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Danube Transnational Programme
DAREFFORT

Guidelines on data management
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Introduction

This technical report represents the Output 5.3 Guidelines on data management, as a result of the Activity 5.2. Elaboration of guidelines on data management related to forecasting activities.

This technical report content is based on the related Deliverable – D5.2.1. Summary of good practices, recommendations in report format, and on the main findings of the other project activities: A3.1, A3.2 and A5.1., the country and regional systems factsheets, and representative results and findings from WP4.

The summary of good practices, recommendations of the project covers different aspects of data management in relation with the flood forecasting activities, starting from the monitoring network, data collection, data management processes, data preprocessing and postprocessing modules used in relation with the flood forecasting models and/or in support of different flood forecasting and warning systems activities.

1 Current status of monitoring networks

Reliable hydrological forecast depends, to a great extent, on the quantity and quality of the measured meteorological and hydrological input data, provided by the national monitoring systems of individual countries. It should be mentioned that DAREFFORT project partners are from 12 out of 19 countries covering almost the whole Danube region.

Most countries in the Danube River Basin have made a significant progress in the modernization of the meteorological and hydrological monitoring networks (Table 1). The modern networks provide high quality input data that are used in warning procedures, forecasting systems and other specific data processing.

Furthermore, reliable data control and data processing, as well as an effective data flow, are extremely important for efficient data management and also for hydrological forecasting and warning activities.

Meteorological observations are an essential part of flood and ice warnings and forecasting systems. The most important variables are: precipitation, air temperature, soil moisture, snow depth and snow water equivalent, evaporation, air humidity, wind speed, air pressure, solar radiation, sunshine duration.

Table 1: Number of meteorological and hydrological stations in the Danube River Basin (DRB), operated by the countries participating in the DAREFFORT project

Country	Territory in the DRB (km^2)	Number of meteorological stations operated in DRB	Number of hydrological stations operated in DRB
Austria	80,423	130	150
Bulgaria	47,235	141	66
Croatia	35,101	12	284
The Czech Republic	21,688	90	153
Germany	56,184	84 (LfU), additional 330 (DWD)	488
Hungary	93,030	appr. 300	350 main stations
Moldova	12,834	6	17
Romania	232,193	160	972
Serbia	81,560	300	183
Slovakia	47,084	851	366
Slovenia	16,381	295	149
Ukraine	30,520	17	51

In the frame of hydrological monitoring, all countries collect data on the following hydrological parameters: water level, discharge and water temperature. Some of them collect also information about sediments and ice on river phenomena, and there are practically no systematic measurements of water flow velocity. There are also no systematic measurements of channel morphology, with the exception of navigable waterways along the Danube and its main tributaries.

Moreover, ice measurements are conducted mainly along the Danube River's main flow and its navigable tributaries, based on the recommendation adopted by the Danube Commission.

Despite the fact that most countries in the Danube River Basin have made a significant progress in the modernization of the meteorological and hydrological monitoring networks and that the modernized networks provide high quality data for forecasting models and warning procedures, there is still room for improvements.

2 Data management best practice examples from the National Flood Forecasting Systems

Based on the particularities and characteristics of data management approach, in different National Flood Forecasting Systems, as they were presented in the country factsheets – Activity 3.1., several examples of good practice have been selected, and are shortly presented in this chapter.

In Germany, all collected data is transmitted to internal servers of the HND. Data from the official measuring stations for water levels, own stations for water levels and own stations for precipitation data is transmitted automatically. Data from the DWD is transmitted by an FTP-Server.

For the water level stations, every measuring station has a data collector which stores the level data with an update interval of 15 minutes. Level data is transmitted to several so called SODA servers, each for a certain catchment area.

SODA is a system developed by Kisters company for the special purpose of data storage of water level measurement data. The SODA servers are industrial PCs with Linux operating system. The transmission works via phone lines (analog, ISDN, D-Kanal, currently switching to IP transmission) and mobile networks (GPRS, GSM). These servers transmit the data to a central LAMP server at the LfU which stores the data in a MariaDB data base. The MariaDB data base is mirrored by three additional LAMP servers at different locations to protect against failure in case of a flood.

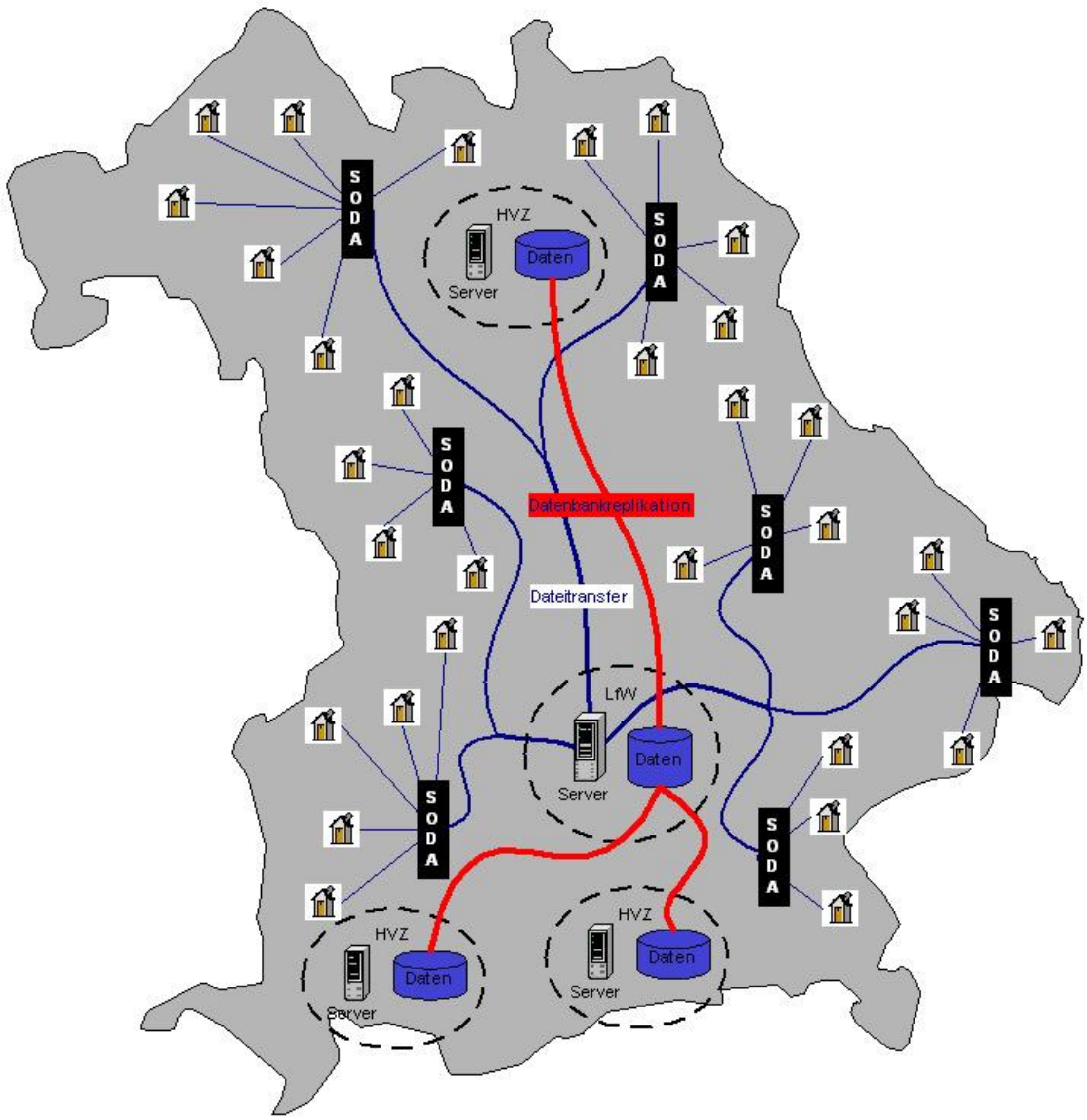

Figure 1: Data management for water level measurement data in Germany

In Austria, the data from all measuring points are entered in the hydrographical database called HyDaMS. Acquisition, processing and controlling of hydrological data is done consistent in all Provinces and in the Central Office. The Provinces as well as the Central Office are using the Hydrographisches Daten-Management-System (HyDaMS). There is a well defined data flow from measuring to analysis with regular controlling measurements, equipment checks and quality controls. Data controlling is first done in the Province´s offices, then again in the Central office before publishing. The evaluation of the yearbook pages and many different data analyzes are carried out with the program HyDaMS. The system combines the subsystems of the national network for monitoring precipitation, groundwater, springs and surface water.

In Slovenia, data from automatic gauging stations come into the database of Slovenian Environment Agency directly through transmission from measuring points. Data from the BOBER automatic stations is transmitted to the database mostly via mobile network every 10 minutes, and from the oldest automatic stations which have not been upgraded yet every 30 minutes with 10 minutes data blocks.

Data control is provided by a three-level system. First level control is automatic and comprises a basic control about the meaningfulness of the data and the operation of the device. The second-level control includes manual control of data and data correction. The second-level control is carried out in the Kolomon tool, which was developed in Slovenia for this purpose.

Further processing and data analyses are performed in the information system of the national hydrology service named HIDROLOG. The system combines the subsystems of the national network for monitoring groundwater, springs, surface water and the sea.

In Croatia, Hydrological data on water levels are collected from several sources (DHMZ, Hrvatske Vode, National parks, HEP) into the data management software Hydras 3 (Ott). Data from automatic stations are sent through a mobile network via ftp in hourly, half-hourly or 15-minute intervals (depending on the settings at each individual station) whereas data from limnigraphs are collected from the stations every three months.

Control readings of water levels are performed during visits to the stations and results are entered directly into the Hydras 3 and serve during the subsequent data analysis.

The basic processing of water levels is conducted periodically through the Hydras, and the verified series are stored in the information system “HIS2000”, which is developed by the Hydrology Department, whereas the database is developed as relational, under the InterBase RDBMS.

Meteorological data are stored in separate databases.

A relational database of type PostgreSQL serves for storing climatological data, precipitation data, sea temperatures, soil temperatures, data on evaporation and data on the stations. Some measured values are daily, some are interval ones for 07, 14, 21 hours.
Data from the automatic stations are stored in the Database of the automatic meteorological stations.

In Hungary, all hydrological data are stored in a MS SQL database. The manual observed data are recorded on data sheet, and are processed monthly. The automatic station recorded data are hourly transmitted by URH and GPRS to Regional Water Directorates.
Data control is provided by several steps. First step is automatic and comprises a basic control about realness of data and operation of device. The second-level control includes manual control of data and data correction. Data are added to the Operational Hydrological Module (OHM) and Hungarian Hydrological Database (MAHAB). Data are controlled one more time automatically and manually straight before hydrological forecasting.

In Serbia, for hydrological data management purposes, RHMS uses a information system WISKI (Water Information System Kisters) from Kisters. WISKI uses a time series approach which enable optimal storage of data and information describing the state and changes in water resources while ensuring high performance and system efficiency. Also, post-processing, analysis, synthesis and decision-making is based on reliable and verified information.
WISKI is currently used for the processing of hydrological data of surface waters and meteorological data for the needs of hydrology. The implementation of groundwater data is in plan for a future period.
For the purpose of controlling the operation of the equipment and observers (data accuracy and data quality), control measurements are performed at all hydrological gauging stations.
Quality control of hydrological data and information obtained through the implementation of hydrological measurement and monitoring programs at hydrological stations (data control) are carried out in order to establish reliability and international comparability of data, removing detected errors and bringing data and information into a form suitable for storage, sharing, use, processing, publishing, and permanent storage. Control of hydrological

data are performed by using manual and / or automatic control methods. Controls are carried out in accordance with the relevant technical regulations of the World Meteorological Organization, WMO No. 168, 2008 Sixth Edition, International Standards.

The basic element of the National System for operational hydrological real time data processing in Serbia is the program „FORECAST“. Program runs under the WINDOWS environment, it is accessible through a specific graphical user interface and it allows efficient, interactive and easy operation with hydrological and meteorological data as well as graphic support.

Data used for operational processing is linked through local Ethernet network with Central Telecommunication Data which enables communication and access to GTS (Global Telecommunications System) network.

The main program includes the following options:

- Hydrological and meteorological data;
- Hydrological bulletins;
- Forecast models;
- Hydrological and weather forecast;
- Data reception;
- Data transmission;
- Graphic support;
- Additional processing programs.

The program allows performance of the following procedures:

- Data reception-transmission;
- Direct data input and overview;
- Data processing;
- Preparation of the data (bulletins) for distribution.

3 HyMeDES Environet Data Exchange Platform - DAREFFORT project solution for standardized data exchange

The HyMeDES Environet Platform is a comprehensive software for exchanging hydrological and meteorological measured data in a common standardized format, that has been developed in the frame of DAREFFORT project (within WP4), and will serve as basis for implementation of future Danube HIS by ICPDR.

Based on the detailed description of HyMeDES Environet Platform from the WP4 deliverables, we present here a short overview of the main characteristics of this new data exchange software solution.

HyMeDES is a web driven service which can be used in three different ways:

- as a distribution node to store and serve all commonly exchanged data;
- as a data node to provide and update national data to distribution node;
- and (optionally) as a client node to cache the data of the distribution node for fast local access.

The hydrological and meteorological data provided by partners from different country in the Danube basin has to be converted to the common data exchange format (HyMeDEM), stored and distributed in an appropriate way.

Since there are many partners involved in this process, especially data providers, it was necessary to develop a decentralized and modularized solution, in order to ensures that:

- horizontal growth is possible easily which respect to data providers;
- the maintenance effort is kept to a minimum for each partner;
- the accessibility and availability of data for the end users is maximized.

To achieve these aims, the software architecture of HyMeDES satisfy the following requirements:

- Data from national data providers should be gathered by the Common Data Exchange Service using existing data exchange interfaces where available to keep the effort for the national data providers as low as possible in order to enhance the acceptance. This also implies that the national data providers only host their own data, not the data of other countries.
- Data has to be converted into the common data exchange data model HyMeDEM by the Common Data Exchange Service, and comprised to a common data pool (common data base).
- The Common Data Exchange Service provides the common data pool to clients, acting as distribution node.

- The development of the software is based on established coding standards and is well commented, to be easy maintainable.
- The Common Data Exchange Service is a web driven application.
- To make the system as open and platform independent as possible the core structure only uses simple and proven web technology (server side: HTTPS, PHP, Cron/Task scheduler, client side [for configuration and administration]: Html5, JavaScript).
- Light-weight software, easy to implement and to maintain.
- Data security: Authentication is verified using appropriate encryption methods.
- The interaction is managed by Web APIs.
- Using plug-ins (plug-in libraries) is encouraged.
- No direct writing interaction with the underlying databases is allowed (only access via API). Reading data from the data base can be allowed.
- Missing data may be imported as files (e.g. csv) triggered by administrator user manually.
- To be compliant with ICPDR future developments regarding Danube HIS following IT infrastructure is supported (all of them are open source):
    - web server: Apache;
    - data base: PostgreSQL with PostGIS extension;
    - sharing geospatial data: GeoServer;
    - interoperability with the already existing DanubeGIS;
    - user management system (e.g. CIS).

To meet international standards, the HyMeDEM data exchange format is OGC WaterML 2.0: Part 1 - Timeseries (WaterML), which is an XML format standardized by the Open Geospatial Consortium (OGC). It is a data exchange standard for hydrology, and it can be used to exchange many kinds of hydrological and meteorological observations and measurements.

The data exchange between national data providers HyMeDES data nodes and a HyMeDES distribution node is done using WaterML. The data uploaded by the national data providers via HyMeDES data nodes to the HyMeDES distribution node is stored on the distribution node in a PostgreSQL data base. Data is disseminated by the distribution node to third-party users in WaterML 2.0 timeseries format after authentication.

The database structure of a HyMeDES node is aligned towards the data exchange format WaterML to avoid a huge amount of data conversion when storing the incoming data to the database and when serving data to the users.

A national data provider running a data node to provide its data to a distribution node is not required to run a database software on its servers for this purpose.

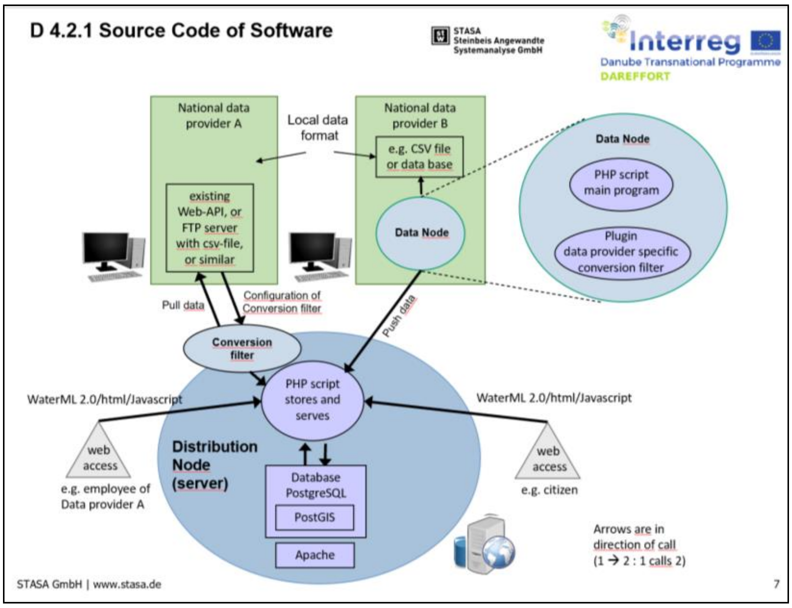

Figure 2 Main components of HyMeDES (data node, distribution node) and data exchange concept

The HyMeDES Environet Data Exchange Platform software package was developed as an Open Source component, and it is hosted on Github: (https://github.com/environet/).

4 Data management best practice examples from the Regional Flood Forecasting Systems

European Flood Awareness System (EFAS)

EFAS European Flood Awareness System is the first operational European system monitoring and forecasting floods across Europe and the first operational European warning system.

The aim of EFAS is to support preparatory measures before major flood events strike, particularly in the large trans-national river basins and throughout Europe in general.

It provides complementary, added-value information (e.g. probabilistic, medium range flood forecasts, flash flood indicators or impact forecasts) to the relevant national and regional authorities. Furthermore, EFAS keeps the Emergency Response Coordination Centre (ERCC) informed about ongoing and possibly upcoming flood events across Europe.

An EFAS partner is any national, regional or local authority that is legally obliged to provide flood forecasting services or has a national role in flood risk management within its country and the European Commission Services, i.e. DG ECHO-ERCC, DG ENTR-COPERNICUS and DG JRC.

The operational EFAS organization consists of four centres:

- **EFAS Hydrological data collection centre** - REDIAM and SOOLOGIC is responsible for collecting historic and real-time discharge and water level data.
- **EFAS Meteorological data collection centre** - KISTERS AG and the German Weather Service (DWD) collecting historic and real-time meteorological data across Europe.
- **EFAS Computational centre** - European Centre for Medium-Range Weather Forecasts (ECMWF) - runs the forecasts and post-processing calculations as well as the web interface of the EFAS-Information System.
- **EFAS Dissemination centre** - Swedish Meteorological and Hydrological Institute, Slovak Hydrometeorological Institute and Dutch Rijkswaterstaat - analyses EFAS results on a daily basis, disseminates information to the EFAS partners, organizes user meetings and provides training.

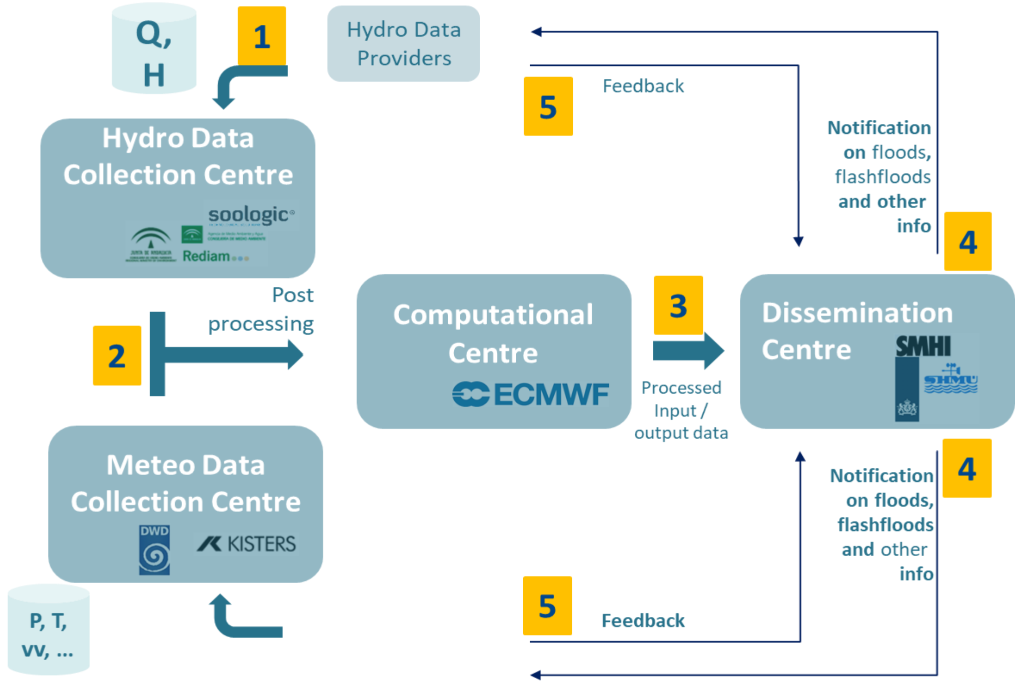

Figure 3: EFAS structure

Both, the hydrological and meteorological data collection centres perform extensive quality control and data validation on in-situ hydrological and meteorological data. They have set up data validation using quality codes and, depending on the type of variable, different data validation types. An example of the workflow for the meteorological data collection is shown in Figure 4.

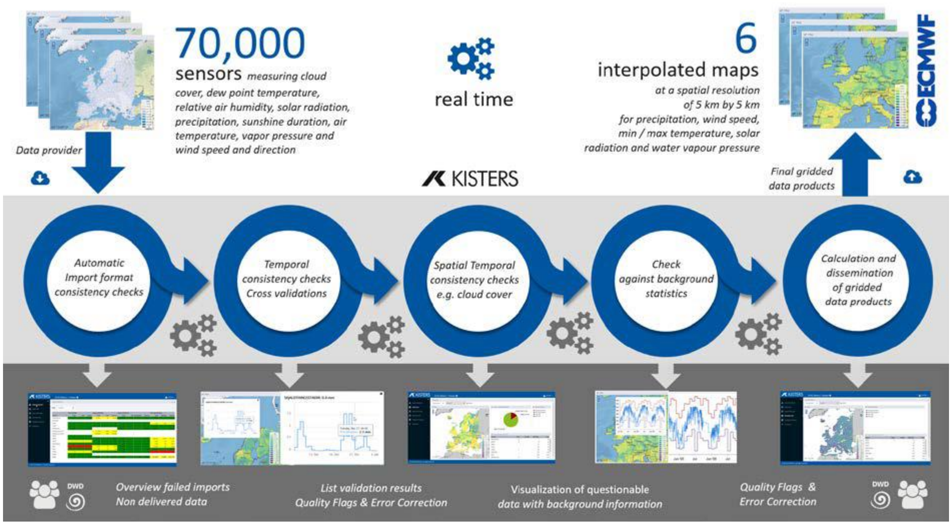

Figure 4: The workflow of the Meteorological Data Collection Centre to produce high quality interpolated maps for EFAS

EFAS provides two main data services:

- A **data access service** that provides direct access to hydrological time series simulation (medium-range forecasts and historical runs) data files. The way and type of files accessible depends on EFAS user credentials;
- **A web service**, that provides direct access to EFAS forecast products (maps and associated graphical outputs). The type of information accessible depends on EFAS user credentials.

EFAS has a dedicated data service enabling users (public or EFAS registered users) to access hydrological simulation time series produced by the system. Two types of hydrological time series datasets are available: operational medium-range forecasts and historical hydrological simulations.

Access to EFAS data depends on their release date:

- Near real-time data. This is a restricted service only available to registered authorised EFAS users, providing access to operational hydrological time series data within 30 days of their release date. Access is possible through a dedicated password-protected ftp service.
- Archived data. This is a service open to all, conditional to license conditions acceptance, providing access to operational hydrological time series data after 30 days of their release date, and to reference historical hydrological time series data. Access is possible through the Copernicus Climate Data Store and the ECMWF MARS archive server.

Climate Data Store - The Copernicus Climate Data Store (CDS) is an easy way for users to access climate-related data, including EFAS data. It offers a web interface service where users can select which data to access or view.

FTP services - Registered EFAS users with access to EFAS real-time information can access real-time EFAS hydrological forecasts through the ECMWF's production Data Store (ECPDS).

MARS archive – MARS is ECMWF's Meteorological Archival and Retrieval System. The system has the following features:

  - Facilities to archive and retrieve environmental data
  - 24/7 service
  - Batch and interactive modes

- Large amount of data, both in size and number of items stored
- Large number of users with different requirements.
- Access to the MARS archive requires being an ECMWF registered user.

EFAS provides also OGC (Open Geospatial Consortium) compliant web services of selected products. This includes a Web Map Service – Time (WMS-T) for geospatial products as well as a Sensor Observation Service (SOS) for post-processed river discharge forecasts at selected locations.

Sava Flood Forecasting and Warning System (Sava FFWS)

The development of a joint Flood Forecasting and Warning System in the Sava River Basin (Sava FFWS) was launched in June 2016, as a component of the project Improvement of Joint Actions in Flood Management in the Sava River Basin, funded by the Western Balkans Investment Framework and implemented by the World Bank.

After two years of development period, in October 2018, the Sava countries, coordinated by the Sava Commission successfully established Sava FFWS which is now operational.

The Sava FFWS is based on the Delft-FEWS platform, which has also been applied in a number of basins across the world. The Sava FFWS is implemented as an open shell for managing the data handling and forecasting process, allowing a wide range of external data and models to be integrated.

This concept is particularly important for the five cooperating Sava countries (Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia), and each country has its own models, monitoring systems, forecasting systems, water authorities and interests.

The Sava FFWS integrates various numerical weather prediction models, available weather radar and satellite imagery, outputs of the existing national forecasting systems, different meteorological, hydrological and hydraulic models which are easily ‘plugged’ into a common platform.

One of the main aims of Sava FFWS is to bridge differences and support collaboration in the field of hydrological forecasting (current focus are floods) keeping the countries’ own autonomy in monitoring, modelling and forecasting and remain open to developing its own models and supplementary forecasting initiatives.

Sava FFWS integrates Sava HIS, as a data hub for the collection of real-time hydrological and meteorological data, as well as various Numerical Weather Prediction models, available weather radar and satellite products, outputs of the existing national forecasting systems, different meteorological, hydrological and hydraulic models which all are ‘plugged’ into a common platform.

The Delft-FEWS application is used as backbone for data integration and user interface. The system runs hydrological and hydraulic simulation models, like HEC-HMS, Mike11 etc.

The Delft-FEWS software comprises the several components as illustrated in Figure 5. Note that this figure just shows the components of one single duty system. These components can be separated in two groups: components on the server and components on the client.

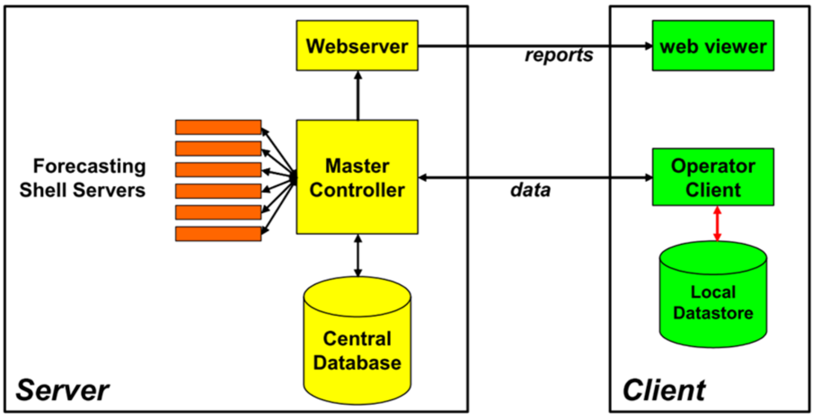

Figure 5: Functional Components in a Delft-FEWS client-server application

Actual tasks, like importing data or running of models are performed on the FSS. The system uses a central database which can be of Oracle, MS SQL Server or PostgreSQL. Currently the system use PostgreSQL as it is free of charge available.

On the client (a laptop or PC where the users use the system), the so-called Operator Client (OC) is run. This is a thick-client, Java based application, that connects to the Master Controller through https over the internet. Data is read and cached in a local data repository (referred to as the LocalDataStore).

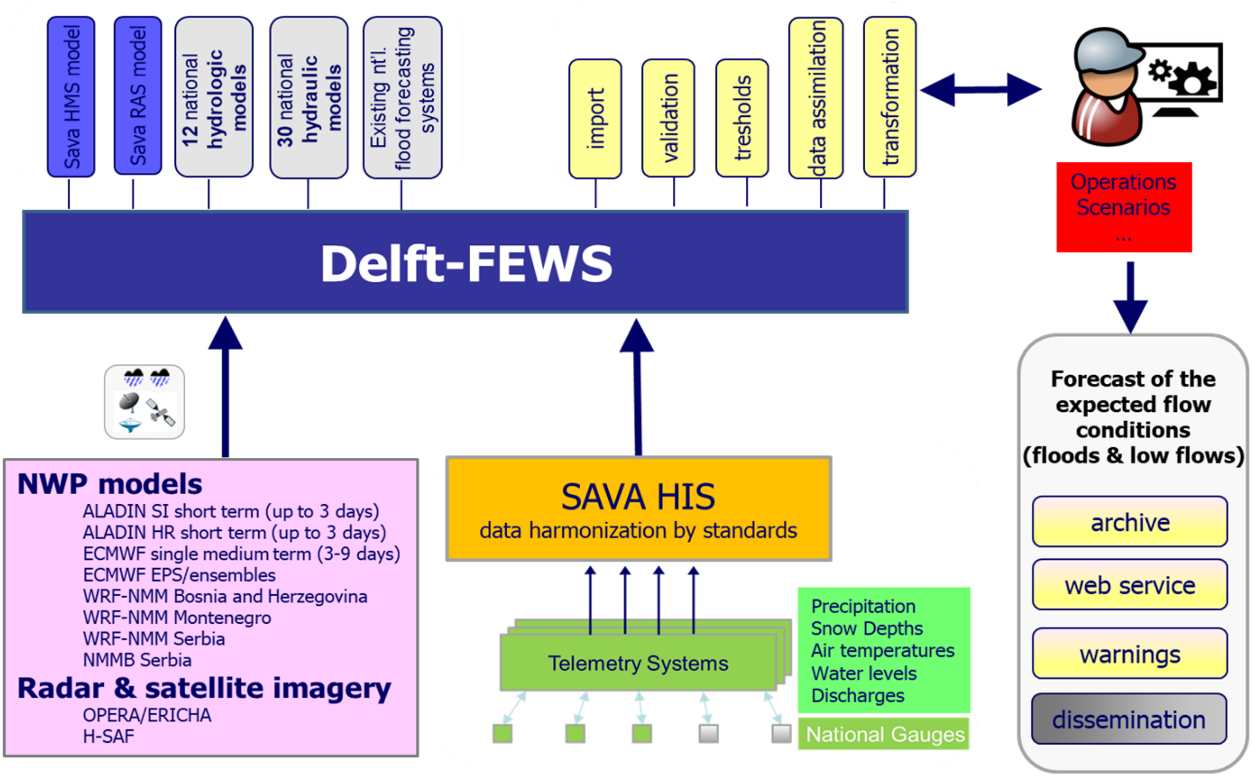

Figure 6: Schematic overview of Sava FFWS approach

Sava FFWS consists of five hosting locations, i.e. one Primary and three Backup server locations as well as Archive and Web server.

Currently, Sava HIS is collecting observed data from 310 hydrologic and 220 meteorological stations. Since the Water ML 2.0 format (WMO's standard) is implemented in Sava HIS, the system enables storage of countries observations in a standard format and supports data sharing and publication via web services for further use in the Sava FFWS.

South East Europe Flash Flood Guidance System (SEE-FFGS)

The South East Europe Flash Flood Guidance System (SEEFFGS) is developed as one of the Flash Flood Guidance Systems (FFGS) implemented around the world by the Hydrologic Research Center (HRC) in collaboration with the World Meteorological Organization (WMO), the US Agency for International Development Office of Foreign Disaster Assistance (USAID/OFDA), and the US National Oceanic and Atmospheric Administration (NOAA).

FFGS products provide up-to-date information to National Meteorological and Hydrological Services (NMHSs) for their use in rapid assessment of current flash flood risk and to enable

NMHSs to issue timely and location specific flash flood alerts, watches or warning. The primary purpose of the FFGS is to provide real-time guidance products pertaining to the threat of potential flash floods in relatively small basins. The system provides the necessary products to support the development of warnings for flash floods from rainfall events through the use of remote sensing-based rainfall estimates.

The regional system incorporated remotely-sensed precipitation with the local but relatively sparse surface observation network, and semi-distributed hydrologic modelling with high spatial resolution to produce guidance products pertaining to the threat of small scale flash flooding.

Evaluations of the threat of flash flooding are done over hourly to six-hourly time scales for basins from 100-300 km^2 in size. Satellite precipitation estimates are used together with available regional in-situ precipitation gauge data to obtain bias-corrected estimates of current rainfall volume over the region.

These precipitation data are also used as input to hydrologic models that update soil moisture conditions.

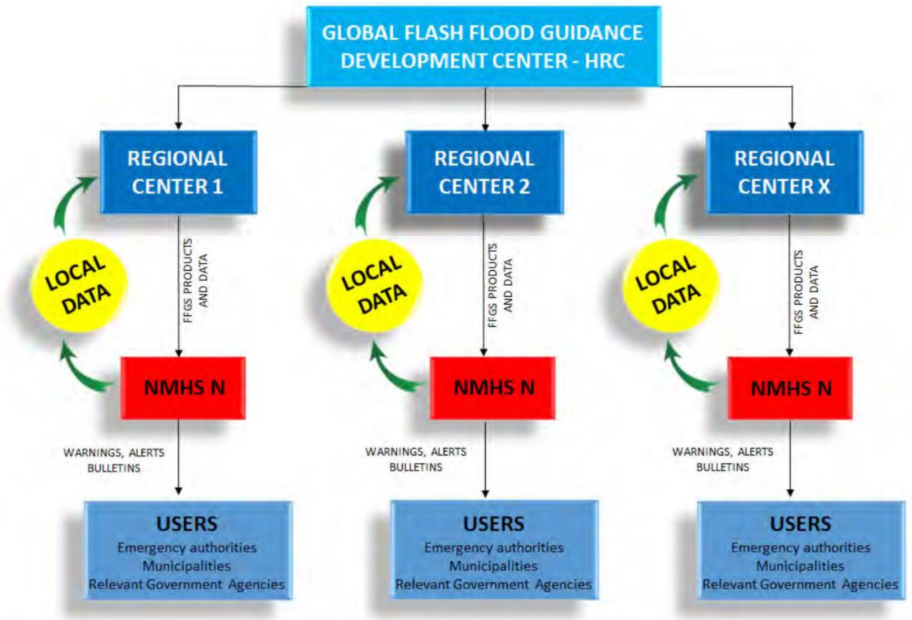

Figure 7: Global Flash Flood Guidance program concept (Source WMO)

The South East Europe Flash Flood Guidance System covers the countries of Albania, Bosnia and Herzegovina, Croatia, Moldova, Montenegro, Republic of North Macedonia, Romania, Serbia, and Slovenia. In January 2013, it was agreed to establish the Regional Center of the SEEFFGS at the Turkish State Meteorological Service (TSMS) in Ankara.

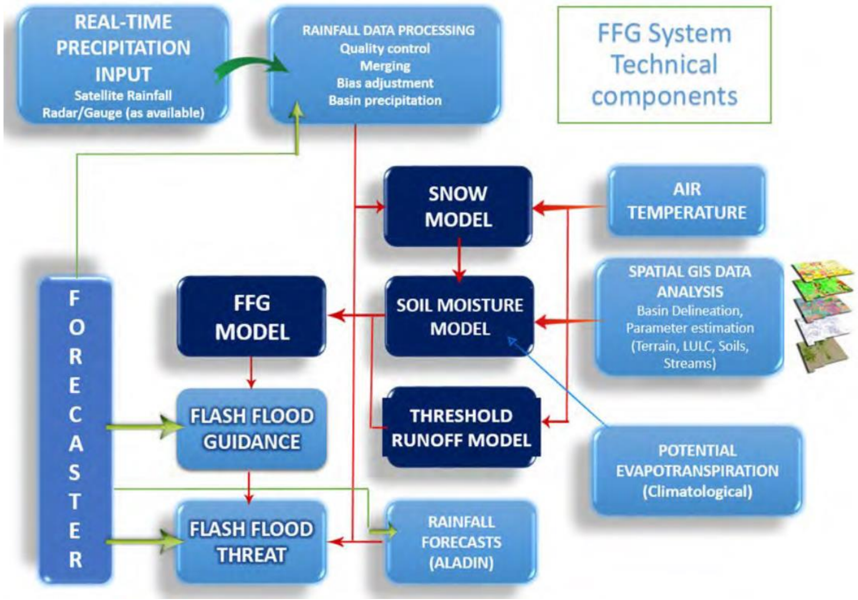

Figure 8: Flash flood guidance system technical components (Source WMO)

The processing and modeling components of the FFGS utilize the available real-time data from in-situ gauging stations and from remote sensing platforms, suitably adjusted to reduce bias, together with physically based soil water accounting models to produce flash flood guidance estimates of various durations over small flash flood prone catchments.

South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A)

WMO initiated the South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A) project in 2016 to assist Members in the region. This project builds on the outcomes of several recent projects in the region related to disaster risk reduction that were implemented with funding from the European Union, United Nation agencies, the World Bank and a number of other international and national organizations.

The SEE-MHEWS-A project will benefit the National Meteorological and Hydrological Services of WMO Members from the region - that is Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Hungary, Israel, Jordan, Lebanon, North Macedonia, Republic of Moldova, Montenegro, Romania, Serbia, Slovenia, Turkey and Ukraine. The Project Steering

Committee, composed of the Directors of the NMHSs of the WMO Member States listed above, will manage the advisory system developed under the project.

The development of the SEE-MHEWS-A will support the NMHSs in fulfilling their mandate to provide timely and accurate warnings in order to minimize the impacts on people, infrastructure and industry of hazardous weather events and to protect the lives and livelihoods of the people.

The main objectives of SEE-MHEWS-A are:

- Strengthened regional cooperation through leveraging of national, regional and global capacities to develop improved hydrometeorological forecasts, advisories and warnings, which will contribute to saving lives and reducing economic losses and damage;
- Strengthened national MHEWS systems by making regional and sub-regional observing, monitoring and forecasting tools and data available to the participating countries and other beneficiaries;
- To implement impact-based forecasts and risk-based warning capacities that contribute to better informed decision-making by national governments, disaster management authorities, humanitarian agencies, and NGOs;
- Harmonized forecasts and warnings among the NMHSs especially in transboundary areas of the region;
- Increased operational forecasting capabilities of NMHSs staff.

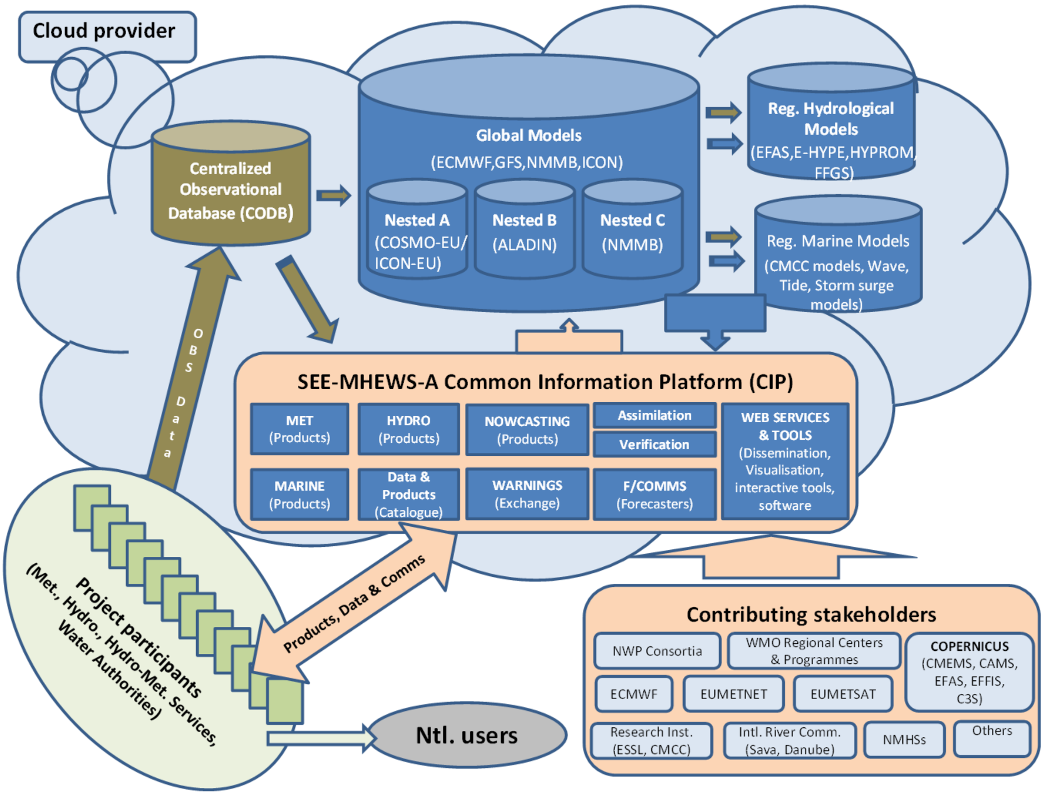

Figure 9: General architecture of the SEE-MHEWS-A System (Source WMO)

Currently, there is a lack of observational as well as high-resolution model data for many areas in the SEE region.

During the second phase of the project, current status of the observational networks including inventory of the data and recommendations for improvements to the existing observational networks supporting SEE-MHEWS-A was prepared.

In November 2019, the project countries agreed to extend their cooperation regarding data exchange with development and signing of the Policy on the Exchange of Hydrological and Meteorological Data, Information, Forecasts and Advisories under the South-East European Multi-Hazard Early Warning Advisory System.

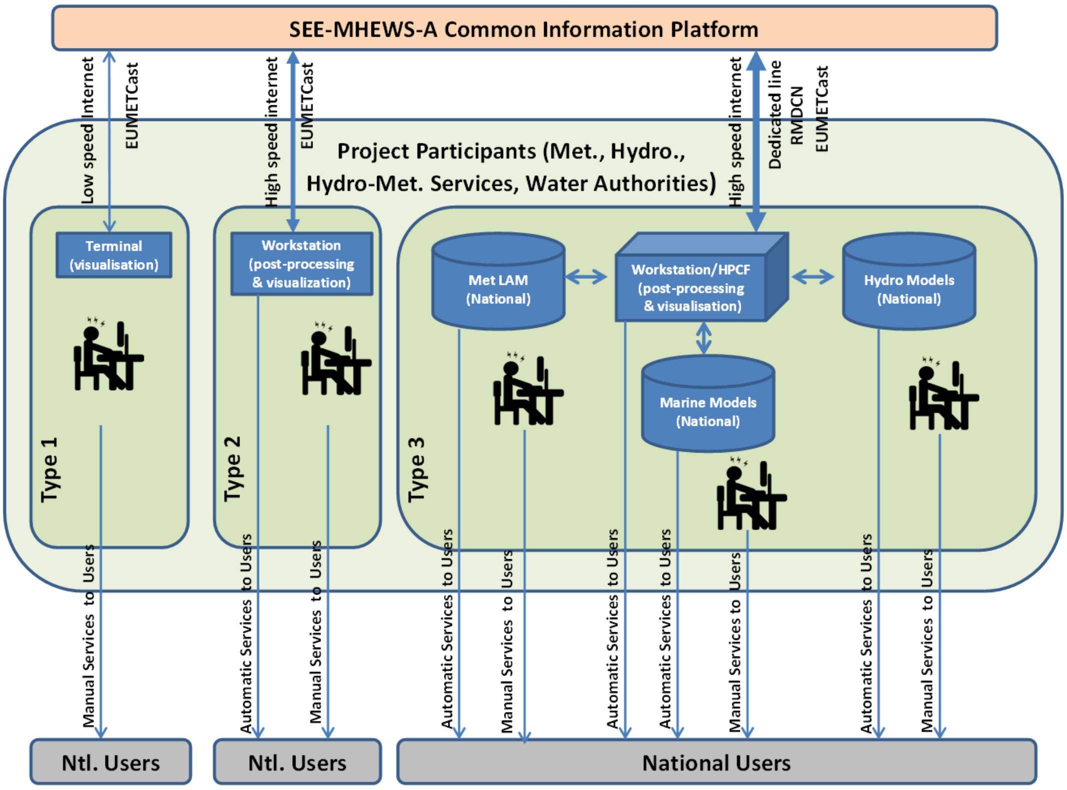

Figure 10: General concept of operation and collaboration within SEE-MHEWS-A System (Source WMO)

This Policy provides technical and conceptual principles required to promote data, information, forecast, and warning exchange and interoperability within the SEE region.

This will allow access to a large quantity of additional observations, which are currently not shared regionally, to be utilized for various project purposes, such as numerical weather prediction data assimilation and verification, hydrological modelling and nowcasting.

The Data Policy has been signed by 15 NMHSs from the region as well as European Centre for Medium-Range Weather Forecasts (ECMWF), who is supporting the implementation of the Policy. The signatories of the Policy provide additional observations to those they routinely share via Global Telecommunication System (GTS).

These additional observations are collected in the Central Observational Database (CODB) for SEE-MHEWS-A hosted by the ECMWF.

Pilot version of the CODB was developed to facilitate data collection, assimilation, model verification, post-processing and nowcasting. By August 2020, over 13,000 additional daily observations are being provided regularly by the countries to ECMWF.

5 Recommendations for improving the monitoring activity in the Danube River basin

Based on the results of the Activities 3.1 and 3.2 prepared in the frame of DAREFFORT project, and also the project partners inputs within Activity 5.2, the following main recommendations were made:

- The Danube River Basin countries should consider the need to improve the meteorological measuring network in terms of the station density and the inclusion of measurements of additional variables such as evapotranspiration, soil moisture, snow water equivalent, etc.
- In most countries, there are not adequate systematic measurements of snow water equivalent or its spatial distribution, despite the fact that floods in the Danube River Basin are mainly generated in mountainous areas as a combination of rainfall and snowmelt. In the future, this issue needs to be addressed, both by improving the monitoring of snowpack parameters on the ground, but also by implementing and using new data management processes, based on data fusion of ground observation, satellite products and snow model simulations.
- The Danube River Basin countries should consider the need to improve the hydrological measuring network in terms of the station density and the inclusion of measurements of additional variables such as bed load, periodical cross-section morphology, water velocity measurements, etc. In the last decades, the number of observation stations has unfortunately decreased and therewith the valuable information regarding the heterogeneity and dynamics of the phenomena measured is lost.
- The Danube River Basin countries should consider the need to improve the measuring network in terms of the inclusion of ice on rivers measurements, since the combinations of extremely rare events the so-called compound events, such as ice and rainfall, snow cover and rainfall, are not covered adequately enough by hydrological models or forecasting protocols.

- The Danube River Basin countries should consider the need for further development and using of meteorological products also at regional level, e.g. development of composite weather radar outputs at regional level.
- Development of hydrological products at regional level, e.g. hydrological bulletins of transboundary rivers, etc. Such efforts could be also supported by making use of the Danube River Basin wide outputs from EFAS.
- Countries should consider providing free access to some of the meteorological and hydrological data related to the national hydrological forecasting services in the Danube River Basin for their official needs.
- Improvement of the collection of historical meteorological and hydrological data records, digitization and storage in standard format, since this data is very important for water resources management and modelling, climate change assessment, flood modelling and other meteorological and hydrological analyses.
- In relation to the project scope, countries should consider standardized data exchange for sharing hydrological data. The HyMeDES Environet Data Exchange Platform, developed within DAREFFORT project, supports this standardized data exchange. It is highly recommended to use this platform and to establish it as a standard for hydrological data exchange within the Danube basin, e.g. in future Danube HIS.
- In relation to all above recommendations, the meteorological and hydrological services should consider providing strong arguments for obtaining sufficient financial, technical and human resources to operate the services.

Also, the following recommendations could reduce the impact of periods with insufficient financial, technical and human resources for the proper maintenance and periodical upgrade of the national hydrological monitoring network, and in general on the availability and quality of critical hydrometeorological data, which are very important for the operational flood forecasting models and warnings procedures:

- It is recommended to define a “first order” national network, in which to include the most important hydrometrical stations, both for modelling system real-time adjustment and control, but also in the locations which are critical in real-time for the management of the emergency situations generated by floods.

- This first order network will include also selected precipitations stations, representative for the basin areas, where the runoff is mainly generated.
- For these important water levels and precipitations stations is recommended to:
    - Install more reliable and accurate sensors.
    - Install redundant sensors, especially for water levels.
    - Install redundant communication channels.
- These stations need to remain in proper function and communicate in real time even during very extreme events (event with a mean return period > 100 years).
- At least one of the communication channels need to send the data also directly to the national centre, or to a backup collecting centre.
- The budget needed for the annual proper maintenance could be obtained by different mechanisms, than for the other stations, part of the “second order” network.
- The stations from the second order stations network will be compatible and integrated with the first order network.

In general, in all the countries within Danube River Basin, the existing National Monitoring Stations Networks are able to provide the necessary input data (in term of both spatial and temporal resolution) for hydrological forecasting and warning elaboration in case of fluvial floods events, in medium and large river basins.

However, the actual National Monitoring Stations Network, could not fully satisfy the observational input data needs for flash floods and pluvial floods forecasting and warning activities. Also, as medium and long term perspective, we consider it is unrealistic to assume that the future extension and modernization of National Monitoring Stations Network will be able to satisfy the specific high spatial and temporal resolution needs for properly forecasting flash floods events, even in the most developed countries.

The recommended actual approach is to combine the precipitation estimates products from the meteorological radar data, and/or satellite data, with the existing automated gauging stations data, in order to produce the estimation of precipitation at the needed spatial and temporal resolution. However, this solution still has, in many countries, significant issues in term of accuracy and uncertainty levels.

Due to the perspectives of further increase of the frequency of such extremes events as results of the climate changes, the needs for analysing and simulating the hydrological processes associated with flash floods events become more and more a priority for the scientific hydrological community.

We consider that a dedicated research and development EU program could be the best option, in order to propose and test several new adequate monitoring solutions, that will be able to complement the existing information from the national networks, in order to provide significantly improved input data that could further support a significant accuracy improvement of flash floods forecasting and warnings products.

As a first set of recommendations for research topics, we propose the following:

- Develop a new generation of sensors, using the already existing experience from the field of Internet of Things (IoT) sensor technologies and real-time data acquisition, first priority being to develop sensors for precipitation and second priority for detection of initiation on significant / fast runoff on slopes and small non-permanent rivers. The main characteristics expected from this new generation of sensors are the following: robust, very low maintenance, threshold oriented, not necessary high accuracy, significant low price comparing with the existing sensors.
- As example of where the new sensors could be installed / deployed we could mention several possible locations: official building, schools, hospitals, trains, buses, private houses, private cars.
- Develop dedicated mobile applications, that will allow the people to provide directly standardized real time observational reports on rainfall and runoff intensities. Using both subjective classification of the real time situation comparing to existing predefined classes in the application, and automatic machine learning algorithm classification based on the pictures processing in real time, at the level of the observer mobile device.
- Develop new data fusion methods, that will be able to use and combine all available monitoring data (stations from the national networks, data from the new generation of sensors, qualitative data from the mobile applications, different radar networks,

satellite data, NWP model simulations, etc.), and finally produce a set of ensemble QPE and short term QPF products, and / or a single product with the most probable values and estimation of related uncertainty.

Involvement of people in the monitoring process will also has the advantage of improving the awareness and understanding of these hazards, helping them to better understand and react on received warnings messages.

6 Guideline on data management related to hydrological forecasting activities

Traditionally, data management aspects related to hydrological forecasting activities were generally considered mainly in relation with the management and preparation of observational input data for the hydrological forecasting models (e.g.: collection, storage, quality-control, gap filling, general time series operations, final formatting according to each model requirements).

Recent developments in Flood Forecasting Systems (extensive use of high resolution NWP, radar, and/or satellite gridded input data, implementation of distributed rainfall-runoff and routing models, multimodel approach, generation of ensemble forecasts), resulted in a significant increase of requirement of data management processes (data storage, data import / export and data processing general functionalities).

Significantly greater amount of data and information needs to be processed and distributed between different components and/or system modules at different levels, different time and in different format.

Despite the significant development of the hydrological models structure, configuration and complexity, we still have to calibrate all the hydrological models, even if they are physically based models.

This calibration process, together with the model configuration process are a time consuming task, which generates significant implementation issues for the real time forecasting systems, especially when the changes are significant or a completely new system is planned to be implemented.

Special considerations for flash flood forecasting and warning activities:

- Flash floods are considered in general the floods with time to peak less than 6 hours. The critical issue is to have the necessary lead time for the warning messages, in order to be useful, especially for avoiding loss of life.
- The forecasting system need to receive at least hourly precipitations observations, with minimum delay.
- In general, the flash floods events occur in small ungauged basins.
- For very small basins, we could have extreme flash floods – generated mainly due to very intense surface runoff on slopes, with quick integration on small non-permanent river network, the time to peak could be less than 30 minutes.
- For these events, driven primarily by very high rainfall intensity, a good coverage from the warning system is not possible without the use of meteorological radar products for estimating in real time the precipitation field (every 5 – 10 minutes), and <=1 km spatial resolution.
- Availability of special run of numerical meteorological model, at local regional scales with high resolution, on small computation domain around the possible affected areas could be very useful for increasing the warning lead time.
- Real time nowcast products, for precipitation field evolution within the next 1 – 2 hours are also recommended.
- Rainfall estimations with radar have a lot of potential errors and uncertainty, the system need to use a adequate rain-gauge correction procedure.

The Flood Forecasting and Warning System (FFWS) needs special meteorological products, both for the real time operation and for the model calibration.

Taking into consideration the importance of meteorological input data for the hydrological forecasting activities, it is mandatory to continue the implementation, maintenance and periodical upgrade of national meteorological monitoring and forecasting systems, in order to provide the specific needed meteorological products for the FFWS.

The following are examples of such products:

- Gridded estimation of all the meteorological parameters needed for hydrological model calibrations, from a representative historical period. It is recommended to use all the available station observations and high resolution reanalysis numerical meteorological runs, for getting all the needed parameters with the best possible accuracy.

- Real time gridded estimation of recorded precipitations, at adequate spatial and temporal resolutions, accuracy, and with minimum delay time.
- Daily gridded estimation of snow water equivalent, during the snow season.
- Meteorological forecasts, for all the needed parameters for running in real time the hydrological models, at the adequate spatial and temporal resolution, and with enough lead time, 2 or 4 model cycles every day.
- It is recommended to use ensemble meteorological forecasts, if possible, or at least to use some scenarios for the future evolution of the precipitation field.
- The possibility to launch special numerical meteorological models runs, for 9 - 12 hours lead time, for limited computation domain, and at high spatial resolution, during extreme basins/local rain events.

Both meteorological and hydrological forecast elaboration, especially in case of extreme events, could still be considered to be in the same time science and art (human forecaster + the forecasting system must “work in harmony” for maximum benefit).

Hydrological forecasters proper training, formation and team stability need to be recognized as having a high priority. It is highly recommended to implement Flood Forecasting Systems simulators, or at least post event simulation analysis functionalities, for better preparing the forecasters to analyse, interpret, and elaborate warnings during extreme events conditions.

During extreme floods events, we could also have significant problems in operating the monitoring networks, important hydrometric stations could be flooded / damaged, impossible to make / get further observation from some river sections, and we have to deal with increase uncertainty in estimating the peak discharge values (significant rating curve extrapolation). A good design of data management processes and operations could limit the negative impact on the final forecast products of such conditions.

In order to improve also the last component of the End-to-End Flood Forecasting Systems chain, it is recommended to implement, maintain and prepare periodical upgrade of national integrated information systems for data and products exchange in real-time between all the institutions involved in the management of emergency situations generated by floods.

- It is recommended first to start with basic functionalities for sharing data and information, in real time, in standard format, between all these institutions.
- As the next steps, depending on the available resources, continue by improvements of the interactive and control access functionalities on this platform, integrating procedures for management of emergency situations, including functionalities to do simulation exercise in order to test and/or refine the real time cooperation procedures.

Taking into consideration the existing limitations encountered at national level, in many countries, on financial, hardware, and human resources, but also in order to reduce the duplication of several data management activities, it is recommended to increase the support provided from the Regional Systems toward the National Systems:

- Act as an interface between the national systems and the regional and/or global meteorological and/or hydrological systems, especially as an interface between the meteorological and hydrological communities, simplifying the integration of meteorological systems outputs into the hydrological forecasting systems, and producing specific standard meteorological products adequate for hydrological applications, within the national hydrological forecasting systems.
- Facilitate the development of the national systems for using new types of satellite products, and ensemble meteorological forecasts, adequate for operational hydrological applications.
- Could be used for significantly reduce the recovery time of national systems after a system failure (generated either by hardware, software or data communication issues), by providing reasonable estimate of initial conditions for hydrological forecasting models.
- Provide, to a certain extent, backup capabilities to the national systems.
- Could provide specific grid computing and storage hardware resources, and/or specific meteorological/hydrological modelling web services for the national services.

7 Conclusions and final recommendations

Implementation of Flood Forecasting and Warning Systems needs to be understood and planned as a continuous process. After each implementation stage, based on the lessons learned, on the new scientific and technological development both for the models and monitoring, the design and plan for the next system upgrade is recommended to be done.

All the hydrological models need to be calibrated and validated using observational data and/or reference data derived from observations, and the calibration process is also a continuous periodical process, and sometimes the model parameters could be improved/adjusted even after each important flood event.

Data management components are critical components within a flood forecasting and warning system, and in general are used to support the following main functionalities:

- preprocessing and provision of input data for the hydrological forecasting models;
- implementation of real-time data and products workflows between Flood Forecasting Centres;
- postprocessing of models results and generation of final hydrological forecasting and warning products;
- hydrological forecasting models configuration, calibration and validation;
- supporting forecasters training activities.

When designing the Flood Forecasting and Warning Systems, and especially the data management part, it is recommended to follow a modular, flexible, robust structure approach in order to allow the Hydrological Forecasts Centres to elaborate the official forecasts and warnings under different type of failure scenarios for the data communication, and/or different flood forecasting system components.

In general, in all the countries within Danube River Basin, the existing National Monitoring Stations Networks are able to provide the necessary input data (in term of both spatial and temporal resolution) for hydrological forecasting and warning elaboration in case of fluvial floods events, in medium and large river basins.

However, the actual National Monitoring Networks, could not fully satisfy the observational input data needs for flash floods and pluvial floods forecasting and warning activities. Due to the perspectives of further increase of the frequency of such extremes events as results of the climate changes, the needs for properly monitoring, analysing and forecasting the hydrological processes associated with flash floods events remain a high priority for the scientific hydrological community.

There is no perfect hydrological forecasting model. Both meteorological and hydrological forecasts have associated a certain degree of uncertainty.

In many situations, the forecaster in deep understanding of models' limitations, particularities, model products interpretation and detailed knowledge of the hydrological and/or meteorological processes is more important than the model performance itself.

The quantitative precipitation estimation in real time and the forecasted precipitation are still the main source of errors for hydrological forecasting and warning systems.

The hydrological forecasters are very special users of meteorological forecasts, and they need specific particular products.

The significant increase in the complexity of data management processes, embedded in the National Flood Forecasting and Warning Systems, require for proper maintenance activity the strengthening of the IT support (skilled staff) and the IT capabilities (resources, tools, services) dedicated for flood forecasting, in the individual forecasting services.

Hydrological forecasting systems primarily use data from the observation network, which is maintained by the hydrological service. Data measured and collected by individual water users like hydroelectric power plants, water supply and irrigation systems and other users are not usually included in the forecast system. Therefore, it is recommended to collect all the water regime data in a single database, including data from private companies.

In order to accelerate the general improvement and adoption of new advanced tools on data management related to flood forecasting activities, it is recommended to improve the cooperation among the hydrological services within the Danube River Basin by organising regular expert meetings on flood forecasting.