. NWP models in use under Sava FFWS

Source	Spatial resolution	Temporal resolution	Forecasting period
ECMWF	8 x 10 km	1 h	10 days
ECMWF eps	16 x 20 km	1 h	10 days
Aladin SI	4.5 km	1 h	3 days
Aladin HR	4 km	1 h	3 days
NMMB RS	3 x 4 km	3 h	3 days
WRF RS	4 x 6 km	3 h	3 days
WRF BA	2.5 km	1 h	4 days
WRF ME	1 km	1 h	5 days
WRF ME	3 km	3 h	5 days

Nowcasting products are currently not available within the Sava basin. The first step towards nowcast is to have a radar-based composite rainfall image (precipitation field), corrected with observed ground rain gauge data. The radars in the Sava basin are currently not able to produce accurate rainfall images. In the Sava FFWS the Lisca radar data from ARSO (Slovenia) are implemented, next to Opera radar composite images. These images are only displayed within the system but are not connected to any of the hydrological or hydraulic models implemented in the Sava FFWS. This also counts for the EUMETSAT H-SAF satellite images.

Existing simulation models

The Sava FFWS currently contains 13 hydrological models, some covering the whole Sava basin or a large portion of the basin, and others only smaller river catchments. The system currently contains 13 hydraulic models, with different coverage.

Table A.3. Simulation models in use under Sava FFWS

Hydrological models	Coverage	Hydraulic models	Coverage
HEC-HMS Sava	complete basin	HEC-RAS Sava	major part of the river (HR, BA, RS) and sections of main tributaries of different lengths
WFlow Sava	major part of the basin (BA, ME, RS)	Mike 11 Sava (Croatia)	part of the river (HR, BA)
Mike-NAM Sava (Croatia)	part of basin (HR, BA)	Mike 11 Una	complete river
Mike-NAM Una	complete basin	HEC-RAS Una (1)	part of the river (Bihać section)
Mike-NAM Vrbas	complete basin	HEC-RAS Una (2)	part of the river (Bosanska Krupa section)
HBV-light Bosna	complete basin	HEC-RAS Una (3)	part of the river (Kulen Vakuf section)
WFlow Drina	part of basin (ME)	HEC-RAS Sana	part of the river (Sanski Most section)
HEC-HMS Kolubara	complete basin	HEC-RAS Vrbas	part of the river (G. Vakuf-D. Vakuf section)
HBV Kolubara	complete basin	Mike 11 Vrbas	complete river
HBV Jadar	complete basin	HEC-RAS Bosna	complete river
HBV Tamnava	complete basin	HEC-RAS Usora	part of the river (Kaloševići-mouth section)
HBV Ub	complete basin	HEC-RAS Drina	part of the river (Goražde section)
HBV Ljig	complete basin	HEC-RAS Kolubara	complete river

In the subsequent paragraphs, only the so-called backbone models of the system, that cover a complete basin or a large area are briefly discussed.

The HEC-HMS (v.4.2) Sava model, covering the entire Sava River basin, consists of 235 subbasins, carefully selected to take the local hydrological conditions into account, 174 junctions mainly located at the locations of hydrological stations or locations of confluences, 158 river sections and 20 reservoirs. The model was initially calibrated on several selected periods (up to six months long), characterized by average to high flow conditions. As dry and low-flow episodes were not included in the calibration periods, the model performs poorly (even becomes unstable) under low-flow conditions. Schematization of the behavior of reservoirs also deserves attention, so an add-on should be developed and implemented. The model was upgraded to the new software version (v.4.11) and recalibrated to the long-term period 2010-2018, but this model has not been fully integrated into the operational system yet. It is recommended to improve the input data and to continue the process of enhancement of the model using also new meteorological inputs that are being improved for the region. Finally, when connecting the model to the hydraulic model and in case a high resolution is needed, a local refinement of the HEC-HMS Sava is necessary, or a development of a separate finer model.

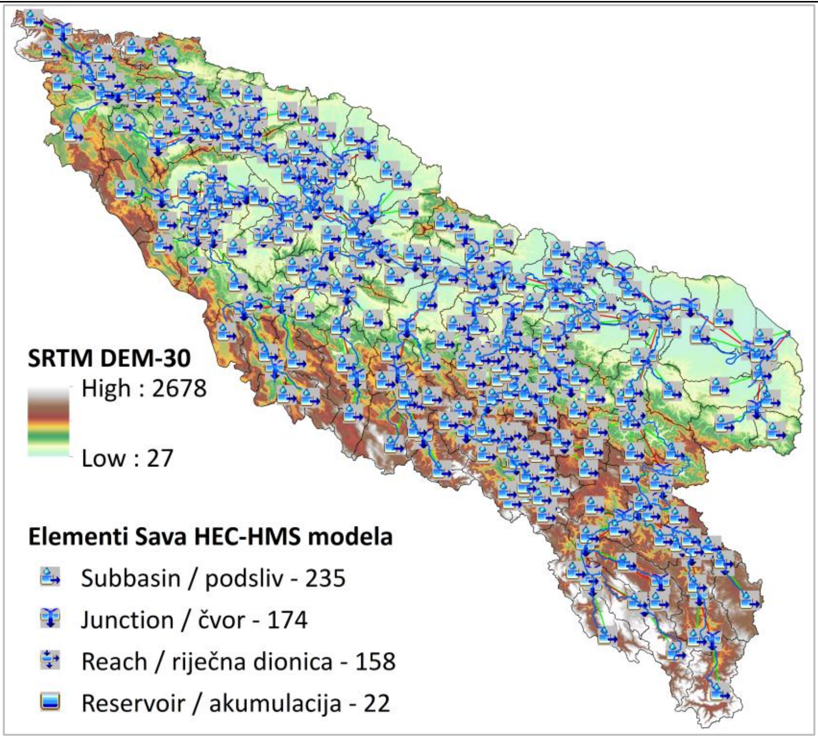

Figure A.4. HEC-HMS Sava model elements

The WFlow Sava model is a distributed grid-based hydrological model that currently covers the area of Bosnia and Herzegovina, Serbia, and Montenegro, with a spatial resolution of 250 meters. The model is divided into six subbasins: Sava (downstream), Una, Vrbas, Bosna, Drina and Kolubara. It is coupled with the RTC-Tools package for the analysis of 10 major reservoirs in the basin and also with the OpenDA package for data assimilation. The Wflow Sava model has to be calibrated before it can be used for operational forecasting.

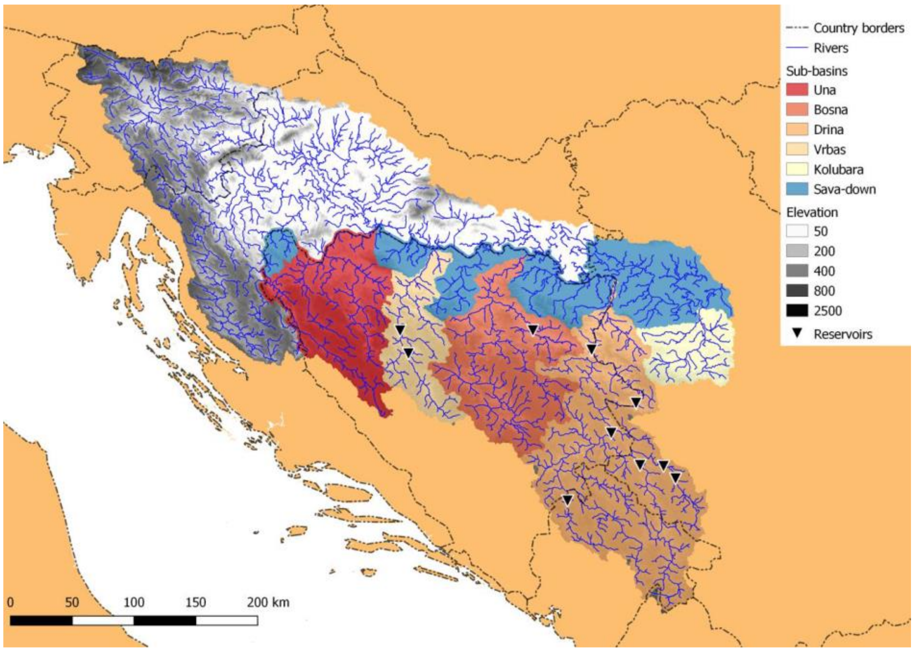

Figure A.5. WFlow Sava model subcatchments coupled with OpenDA and RTC-Tools

The HEC-RAS (v.5.0.3) Sava model includes the Sava River (main course), from Čatež hydrological station (SI) downstream to the confluence with the Danube River in Belgrade, and the major tributaries up to the Sava River backwaters and more. The HEC-RAS Sava is coupled with the HEC-HMS Sava model. The HEC-HMS Sava output locations match the (lateral) inflow points of the HEC-RAS model. The HEC-RAS Sava model is a combined 1D/2D model. 1D part of the model's geometry is based on historical cross-section data collected from different sources, generally connected by lateral structures with adjacent storage areas (SA) and 2D areas. SA and 2D areas are generated based on a high-resolution digital elevation model based on the LiDAR data, surveyed in 2017. The HEC-RAS Sava was initially calibrated on three selected flood event periods. The HEC-RAS Sava model has been upgraded to the newest software version (v.6.5) and significantly improved in terms of geometry. This model version has not been yet integrated into the operational system but it will be available to the Consultant.

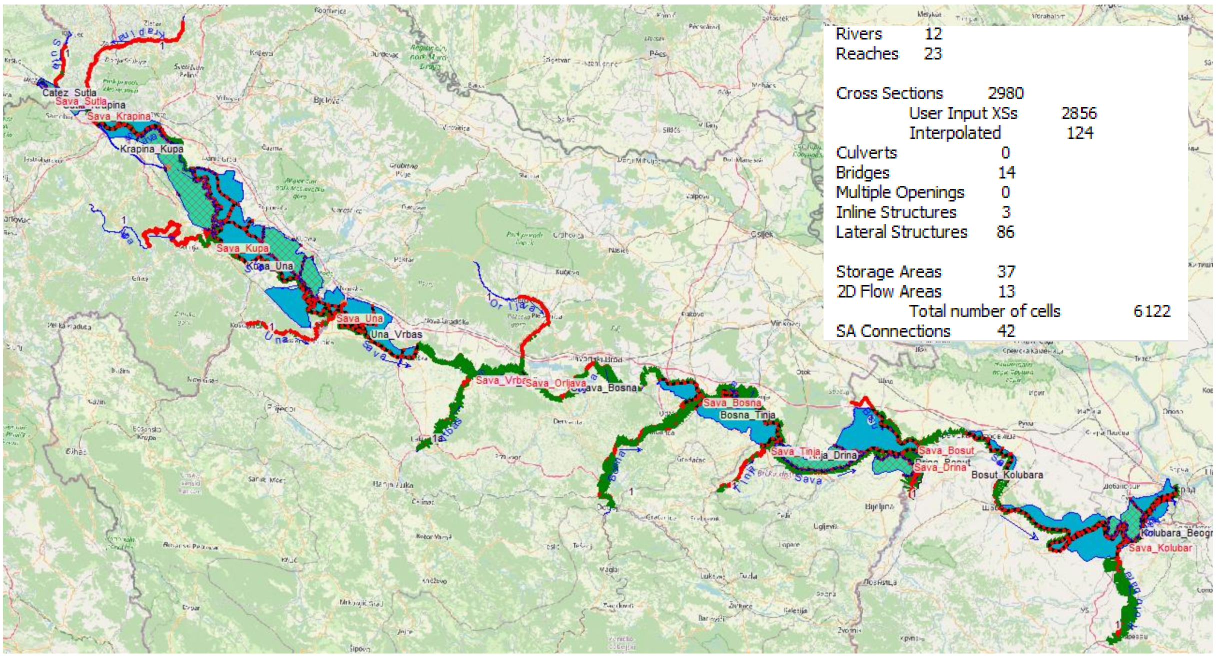

Figure A.6. HEC-RAS Sava model geometry

In addition to the models operating under Sava FFWS, the responsible organizations in the Sava countries use several other models, many of them recently developed.

Table A.4. Simulation models in use in the Sava countries

Hydrological models	Coverage	Hydraulic models	Coverage
Mike-NAM Sava (Slovenia)	part of basin (SI)	Mike 11 Sava (Slovenia)	part of the river (SI)
Mike-NAM Sava (Croatia, new version)	part of basin (HR, BA)	Mike 11 Sava (Croatia, new version)	part of the river (HR, BA)
Mike-NAM Vrbas (new version)	complete basin	Mike 11 Vrbas (new version)	complete river
Mike-NAM Bosna	complete basin	Mike 11 Bosna	complete river
Mike-NAM Ukrina	complete basin	Mike 11 Ukrina	complete river
Mike-NAM Tinja	complete basin	Mike 11 Tinja	complete river
Mike-NAM Brka	complete basin	Mike 11 Brka	complete river
HEC-HMS Drina HEC-ResSim Drina	complete basin	HEC-RAS Drina	complete river

Setup of the forecasting platform

The setup of Sava FFWS is modular. Each forecast workflow is defined by the combination of NWP precipitation and temperature data, a hydrological model converting this data to discharge, and, in most cases, a hydraulic model routing discharge downstream and computing water levels. Due to the availability of many hydrological models, hydraulic models, and NWP models, several forecast workflows are configured.

The warm state is established based on in-situ measurements obtained through Sava HIS. In case there is no hydrological model connected to a hydraulic model, the HEC-HMS Sava model is utilized to deliver lateral flows. All hydraulic models are unsteady. The forecast workflows in Sava FFWS consist of various combinations of NWP and H&H models, as listed in Table 6. Note that the basin-wide hydrological models use the basin-wide NWP products. Besides the basin-wide hydrological models, the local hydrological models also use NWP models that cover the specific local hydrological model.

Table A.5. Sava FFWS forecast workflows: NWP-hydrological/hydraulic model combinations

Simulation models		**Numerical Weather Prediction (NWP) models**							
		Basin						Local	
Hydrological	**Hydraulic**	Aladin SI + ecmwf	Aladin HR + ecmwf	ecmwf eps	wrf-ME 3km	wrf RS	nmmb RS	wrf BA	wrf ME 1km
HEC-HMS Sava	HEC-RAS Sava	x		x	x	x	x		
	HEC-RAS Una (1)	x		x	x	x	x		
	HEC-RAS Una (2)	x		x	x	x	x		
	HEC-RAS Una (3)	x		x	x	x	x		
	HEC-RAS Sana	x		x	x	x	x		
	HEC-RAS Vrbas	x		x	x	x	x		
	HEC-RAS Bosna	x		x	x	x	x		
	HEC-RAS Usora	x		x	x	x	x		
	HEC-RAS Drina	x		x	x	x	x		
WFlow Sava	/	x		x		x	x		
Mike-NAM Sava (Croatia)	Mike11 Sava (Croatia)		x						
Mike-NAM Una	Mike11 Una		x						
Mike-NAM Vrbas	Mike11 Vrbas	x		x	x	x	x	x	
HBVlight Bosna	/	x		x	x	x	x	x	
WFlow Drina	/	x		x	x	x	x		x
HEC-HMS Kolubara	HEC-RAS Kolubara	x		x	x	x	x		
HBV Kolubara Total	/	x		x	x	x	x		
HBV Kolubara	/	x		x	x	x	x		
HBV Jadar	/	x		x	x	x	x		
HBV Tamnava	/	x		x	x	x	x		
HBV Ub	/	x		x	x	x	x		
HBV Ljig	/	x		x	x	x	x		

The current set of forecast workflows in the Sava FFWS is based on the fact that all meteorological and hydrological/hydraulic models available in the initial development phase were implemented. However, this approach has resulted in an undesirable outcome, as it has led to an excessive number of workflows, making the system overly complex. Currently, there is a wide variation concerning the accuracy of the different workflows. Since the quality and accuracy of forecasts are paramount, rather than the number of workflows, it is necessary to reconsider the number of NWP-model combinations because some workflows do not significantly contribute to the usability of the system. Figure A.7. shows the spatial distribution of the forecast locations, with the color scale indicating the number of models providing outcomes and total statistics for each location.

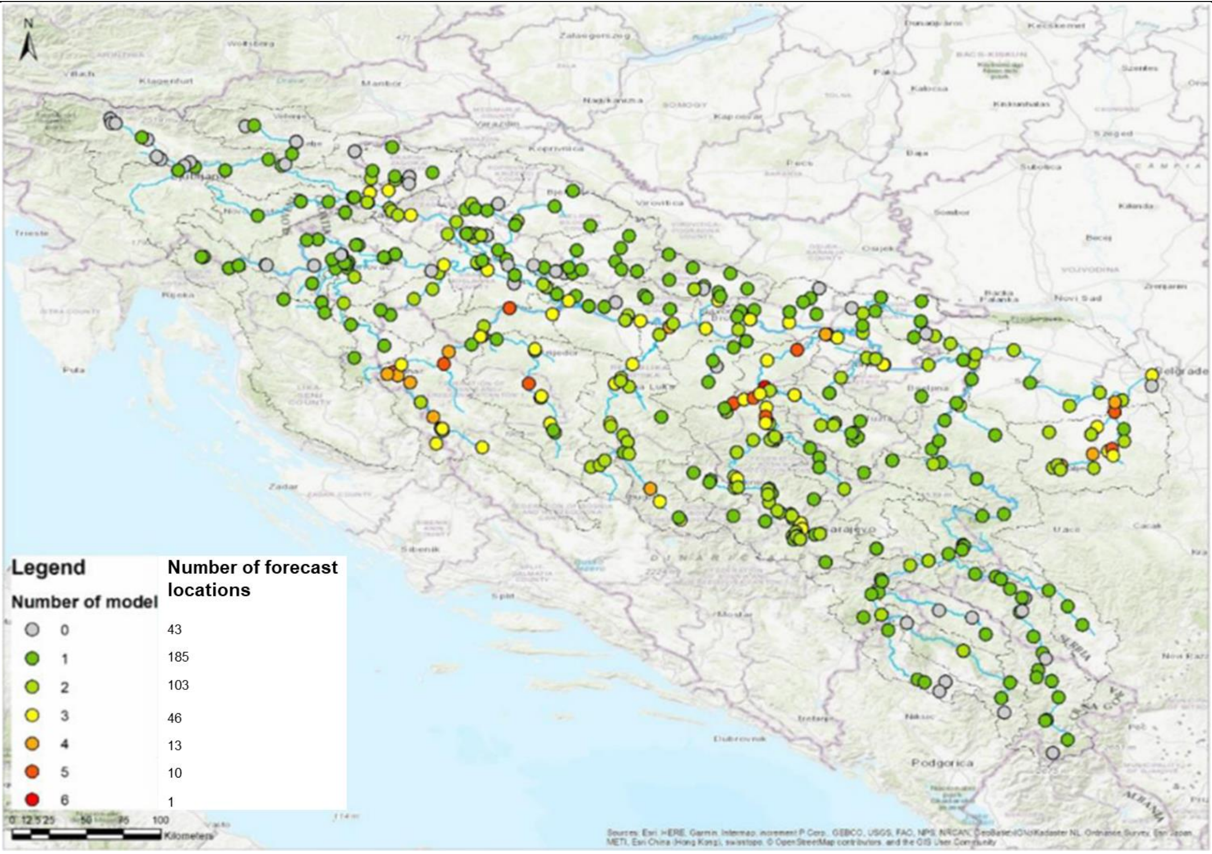

Figure A.7. Overview of forecast locations - showing for each location how many models cover the location

A possible development is to create an optimal weighted average for each location in the basin, based on the skill of each available NWP model. This could be a mix of NWP models available for the entire basin, supplemented locally with NWP models applicable only in certain countries or regions. This approach would help reduce the number of workflows, as there would be a single source of meteorological input (which is known to be the best), and as such could replace the default run with ECMWF data.