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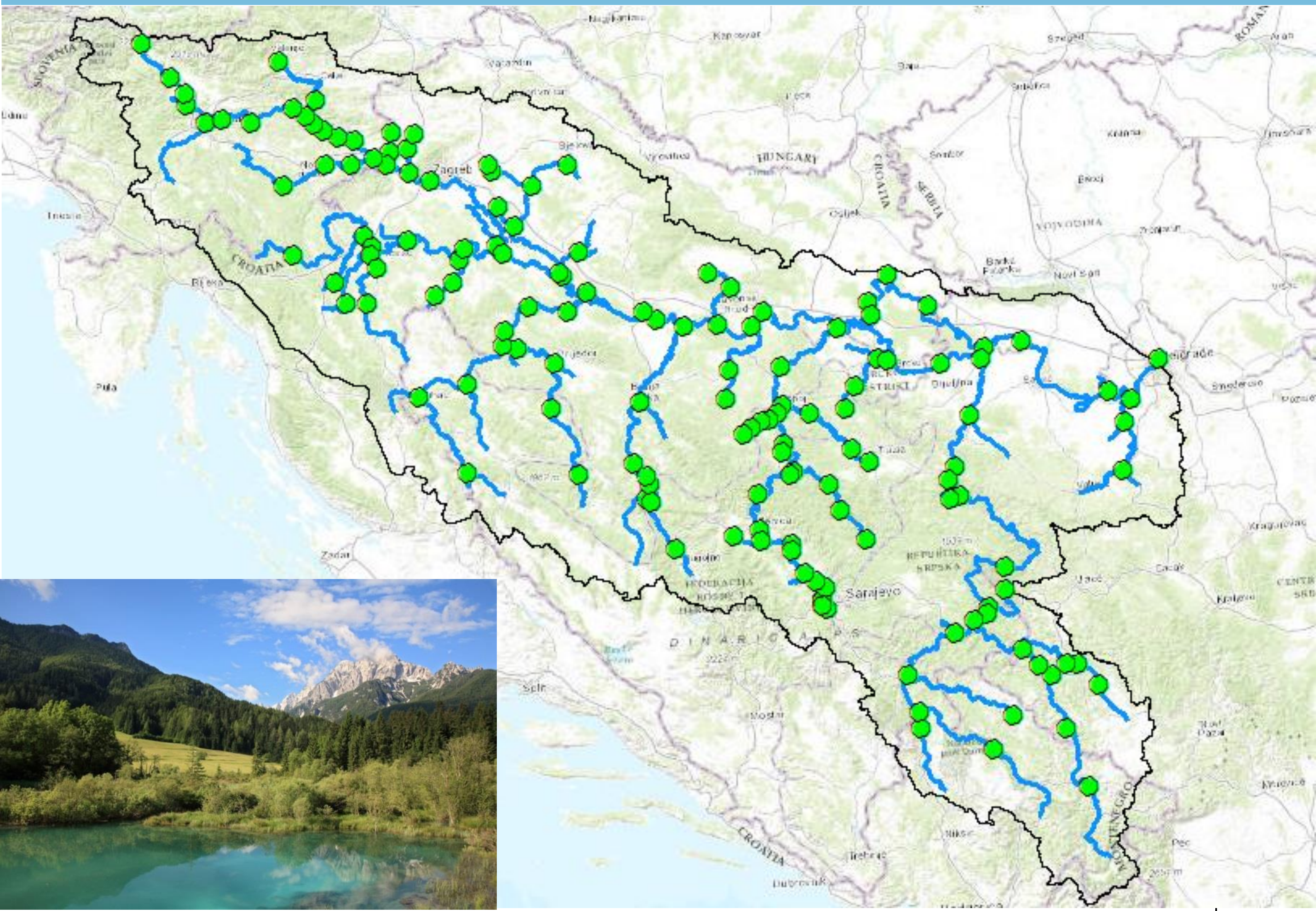
Enabling Delta Life

Sava Flood Forecasting and Warning System

Deltares – The Netherlands



Final Report

Western Balkans Investment Framework WBIF

In association with

HEIS

Royal HaskoningDHV Enhancing Society Together

Mihailo Anđelić

eptisa

Deltares

Final Report

Sava Flood Forecasting and Warning System

Klaas-Jan van Heeringen

1220579-000

Deltares

Title
Final Report

Client	Project	Attribute	Pages
World Bank	1220579-000	1220579-000-ZWS-0066	28

Keywords
river flows, flood, forecasting, Delft-FEWS, uncertainty estimation, data assimilation, Sava, Sava FFWS

Summary
Starting from June 2016 onward, Deltares, along with Royal HaskoningDHV, Eptisa, the Hydro-Engineering Institute of Sarajevo and Mihailo Anđelić has been implementing the World Bank-funded regional project entitled “Joint Flood Forecasting and Management in the Sava River Basin”. The project’s main objective is to develop and establish an integrated real-time flood forecasting and warning system for the entire Sava River Basin (the so called Sava FFWS), which is jointly operated and maintained by the 5 Sava riparian countries (Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia) in close cooperation, coordination and support of the Secretariat of the International Sava River Basin Commission (ISRBC).

The principal objective of the Flood Forecasting and Warning System of the Sava River basin is to support the stakeholders in taking balanced decisions in emergency situations of floods. The Sava FFWS enables the five riparian countries to take the right management decisions and carry out measures to prevent and mitigate severe flood events, based on accurate forecasts of flows and discharges with a sufficiently long lead time. This requires close cooperation with relevant stakeholders, managing the data and models on country level which is crucial for successful development of the system. The Sava FFWS is of key importance in this cooperation; it is essential to highlight that development of such a system would not have been possible without assistance, active support and outstanding cooperation of all the project beneficiaries in the region.

The Sava FFWS provides the forecasters of the hydrometeorological services an expert tool, enabling them to generate hydrological forecasts based on observed telemetry data from hydrological and meteorological gauges and Numerical Weather Predictions (NWP). The Sava FFWS uses hydrological and hydraulic models to compute the catchment runoff and river flows and water levels.

In close cooperation with the beneficiaries, an organizational structure has been established, where the real-time operations, support and maintenance and development activities have been identified. All these three components need both national and international cooperation. Attention is needed for capacity building. While some of the hydrometeorological services that are involved already have a long history in hydrological forecasting and have built a strong experience base, others are yet to develop that knowledge and experience. The establishing of a capacity building and knowledge exchange program is recommended.

The Sava FFWS has proven to be a comprehensive system that includes all data and models contributed by the individual countries. This makes it a unique system when it comes to transboundary cooperation on flood forecasting. Nevertheless, there is always a potential for improvements. The gap analysis report describes the technical and financial aspects of the identified potential improvements, covering topics like (meteorological) data and hydrological and hydraulic simulation models.

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Next to that, we see parallel development of local / regional hydrological forecasting systems. Proper alignment of these with the international forecasting system is needed, both in terms of real-time operations and in terms of future developments.

References
- Request for Proposal #1175353 "Joint Flood Forecasting and Management in Sava River Basin" at November 6, 2015
- Technical Proposal by Deltares, in association with Royal HaskoningDHV, Eptisa, Hydro-Engineering Institute of Sarajevo and Mihailo Anđelić, December 2015
- Contract by World Bank, order 8005561
- Inception Report, 29 December 2016
- Task: Gap analysis to be delivered with the final reports

Version	Date	Author	Initials	Review	Initials	Approval	Initials
2	Oct. 2018	Klaas-Jan van Heeringen et al		Micha Werner	b.a.	Gerard Blom	b/a

Status
final

Contents

Appendices

1 Introduction

1.1 General

This document is the final report for the project Flood Forecasting and Warning System for the Sava River Basin (Sava FFWS). The report provides an overview of the activities undertaken in the entire project and summarizes both the Post-Project Organization (PPO) report and the Gap Analysis report.

1.2 Sava River basin

The Sava River basin covers an area of approximately 97,700 km^2 including large parts of Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia (see Figure 1.1 below). It is the largest tributary by discharge to the Danube River, with an average discharge of about 1700 m^3/s, which accounts for almost 30% of the Danube's total discharge at their confluence in Belgrade. The length of the Sava River, from its source in the western Slovenian mountains to the confluence with the Danube River, is well over 900 km.

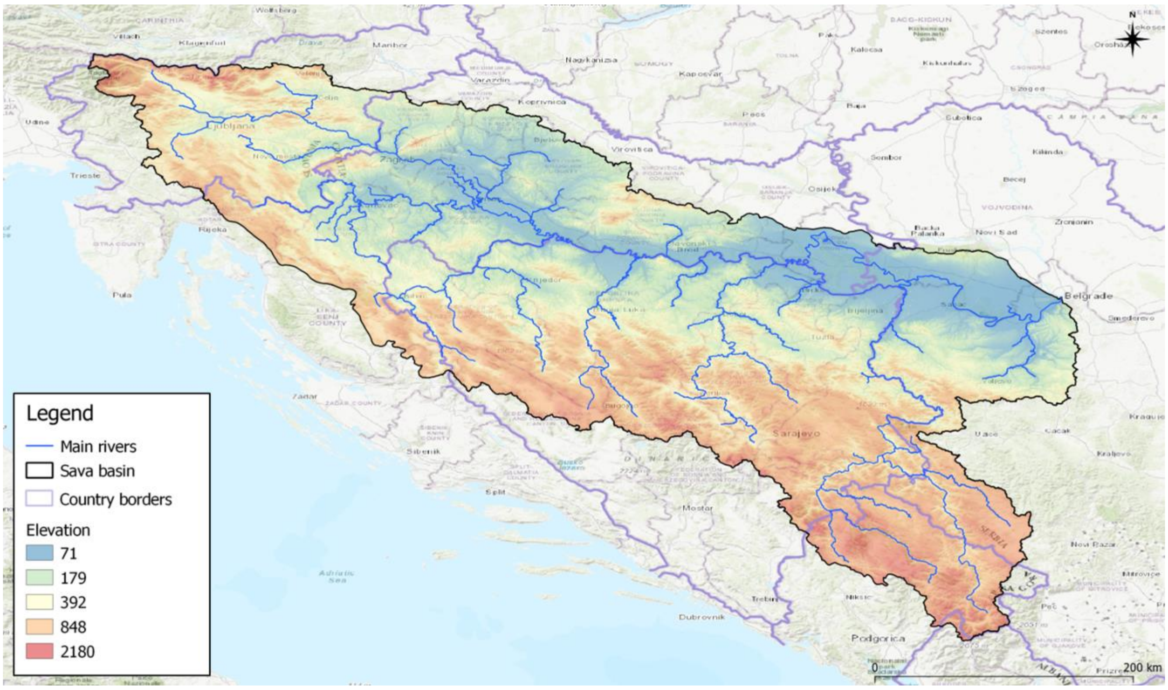

Figure 1.1: Sava River basin (data displayed on map is from the Sava GIS portal)

1.3 Project need and scope

Since 2005 and establishment of the International Sava River Basin Commission (ISRBC) under the Framework Agreement on the Sava River Basin (FASRB), signed by the ISRBC member countries Slovenia, Croatia, Bosnia and Herzegovina and Serbia, there have been various initiatives, coordinated by the ISRBC, to arrive at an improved cooperation between the Parties to the FASRB. Cooperation in the field of flood management is based also on the Protocol on Flood Protection to FASRB (entered into force on November 27, 2015).

Figure 1.2: Impression of the Sava floods of May 2014 (picture by Mathijs van Ledden, RHDHV)

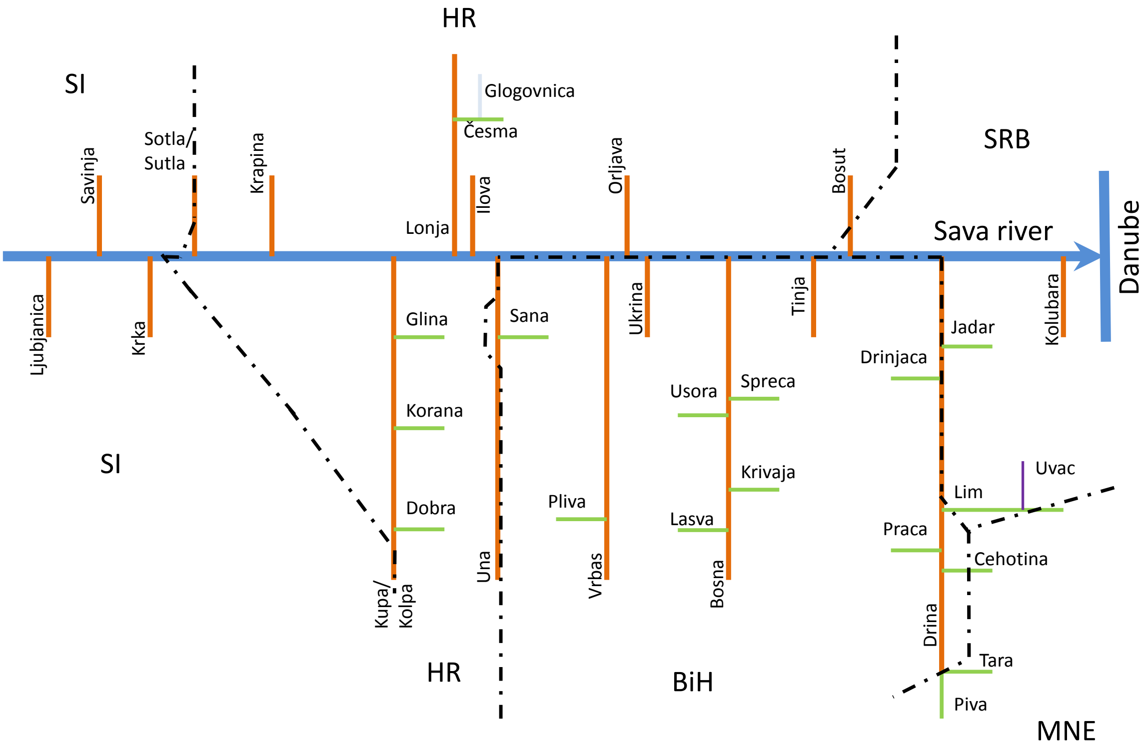

Figure 1.3: Schematic overview of the Sava River and its main tributaries, including schematically the borders between the countries (SI: Slovenia, HR: Croatia, BA: Bosnia and Herzegovina, ME: Montenegro, RS: Serbia)

The Protocol formalizes a firm commitment of the Parties, to further cooperate in implementing joint activities aimed at improvement of flood protection in the Sava River Basin, via their joint platform – ISRBC and to undertake all necessary actions related to the preparation of the “Flood Risk Management Plan”, the establishment of a flood forecasting and warning system, the exchange of information relevant for sustainable flood protection, as well as undertaking any other agreed activities that can contribute to the improvement of the flood protection in the basin.

Proposals to reduce flood risks have been coordinated with the government representatives of the Parties to the FASRB and submitted to the Western Balkan Investment Framework (WBIF) in March 2014, just prior to severe May 2014 flood.

The floods of May 2014 caused significant loss of human life and severe economic damage. Between the 13^{th} and the 18^{th} of May, a storm system affected a large area of Southeast Europe, the Balkans and in particular the Sava River basin, causing unprecedented floods and landslides. Bosnia and Herzegovina and Serbia suffered the severest damages. In both countries the recorded precipitation was the highest in the entire 120 years on record.

Following these events, the World Bank has provided financial support for the development of a Flood Forecasting and Warning System (FFWS) in the Sava River basin. The Bank selected a consortium comprising Deltares in association with Royal HaskoningDHV, Eptisa, the Hydro-Engineering Institute of Sarajevo and Mihailo Anđelić (private consultant) to develop the new forecasting system. This Deltares-led consortium combines the best international expertise in flood forecasting and early warning with strong local expertise and good working relationships with national and regional authorities. The project started in May 2016 and is scheduled to be completed by the end of October, 2018.

Operational forecasting does not only dependent on the availability of a proper forecasting system, but also on skilled, well trained staff and good coordination between its users. As a result of the complex hydrographic network of the Sava basin, many hydrological links exist between the riparian countries, while some of these links are multiple in nature (see Figure 1.3). This is also reflected in the large number of beneficiary institutions (19 in total) involved in the project. This means that there is a strong need for international cooperation and requires the set-up of a mature organization with well-defined and mutually agreed upon set of working procedures.

1.4 This document and relations to other reports

Additional to this final report, several documents have been prepared within the project. These include:

- User Manual for the Sava FFWS
- Technical Reference guide of the Sava FFWS
- Post Project Organization document
- GAP analysis document.

Through the course of the system development and implementation process, several other technical documents, reports, system documentation and memos have been prepared. Their main purpose has been to facilitate decision making process within the project concerned with a wide range of specific technical and/or organizational project issues, where their results have been incorporated in the documents listed above.

In this final report, first Chapter 2 gives more details on the Sava FFWS, while Chapter 3 provides a brief overview of the project stakeholders. Chapter 4 describes in detail the key activities carried out during the project implementation. Chapters 5 and 6 give a summary of the Post Project Organization and Gap analysis reports, respectively. The document culminates with conclusions and recommendations in Chapter 7.

A glossary of terms and abbreviations used in this report is provided as an appendix to the report.

2 Sava Forecasting and Warning System

2.1 Introduction

The principal objective of the Sava FFWS is to support the stakeholders in taking balanced decisions in emergency situations of floods and droughts. The Sava FFWS should enable the five riparian countries to take the right management decisions and carry out measures to prevent and mitigate severe flood and drought situations, based on accurate forecasts of water levels and discharges with a sufficiently long lead time. This required close cooperation of the Consortium team with the relevant stakeholders managing the data and models on country level, which has been crucial for successful development of the system.

The Sava FFWS is intended to provide an expert tool to the forecasters of the hydrometeorological services, enabling them to generate hydrological forecasts based on observed telemetry data from hydrological and meteorological gauges made available through the Sava Hydrological Information System (Sava HIS) and Numerical Weather Predictions (NWP). The Sava FFWS uses hydrological and hydraulic models to compute the catchment runoff, river flows and water levels.

Figure 2.1 gives a schematic overview of the elements and processes of an early warning system. The Sava FFWS that has been developed in the context of this project focusses on the first three of these (i.e. data, models and results). Meteorological input data are the driving force for the hydrological models. These hydrological models, both rainfall-runoff and hydraulic models, provide results at key forecasting locations. At these locations threshold levels are defined to indicate the severity of potential high water levels and/or discharges. The results are disseminated through a web portal and can be additionally customized in accordance with the requirements of different end-users of the system.

The Sava FFWS is now a fully operational client-server application. It is based on the Delft-FEWS software that integrates all relevant data sources and models, as well as many different tools for forecasters enabling them to further process and better understand the results generated by the system. An example of the user interface is shown in Figure 2.2 below.

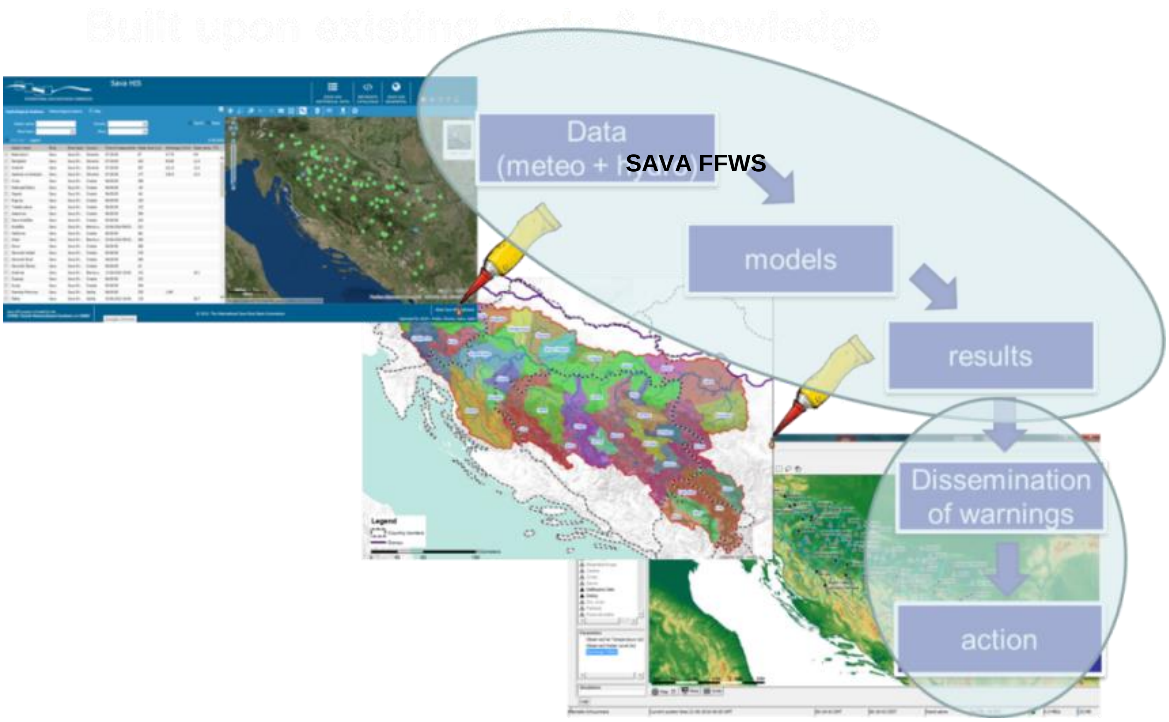

Figure 2.1: Schematic overview of the elements of an early warning system

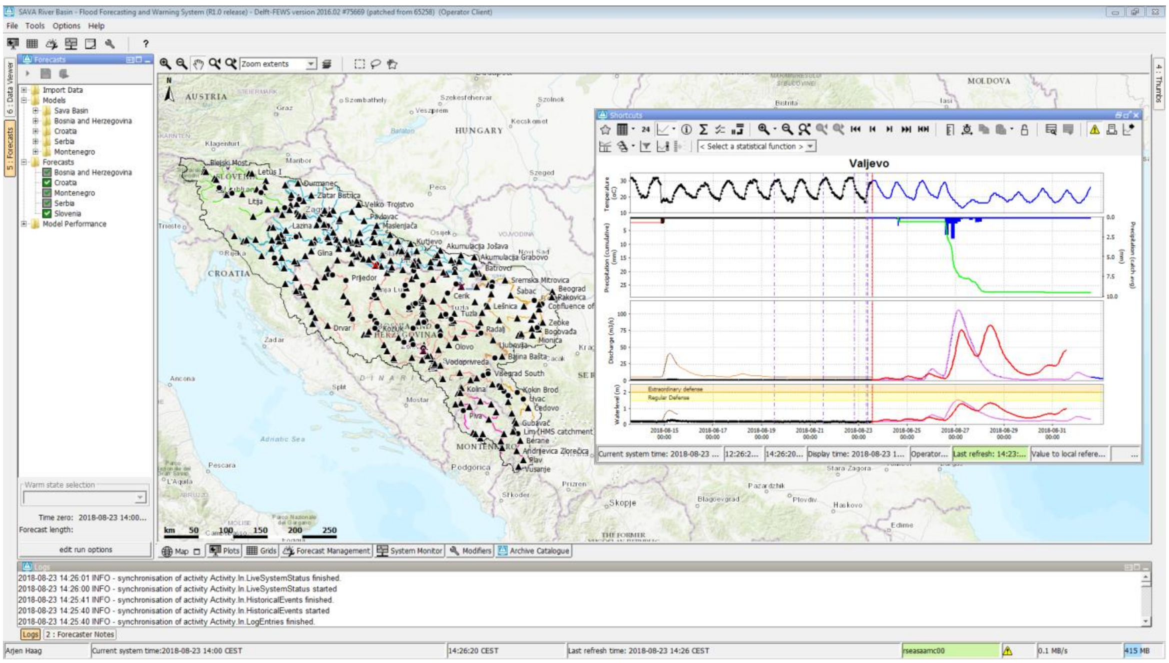

Figure 2.2: Sava FFWS user interface

Within the Sava FFWS a large number of hydrological, hydraulic and Numerical Weather Prediction (NWP) models have been implemented (illustrated in detail in Figure 2.3). With the exception of the WFlow models, which were developed within the scope of this project, all others are based upon pre-existing models available in the beneficiary countries. Where applicable, these have been adapted and made compatible with the Delft-FEWS operational forecasting system. The detailed hydraulic models are coupled with the most suitable hydrological model, and the results of both are stored within the system. Within the Sava FFWS, distinction can be made between *default runs*, which are scheduled to run automatically at certain predefined time intervals, and the *manual user runs*, which can only be run manually.

Models \ NWP			Default Run			Manual User Run				
	Hydrological	Hydraulic	Aladin SI + ECMWF	Aladin HR + ECMWF	ECMWF EPS	NMMB	WRF BiH	WRF MNE 1km	WRF MNE 3km	WRF SRB
Basin BA/RS/ME	HEC-HMS Sava	HEC-RAS Sava	x		x	x			x	x
	WFlow (BA/RS/MNE)		x		x	x			x	x
Local	Mike-NAM (HR)	Mike 11 Croatia		x						
	Mike-NAM Una (BA)	Mike 11 Una		x						
	HBV-light Bosna (BA)		x		x	x	x		x	x
	HEC-HMS Sava	HEC-RAS Bosna (ISRBC)	x		x	x			x	x
	HEC-HMS Sava	HEC-RAS (BA) [9]	x		x	x			x	x
	Mike-NAM Vrbas	Mike 11 Vrbas	x		x	x	x		x	x
	Wflow MNE		x		x	x		x	x	x
	HEC-HMS Kolubara (SRB)	HEC-RAS Kolubara (SRB) [17]	x		x	x			x	x
	HBV (SRB) [5] Jadar, Kolubara, Tamnava,Ub, Ljig		x		x	x			x	x

Figure 2.3: Forecast workflows with NWP and model combinations within Sava FFWS

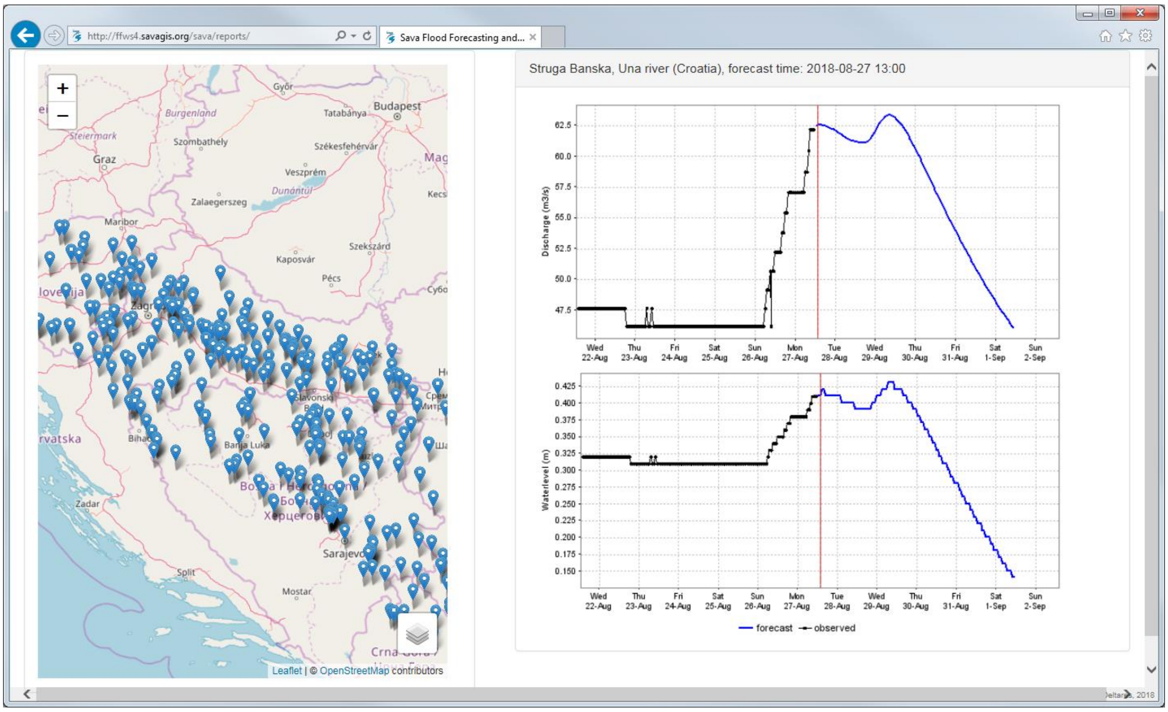

Figure 2.4: Internet webpage of the Sava FFWS

2.2 Hosting of the Sava FFWS

The post project organization of the Sava FFWS, concerned in particular with its support and maintenance, depends to a degree on the system architecture and the agreed arrangements for hosting the Sava FFWS. To this effect, the Sava FFWS consists of four hosting locations, i.e. one Primary and three Backup locations. Under normal conditions, the Backup systems will retrieve data from the Primary system through an automatic data synchronization process. The Primary system is the only system that is used to carry out operational tasks under normal circumstances, such as the running of forecasts or the uploading of changes to the configuration. A separate set of servers is configured to host the additional functionality, such as the archive and web dissemination.

The responsibilities with respect to hosting of these systems have been distributed as follows:

- ARSO Slovenia: Primary System and Sava HIS-RT
- AVP Sava Bosnia and Herzegovina: 1st Backup System
- DHMZ Croatia: 2nd Backup System
- RHMZ Serbia: 3rd Backup System +Testing System
- ISRBC Secretariat: Archive, Web Portal and Sava HIS

For the purpose of the future development and for the testing of new features of the Sava FFWS before their inclusion into the operational system, a 100% independent Stand-Alone (SA) application of the Sava FFWS is available. This SA runs on any suitably configured desktop computer, and has no interaction with any other application or the live system.

3 Stakeholders

3.1 Introduction

3.1.1 Stakeholders at national level within the riparian countries

The five riparian countries of the Sava River basin are Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia. These countries with the exception of Montenegro, are members of the International Sava River Basin Commission (ISRBC) that has been established to implement the Framework Agreement on the Sava River Basin (FASRB). The ISRBC Secretariat is the administrative and executive body of the ISRBC. In addition to the ISRBC, Table 3.1 provides an overview of the national organizations that are (direct) stakeholders in the Sava FFWS project.

3.1.2 International Sava River Basin Commission

In 2005 the riparian countries established the International Sava River Basin Commission (ISRBC). The objectives of the ISRBC are[1]:

- *Establishment of an international regime of navigation* on the Sava River and its navigable tributaries.
- *Establishment of sustainable water management*, which includes cooperation on management of the Sava River Basin water resources in a sustainable manner, including integrated management of surface and ground water resources.
- *Undertaking of measures to prevent or limit hazards*, such as floods, ice, droughts and accidents involving substances hazardous to water, and to reduce or eliminate related adverse consequences.

For the third objective the ISRBC has elaborated the *Protocol on Flood Protection to the Framework Agreement on the Sava River Basin in 2013[2].* This protocol gives a general basis for the FFWS. The protocol *"regulates the issues of sustainable flood protection in the Sava River Basin caused by:*

> *(a) natural phenomena such as high flows of rivers, as well as ice jamming, and*
> *(b) artificial impacts like water discharge from reservoirs and retentions induced by dam collapsing or inadequate handling, changes in river basin, riverbeds and floodplains, etc.,*
> *with aim to prevent or limit flood hazard, to reduce flood risk and to reduce or mitigate detrimental consequences of floods."*

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[1] *http://www.savacommission.org/mission*

[2] *PROTOCOL ON FLOOD PROTECTION TO THE FRAMEWORK AGREEMENT ON THE SAVA RIVER BASIN (http://www.savacommission.org/dms/docs/dokumenti/documents_publications/basic_documents/protocols/protocol_on_flood_protection_to_the_fasrb.pdf visited on 29-09-2016)*

Table 3.1: Stakeholders in the Sava Flood Forecasting and Warning System Project

Country	Organization	Role in Post Project Organization
Bosnia and Herzegovina	Federal Ministry of Agriculture, Water Management and Forestry	Policy making
	Ministry of Agriculture, Forestry and Water Management of Republic of Srpska	Policy making
	Federal Hydrometeorological Institute	Operational forecasting for BiH
	Republic Hydrometeorological Institute	Operational forecasting for BiH
	Public Institution JU “Vode Srpske”	Operational forecasting for BiH
	Sava River Watershed Agency	Operational forecasting for BiH
	Brčko District Government: • Department of Public Safety District, • Department for agriculture, forestry and water management.	Direct use of forecasts
Croatia	Ministry of Environment and Energy	Policy making
	Meteorological and Hydrological Service	Operational forecasting for Croatia
	Croatian Waters	Public water management institution, legal entity for water management, in cooperation with DHMZ developing and making the forecasts
Montenegro	Ministry of Agriculture and Rural Development, Water Management Directorate	Policy making and water management, makes use of forecasts
	Institute of Hydrometeorology and Seismology of Montenegro	Operational forecasting for Montenegro
Serbia	Ministry of Agriculture, Forestry and Water Management, Water Directorate	Policy making
	Republic Hydrometeorological Service of Serbia	Operational forecasting for Serbia
	Public Water Management Company “Srbijavode”*	Public water management organization, makes use of forecasts
	Public Water Management Company “Vode Vojvodine”	Public water management organization, makes use of forecasts
Slovenia	Ministry of the Environment and Spatial Planning	Policy making
	Slovenian Environment Agency	Operational forecasting for Slovenia
	Slovenian Water Agency**	Public water management organization, makes use of forecasts
-	International Sava River Basin Commission	Coordination

** Note that PWMC Beograd Vode has been provided in the list of stakeholders and meanwhile has become a part of PWMC Srbijavode*
*** Note that the Slovenian Water Agency has been added to the list of stakeholders, as new body affiliated to the Ministry of the Environment and Spatial Planning*

Article 9 states: *"Flood Forecasting, Warning and Alarm System*

1. *The Parties shall establish a coordinated or joint Flood Forecasting, Warning and Alarm System in the Sava River Basin (hereinafter: the System).*
2. *In order to establish the System, the Parties shall jointly undertake all necessary actions for establishment of the System, including the development of the project documentation.*
3. *The Sava Commission shall coordinate the activities on establishment of the System.*
4. *After the System is established, the Parties shall ensure its regular maintenance and performance control, as well as regular training of the engaged personnel, with application of joint standards."*

ISRBC has been - as existing coordinating authority for four of the five riparian countries - one of the crucial "umbrella stakeholders" for successful development and implementation of Sava FFWS. The main stakeholders at the country level for development of Sava FFWS are state authorities, national bodies responsible for river management, monitoring, data collection and modeling.

3.2 Organizational Structure and stakeholder interaction during the project

For efficient stakeholder interaction, project management and decision making the following organizational structure has been established within the project:

- Steering board.
- International Working Group.
- Country Working Groups.

The Steering Board, the International Working Group and the Country Working Groups were established for the general purpose of management, monitoring and coordination of the Sava FFWS project implementation.

The purpose of the Steering Board has been to monitor and make decisions about the FFWS project and its progress. The Steering Board members have been responsible for final decisions and resolving issues arising. They also comment on and approve conclusions of the International Working Group and share their opinion about the deliverables with the World Bank.

The purpose of the International Working Group has been to harmonize and verify the input of the Country Working Groups, discuss international elements of the Sava FFWS and test the milestone products before the products were considered sufficiently mature to be presented at the Steering Board meetings.

The general purpose of the Country Working Groups has been to secure the input of the local interests, knowledge and workflows of each country.

Nominated representatives from all five riparian countries have actively participated in the work of the above three project management bodies. As far as it has been practical and possible, the countries' specialists who were already active in the existing ISRBC technical bodies have also been nominated to serve in these project bodies.

4 Completed Activities

4.1 Introduction

The project was divided in seven phases, starting in June 2016 and scheduled to be completed in October 2018 (see Table 4.1 on the next page). The original project closing date was scheduled to be in July 2018, but a delay in the delivery of the necessary hardware and equipment resulted in an extension of 3 months. During each of the phases, different activities have been carried out which are discussed in more detail below.

4.2 Kickoff and Inception Phase

The launch of the project took place at the project kickoff workshop, held on June 21, 2016 at the Hotel Arcotel in Zagreb. The kickoff workshop was attended by thirty participants from the beneficiary organizations.

Figure 4.1 Participants of the Kickoff Workshop

The Inception Phase was intended to review the terms of reference (ToR) and to make the final decisions on all project implementation details. The subsequent Inception workshop was organized on October 13 and 14, 2016 at the Palace Hotel in Zagreb.

Figure 4.2 Participants of the Inception Workshop

Table 4.1: Project phases and final planning

Month/phase	1	2	3	4	5	6	7	8	9	10	SB	WG	PM		reports	Deliverable
Jun 2016	■	■														
Jul 2016	■	■	■												draft inception	
Aug 2016	■	■	■	■	■										Inception	inception report
Sep 2016		■	■	■	■											
Oct 2016		■		■	■						A.1					
Nov 2016		■		■	■											
Dec 2016		■		■	■						A.2	IW1				
Jan 2017				■	■									WS	manual	pre release 0.1
Feb 2017				■	■										intermediate	
Mar 2017				■	■							IW2				
Apr 2017				■	■						B					
May 2017				■	■											
Jun 2017				■	■							IW3		WS	manual	pre release 0.2 + models
Jul 2017					■	■										
Aug 2017					■	■										
Sep 2017					■	■										
Oct 2017					■		■					IW4				
Nov 2017					■		■				C					
Dec 2017							■					IW5		WS	manual	pre release 0.3
Jan 2018								■								
Feb 2018								■				IW6		WS	manual	release 1.0
Mar 2018									■		D			T		
Apr 2018										■						
May 2018										■		IW7			intermediate	
Jun 2018					■							IW8		T		
Jul 2018					■											
Aug 2018					■									WS	draft	testing results
Sep 2018					■											
Oct 2018					■						E	IW9		WS	final	release 2.0

	Inception phase
	Data and GIS information
	Models in FFWS
	Uncertainty and forecasting
	Testing
	Testing by users
	Finalization

WS	Work shop
SB	Steering board
WG	International work group
PM	Project management
T	Training
	meetings
	monthly meeting

Unfortunately, the completion of this phase was delayed due to a prolonged discussion on where to host the Sava FFWS. Eventually, it was decided to accept the Inception report without this topic, in order to not delay further execution of approved project activities. The final decision on the hosting arrangements was made at a later stage (i.e. in March 2017).

4.3 Pre-releases of the Sava FFWS

During the project, a number of pre-releases of prototype versions of the system were used as the intermediate project milestones. These also served to allow the users in the region to gain familiarity with the Sava FFWS. Each pre-release was accompanied by a User Manual, a Technical Reference Manual and training courses that were linked to the new features of the particular pre-release. These are described in more detail in the following paragraph.

For easy reference, a detailed list of all the technical documents, training manuals, intermediate reports and other documents generated within the project is given at the end of this report. A brief description of each of the pre-releases is providing below, demonstrating the incremental development of the system.

4.3.1 Pre-release 0.1

The first pre-release of the Sava FFWS (January 2017) included hydrological and meteorological real-time data and existing forecasts from each country (labelled as external forecasts within the system). These established procedures for data exchange between the various national forecasting institutions in the 5 riparian states and the Sava HIS. Within the pre-release 0.1 the users were able to become familiar with the general user interface of the Sava FFWS and to inspect the real-time data from various sources within an integral framework for the whole Save River basin.

Along with this pre-release a separate training for the IT staff was organized to train them on the support and maintenance of the backend IT infrastructure.

4.3.2 Pre-release 0.2

The second pre-release (June 2017) contained several additional features, most notably the ability to run forecasts using various hydrological and hydraulic models with different NWPs as forcing. This allowed users to run models and create forecasts based upon their own preferences.

4.3.3 Pre-release 0.3

The third pre-release (December 2017) built upon the preceding system (i.e. the Pre-release 0.2) and added flood maps, data assimilation and predictive uncertainty. These features added to the available information already within the system to help users create better forecasts.

4.3.4 Release 1.0

As of release 1.0 (February 2018), the Sava FFWS included all features planned to be implemented within the project. This version was then used for operational testing and further fine tuning of the system. For the first time, users were truly experiencing how the system works in support of their daily routine. During this phase, regular communication with the users was maintained using webinars, the user forum and e-mails. This provided valuable users' feedback and allowed for quick updates of the system, for example to accommodate small feature requests from users.

4.3.5 Release 2.0

Based on the evaluation of release 1.0 and the pre-operational testing phase, final improvements have been applied, resulting in the final version of the Sava FFWS.

4.4 Stakeholder Interaction and Capacity Building

During all of the above phases of the project, close interaction was maintained between the consultants and the stakeholders. Interaction between the stakeholders themselves was also promoted and facilitated by the consultants.

4.4.1 Trainings and workshops

During the entire phase of the project regular workshops and trainings were organized at various levels of expertise. These included training sessions on the use of the Sava FFWS, the configuration of the Delft-FEWS software and the backend IT infrastructure required to keep everything in the system running. Training courses on the use of the Sava FFWS also included topics on the general principles of hydrological forecasting. The courses were hosted by the various national forecasting institutions throughout the region.

4.4.2 Sava FFWS User Portal

An online user portal was set up using the SharePoint environment[3]. This includes a forum that allows for easy communication between users and consultants, and makes sure that other users also have access to it (which would not be the case with e-mails or phone calls). Discussions are listed under several categories:

- General
- Bug Report
- How to …
- Installation
- Models
- NWPs
- Sava HIS

All documentation that has been produced during the project implementation was uploaded on the portal when these became available. In this way, all beneficiaries were updated with last information regarding the project.

4.4.3 Webinars

During the operational testing phase of the release 1.0, regular two-weekly webinars were held for all users of the Sava FFWS. The main goal of these webinars was to give users a chance to directly ask specific questions to the consultants and actively participate in discussions. The use of such a format had the additional benefit that other users could either learn from the answers (which they would have missed if an e-mail or phone call was used) or even help with answering questions posed (as the answer would sometimes require knowledge from other forecasting agencies). Another important goal of the webinars was to share insights between users and allow for the transfer of knowledge and know-how in using the system as well as on forecasting procedures. In this regard, on multiple occasions users were asked to give a presentation on their daily forecasting routine (or what this looked like under specific circumstances, such as during flood). These often led to fruitful discussions about general practices and how things are done at other forecasting institutions.

[3] *https://sava.deltares.nl, available to registered users only*

4.5 Other

4.5.1 Additional Meetings

Within the scope of the project, the consultant was cordially invited to attend several additional meetings that were deemed relevant to the project. These included:

- HEC-HMS workshop, March 2017
- Transboundary Training Workshop on Governance and Technology for Flood Risk Reduction, December 2017
- HEC-RAS workshop, May 2018.

4.5.2 Additional Developments

In addition to the Term of Reference various activities have been completed. Amongst others, the most important activities include developments to connect to the Sava HIS and the development of an independent distributed hydrological model for Montenegro.

The Sava HIS application is hosted by the ISRBC but not intended for operational use at a 24/7/365 service level. Therefore a separate instance of the Sava HIS (real-time component) has been installed at the primary host location. The already existing application hosted at the ISRBC will be used for backup purpose only.

For the Montenegrin hydrometeorological service a separate Wflow model is added so as to enable an independent scenario and model analysis by its forecasters. This independent model has been calibrated for the Montenegrin stations and included in the Sava FFWS.

RHMZ Serbia has started working on the improvement of the HBV model. During training work on the configuration of this model has started, such that RHMZ Serbia is able to continue this work.

5 Post Project Organization

5.1 Introduction

The Sava Flood Forecasting and Warning System (Sava FFWS) project implements a forecasting system that will be jointly operated and maintained by the riparian countries in the Sava River basin. A vision and a practical plan that looks beyond the project implementation period, the Post Project Organization (PPO), is required to establish an effective joint operation and maintenance structure.

Item 4 of the Article 9 -Flood Forecasting, Warning and Alarm System of the Protocol on Flood Protection to the Framework Agreement on the Sava River basin stipulates:

After the System (meaning the Sava FFWS) *is established, the Parties shall ensure its regular maintenance and performance control, as well as regular training of the engaged personnel, with application of joint standards.*

To ensure the Sava FFWS is operated smoothly and sustainably in the 24/7/365 mode in the post project period, a pragmatic structure to organize real-time operations, support and maintenance as well as development activities is required. In close cooperation with the beneficiaries, such an organizational structure has been setup.

These have been elaborated in detail in a separate document, the Post Project Organization (PPO) report, which has been setup in close cooperation with all the beneficiaries. A summary of organization structure described in that report is provided below.

5.1.1 Organization of real-time operation

The Sava FFWS will be used simultaneously by several organizationally independent forecasting teams. The nine organizations involved with operational forecasting are:

Bosnia and Herzegovina
1. Federal Hydrometeorological Service
2. Sava River Watershed Agency
3. Republic Hydro-Meteorological Service of Republic of Srpska
4. Public Institution “Vode Srpske”

Montenegro
5. Institute of Hydrometeorology and Seismology

Croatia
6. Meteorological and Hydrological Service
7. Croatian Waters

Serbia
8. Republic Hydrometeorological Service of Serbia

Slovenia
9. Slovenian Environment Agency

In additional there is also an operational role for:

ISRBC
10. The ISRBC Secretariat.

Given the open nature of the forecasting environment, the responsibilities for the output and the forecast dissemination within each country should be very clearly distributed. The working processes of the national forecasting teams, and their international responsibilities and communication structure need to be mutually agreed, specific and practical. Only in this way can the provision of the best possible forecasting services be ensured, especially during flood or drought events that have a transboundary character.

To achieve this, the recommended roles of the national forecasting organizations have been detailed in the report, together with the role of international coordination through the International Forecasting Team that consists of one national forecasting coordinator per country/entity. International coordination is of key importance for providing adequate forecasts given the hydrological interconnections between the countries. The Sava FFWS provides an important platform for this. To facilitate international cooperation the creation of an International Forecasting Team that consists of forecasters from each country is recommended.

The ISRBC Secretariat has an important role in coordinating between the riparian countries. The Secretariat coordinates the development and use of Sava HIS.

Also connections to the flood related emergency management operations, carried out by Water Agencies along with Civil Protection agencies, water utilities and reservoir operators have been identified, next to dissemination of operational data products to these organizations.

5.1.2 Organization of support and maintenance

Effective support and maintenance is key to the proper functioning of the Sava FFWS platform and associated systems.

In the project implementing period, the responsibilities with respect to hosting of server systems have been distributed between ARSO (primary system server and Sava HIS-RT), AVP Sava, DHMZ, RHMZ (backup system servers) and ISRBC (archive/web server and Sava HIS). For the operational period, the following system server structure, sequence of the backup servers and location of development system has been applied:

- ARSO Primary system server and Sava HIS-RT
- RHMZ 1st backup system server and testing system
- AVP SAVA 2nd backup system server
- DHMZ 3rd backup system server
- ISRBC Archive/web server and Sava HIS (back-up to the Sava HIS-RT).

The organizations that host either the Sava FFWS primary or one of the backup live systems are responsible for ensuring that the system is up and running at all times without interruption. That means that the organization should have adequate in-house experience and skills to be able to organize and manage such a system. Part of the project was aimed at providing trainings to cover this need. A detailed description of the required roles for support and maintenance through the so-called International Support Team, which consists of one national IT support coordinator per country/entity, can be found in the full PPO report.

5.1.3 Organization of system development

Forecasting and warning needs and requirements will develop over time and new technologies will become available. To take advantage of these changes and opportunities, the Sava FFWS will need to be updated to avoid that the system eventually becomes obsolete. Over time, the Sava FFWS is expected to be further enhanced by the riparian countries. Coordinating this development and ensuring that the system remains consistent and in sync with national and international requirements is an important task that needs to be organized, which is foreseen by the International Development Team that consists of one national development coordinator per country/entity.

New developments can be a result of the project's gap analysis (see next chapter), but also from other projects within the basin. These developments are expected to be included in new releases of the Sava FFWS. Each new release will need to be thoroughly tested before it is implemented in the operational Sava FFWS system, not to compromise its availability.

The implementation of new features for the Sava FFWS requires adequate technical knowhow. Trainings specifically tuned for this purpose have been given as part of the project. Should the need arise, additional trainings (which were outside the scope of the project) can be provided in consultation with Deltares.

5.2 Gaps in required capabilities

As described in the full PPO report, gaps in the required capabilities of operational hydrological forecasting have been identified. These have in part been addressed by the training and capacity building of the project itself, but follow-up trainings and exercises that are beyond the current project scope are still of vital importance. The recommended topics include general forecasting and warning skills, real-time forecasting with the Sava FFWS and international cooperation.

5.3 Finances and investment program

The ISRBC Secretariat will play a role as facilitator in the consultation process at the international level. This facilitator role is both technical and substantive to ensure progress in the negotiations and decision making process to come to a Memorandum of Understanding on cooperation on the Sava FFWS. This MoU also includes budget estimates. Facilitated by the ISRBC Secretariat, an investment program is being developed.

6 Gap Analysis

6.1 Introduction

While the Sava FFWS is a comprehensive system that includes all data and models of the individual countries, making it a unique system when it comes to transboundary cooperation on flood forecasting, there is always room for improvement. The gap analysis report describes the technical and financial aspects of potential improvements. This section provides a summary of the main conclusions of the gap analysis.

6.2 Model performance and forecast accuracy

In general, the complexity of forecasting (and early warning systems) is reflected in the interdependency between forecast accuracy and timeliness as indicated in Figure 6.1. As lead time, or timeliness of the forecast increases then so does the potential value of those forecasts as there is more time available to stakeholders to react. However, as lead time increases, the accuracy of forecasts will tend to decrease. It is important to realize that it is nearly impossible to achieve both perfect timeliness and perfect accuracy; instead, one should strive for an acceptable balance between the two.

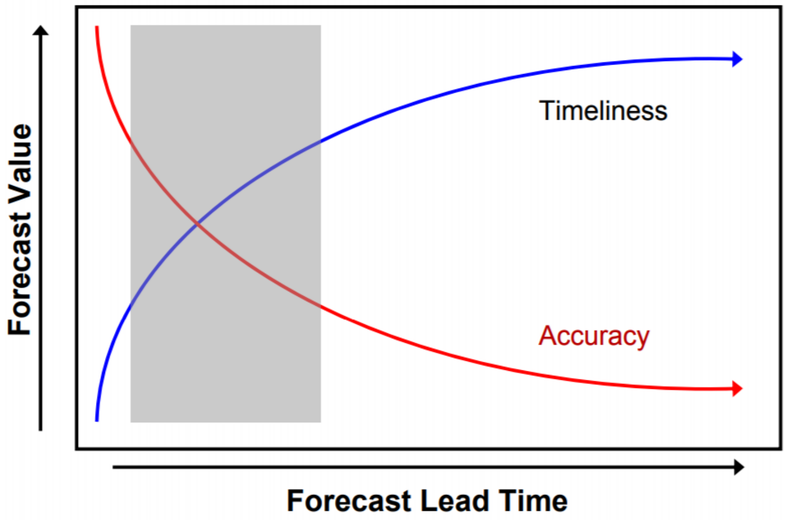

Figure 6.1: Schematic interdependency between accuracy and timeliness of forecasts (source Harold Opitz)

With regards to the Sava FFWS, it should be realized that most of the models have been developed for different purposes than real time flood forecasting. In fact, most of the models were developed for flood risk assessment studies. This means that criteria like time needed for data processing and model runs, as well as computational stability, were previously not an issue. However, these are essential for a model that is run as a part of an operational forecasting system.

As a result, some models have been shown to become unstable, particularly during low flow periods. This causes the workflows to crash and leads to unnecessary maintenance work. To avoid this to the extent possible, it is recommended to (re)calibrate the models for both high flows (for accuracy) and low flows (for stability and model performance).

6.3 Data sources

6.3.1 Gauging stations

The Sava Hydrological Information System (HIS) is the single source for real-time hydrological and meteorological telemetry data within the Sava FFWS. It is hosted at the ISRBC and a special real-time version (Sava HIS-RT) has been implemented at ARSO. Figure 6.2 shows the hydrological and meteorological gauging stations already implemented in Sava HIS as well as in the Sava FFWS (blue), as well as those that have as yet not been implemented (orange). The latter are planned to be added to Sava HIS in the future.

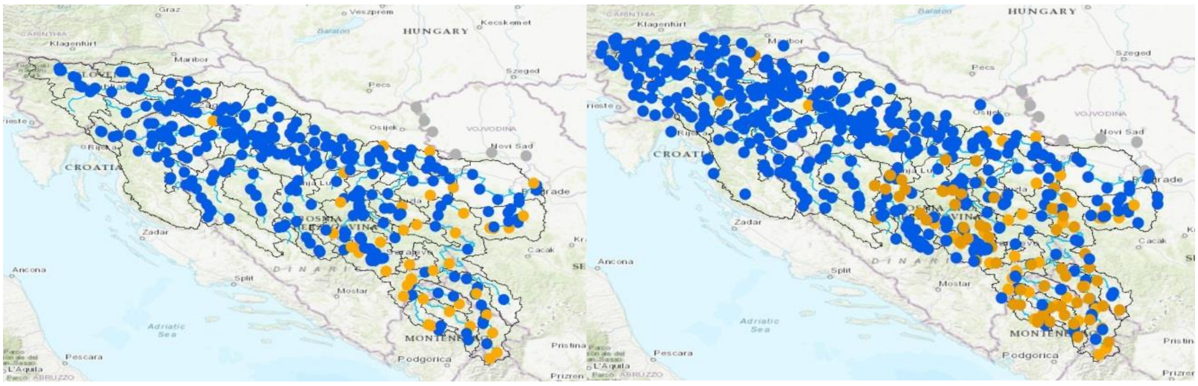

Figure 6.2: Overview of hydrological (left) and meteorological (right) gauging stations with Sava HIS id (blue) and without Sava HIS id (orange)

From these figures it can be seen that there is an uneven distribution of the gauging stations that have been implanted to date. This can be resolved when the newly planned stations are connected to Sava HIS and the Sava FFWS. Besides this, the delivery of data can be improved, as currently around 40% of the active stations do not send adequate real-time data. Besides this, an increase in available discharge data would be beneficial for the data assimilation algorithms.

6.3.2 Weather forecasts

Another source of data are the Numerical Weather Predictions (NWPs), which are used to provide forecast precipitation and temperature that is needed to run the hydrological model forecasts. Selected radar and satellite precipitation products are also included in the Sava FFWS, but these are not connected to any of the hydrological models. It would be worthwhile to investigate the use of these as what is referred to as ‘nowcasting’ products. Application on other systems has shown that these are typically far more accurate than regular NWPs for relatively short lead times (see Figure 6.3).

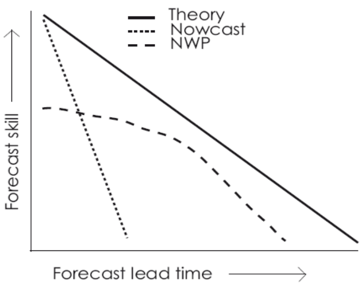

Figure 6.3: Schematic representation of the loss of information in forecasts as a function of lead time (Schuurmans and Bierkens, 2008, after Golding,1998; Lin et al., 2005)

6.4 Workflows and models

6.4.1 Workflows

The Sava FFWS as delivered represents a good framework and integrator platform for available data and models from the individual countries. The combination of a NWP precipitation and temperature, a hydrological model converting precipitation and temperature to discharge and, in most cases, a hydraulic model routing discharge downstream and computing water levels, define a unique *forecast workflow*. Due to the number of hydrological models, hydraulic models and numerical weather prediction models available for Sava, several forecast workflows are configured in the Sava FFWS

Based on the experience during the project, it is recommended to reduce the number of workflows. Table 6.1 shows which forecast workflows should be reconsidered (orange) or have no added value because the quality of the hydrological/hydraulic model is so poor, such that additional scenarios based on other NWP input has no added value. The workflows given in red are recommended to be dropped out.

Table 6.1 Recommendations of reduction of forecast workflows.

Models \ NWP			Default Run			Manual User Run				
	Hydrological	Hydraulic	Aladin SI + ECMWF	Aladin HR + ECMWF	ECMWF EPS	NMMB	WRF BiH	WRF MNE 1km	WRF MNE 3km	WRF SRB
Basin BA/RS/ME	HEC-HMS Sava	HEC-RAS Sava	X		X	X			X	X
	WFlow (BA/RS/ME)		X		X	X			X	X
Local	Mike-NAM (HR)	Mike 11 Croatia		X						
	Mike-NAM Una (BA)	Mike 11 Una		X						
	HBV-light Bosna (BA)		X		X	X	X		X	X
	HEC-HMS Sava	HEC-RAS Bosna (ISRBC)	X		X	X			X	X
	HEC-HMS Sava	HEC-RAS (BA) [9]	X		X	X			X	X
	Mike-NAM Vrbas	Mike 11 Vrbas	X		X	X	X		X	X
	HEC-HMS Kolubara (SRB)	HEC-RAS Kolubara (SRB) [17]	X		X	X			X	X
	HBV (SRB) [5] Jadar, Kolubara, Tamnava,Ub, Ljig		X		X	X			X	X

6.4.2 Models

As can be seen in Table 6.1 there are a large number of hydrological and hydraulic models within the Sava FFWS. For specific improvements of each individual model reference is made to the gap analysis report. This section will instead focus on general principles and the most important recommendations.

The Sava HEC-HMS model is the only model that covers the complete basin. As such, it is important that this model functions well. In addition to the recommendations made in paragraph 6.2 it is advised to improve the spatially distributed rainfall forcing by adding more meteorological stations and/or adding a nowcasting option. Reservoir modelling can also be improved, but this would require an add-in that is still in development at USACE.

For all the hydraulic models, the link with an appropriate hydrologic model is very important in order to receive the correct lateral inflow. This might mean that instead of one of the existing large-scale hydrologic models it is better to construct a new local hydrologic model with more spatial detail. Many of the hydraulic models could be improved by implementing more accurate cross sections. Next, merge of several small models into one bigger hydraulic model (mainly in Bosnia and Herzegovina) is advised. In general, more attention should be given to the aspect of model stability which is essential for an operational system.

6.5 Reservoirs

Reservoirs play an important role in flood forecasting, especially in certain parts of the Sava basin. Within the project, the hydraulic characteristics of the reservoirs are implemented in WFlow using the RTC (Real Time Control) tools. However, there is no real-time data on turbine and outlet flows because there is no operational data exchange between the reservoirs and the Sava FFWS. While it is possible to manually adjust these values, it is recommended to include real-time data for realistic reservoirs levels and turbine flow. In future a reservoir add-on in HEC-HMS is expected which may also benefit from these data.

6.6 Flood mapping

A dedicated flood mapping algorithm is implemented for the Kolubara HEC-RAS, the Bosna HEC-RAS and the Wflow models. The most important source for this is an accurate digital elevation model (DEM) and a hydraulic model with the same elevation for the floodplains. Currently the digital elevation model of the Bosna looks rather good, but the digital elevation model of the Kolubara is poor. Valleys are interpolated in such a way that at some places the river must flow uphill. For better flood mapping it is imperative that the model and the DEM match and are of good quality. Polygons for flood mapping can be constructed in much more detail once a better digital elevation model is available.

7 Conclusions and Recommendations

7.1 General

The principal objective of the Flood Forecasting and Warning System of the Sava River basin is to support the stakeholders in taking balanced decisions in emergency situations of floods. The Sava FFWS enables the five riparian countries to take the right management decisions and carry out measures to prevent and mitigate severe flood events, based on accurate forecasts of flows and discharges with a sufficiently long lead time. This requires close cooperation with relevant stakeholders, managing the data and models on country level which is crucial for successful development of the system. The Sava FFWS is of key importance in this cooperation.

Development of complex systems in a regional, transnational environment, involving many players, can never succeed without assistance and support of all the parties concerned. The same applies to the Sava FFWS; no matter how much effort the Consultant would have exerted into its development, it would have been impossible to arrive at such a sophisticated and versatile system as the Sava FFWS without sustained assistance, unwavering support and excellent cooperative spirit that prevailed among all the project beneficiaries in the Sava region throughout the project implementation period.

The Sava FFWS provides the forecasters of the hydrometeorological services an expert tool, enabling them to generate hydrological forecasts based on observed telemetry data from hydrological and meteorological gauges and Numerical Weather Predictions (NWP). The Sava FFWS uses hydrological and hydraulic models to compute the catchment runoff and river flows and water levels.

One of the large benefits of the FFWS is that all forecasters in the Sava basin have the same information and full insight in what happens in the other countries, as such enabling transboundary flow forecasting.

7.2 Post Project Organization & Finances

In close cooperation with the beneficiaries, an organizational structure has been established, where the real-time operations, support and maintenance and development activities have been identified. All these three components need both national and international cooperation.

Attention is needed for capacity building. While some of the hydrometeorological services that are involved already have a long history in hydrological forecasting and have built a strong experience base, others are yet to develop that knowledge and experience. The establishing of a capacity building and knowledge exchange program is recommended.

The ISRBC Secretariat will play a role as facilitator in the consultation process at the international level. This facilitator role is both technical and substantive to ensure progress in the negotiations and decision making process to come to a Memorandum of Understanding on cooperation on the Sava FFWS. This MoU also includes budget estimates. Facilitated by the ISRBC Secretariat, an investment program is being developed.

7.3 Potential improvements

The Sava FFWS has proven to be a comprehensive system that includes all data and models contributed by the individual countries. This makes it a unique system when it comes to transboundary cooperation on flood forecasting. Nevertheless, there is always a potential for improvements. The gap analysis report describes the technical and financial aspects of the identified potential improvements, covering topics like (meteorological) data and hydrological and hydraulic simulation models.

Next to that, we see parallel development of local / regional hydrological forecasting systems. Proper alignment of these with the international forecasting system is needed, both in terms of real-time operations and in terms of future developments.

A Glossary

BiH	Bosnia and Herzegovina
Delft-FEWS:	Platform for data handling, (hydrological) forecasting and early warning
ECMWF:	European Centre for Medium-Range Weather Forecasts
FSS:	Delft-FEWS Forecasting Shell Server: components doing the actual work (importing data, running models, etc.)
HR	Croatia (Hrvatska)
MC:	Master Controller: Server system controlling all communication between system components
MNE:	Montenegro
NWP:	Numerical Weather Prediction
PPO:	Post-Project Organization
Sava HIS:	Sava Hydrological Information System
Sava HIS-RT:	Version of Sava HIS specifically for real-time data
Sava FFWS:	Sava Flood Forecasting and Warning System
(Sava_)OC:	Operator Client: Desktop version of the Sava FFWS, connected online to the Master Controller (MC)
(Sava_)SA:	Stand-alone: Stand-alone desktop version of the Sava FFWS, used for testing and developing of the configuration
SI	Slovenia
SRB	Serbia

B List of Reports

Final Reports	Date
Inception Report	29 December 2016
Intermediate Report	26 April 2017
Final Report	This report
Technical Reference	Along with this report
User Manual	Along with this report
Post Project Organization	Along with this report
Gap Analysis	Along with this report
IT System Documentation	Along with this report

Other Reports	Date
Training materials IT staff	January 2017
Technical Reference PR0.1	February 2017
User Manual PR0.1	February 2017
Training materials PR0.1February 2017Conditions for Hosting of IT system infrastructure	March 2017
Report on HEC-HMS workshop	March 2017
Investigation in required and available software licenses	May 2017
Technical Reference PR0.2	June 2017
User Manual PR0.2	June 2017
Training materials PR0.2	June 2017
Technical Reference PR0.3	December 2017
User Manual PR0.3	December 2017
Training materials PR0.3	December 2017
Technical Reference R1.0	February 2018
User Manual R1.0	February 2018
Training materials R1.0	February 2018
Training materials, round 1	March 2018
Training materials, round 2	June 2018
Evaluation workshop, minutes and recommendations	September 2018
Webinar minutes	
Meeting minutes	