

# Interreg



## Greece-Bulgaria

### FLOODGUARD

European Regional Development Fund

# Integrated actions for joint coordination and responsiveness to flood risks in the Cross Border area

PP 4: NATIONAL INSTITUTE OF METEOROLOGY AND HYDROLOGY - BULGARIA

## Deliverable 3.4.2

Studies and comparative analyses

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<https://floodguard-interreg.eu/>

# Comparison and assessment of methods and models of flood risk evaluation. Greek and Bulgarian research on flood risk assessment and mitigation

More than 60 scientific papers<sup>1</sup> from Greece and Bulgaria on hydrological problems and flood mitigation were analyzed in following 14 sections:

- **Remote sensing, satellite precipitation products, radar based forecasting**

Remote sensing is the primary source of data for precipitation estimation for Greece as Hellenic National Meteorological Service (HNMS) is equipped with weather radars. Specifically for Evros, Nestos and Strimonas basins are operating weather radars at Xrisoupoli (Kavala), Alexandroupoli and Thessaloniki with range up-to 300 km ([http://emy.gr/emy/en/observation/eikones\\_radar](http://emy.gr/emy/en/observation/eikones_radar)). In addition, a broad use of satellite imagery is exploited specifically for inundation assessment (Fig. 1). Although radars in Bulgaria operated by Agency Hail Suppression (<https://www.weathermod-bg.eu/wr/brd-bg>) are showing precipitation intensity estimation their primary use is hail prevention so they are not operating in winter time neither their precipitation intensity data is calibrated dynamically or compared against measured in-situ rainfall.

- Fotopoulos Ch. Et al., (2011). Validation of satellite rainfall products for operational floodforecasting: the case of the Evros catchment, Theor Appl Climatol (2011) 104:403–414DOI 10.1007/s00704-010-0354-z
- E. Baltas & M. Mimikou (1994) Short-term rainfall forecasting using radar data, International Journal of Water Resources Development, 10:1, 67-77, DOI: 10.1080/07900629408722610
- Tsatsaris, A.; Kalogeropoulos, K.; Stathopoulos, N.; Louka, P.; Tsanakas, K.; Tsesmelis, D.E.; Krassanakis, V.; Petropoulos, G.P.; Pappas, V.; Chalkias, C. Geoinformation Technologies in Support of Environmental Hazards Monitoring under Climate Change: An Extensive Review. ISPRS Int. J. Geo-Inf. 2021, 10, 94. <https://doi.org/10.3390/ijgi10020094>
- T. Perrou, A. Garioud, I. Parcharidis, "Use of Sentinel-1 imagery for flood management in a reservoir-regulated river basin", Frontiers of Earth Science 12(3), pg. 506, (2018); doi:10.1007/s11707-018-0711-2

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<sup>1</sup> Papers in English language were exclusively selected to facilitate readability of the analysis below

- Tsuni A. (2021). Earth Observation assimilation for real time flood monitoring and response [http://beyond-eocenter.eu/images/2021-06-08-EXCELSIOR\\_VIRTUALWORKSHOP2\\_Tsouni\\_Alexia.pdf](http://beyond-eocenter.eu/images/2021-06-08-EXCELSIOR_VIRTUALWORKSHOP2_Tsouni_Alexia.pdf)

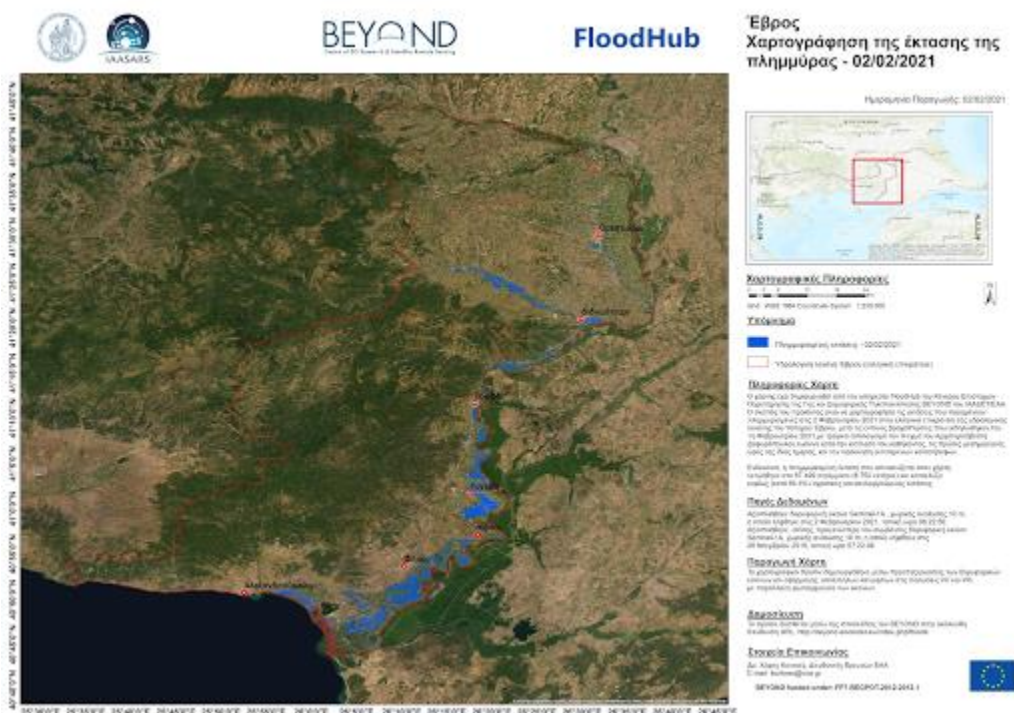


Fig. 1 Picture of Floodhubweb – mapping of flood over Evros basin in Greece (Tsuni A., 2021)

- **Flood hazard mapping, risk assessment and management, decision support**

Development of flood risk management plans under Directive 2007/60/EC are elements of integrated river basin management. For the implementation of Directive 2007/60 / EC, Member States need to carry out a preliminary flood risk assessment based on available or readily derivable information. Based on this flood risk assessment, areas are identified where a potential significant flood risk exist or might be considered likely to occur. As part of a preliminary flood risk assessment, it is necessary to describe floods which have occurred in the past and which had significant adverse impacts on the protected categories "Human Health", "Environment", "Cultural Heritage" and "Economic Activities" and where there is a likelihood of recurrence of similar future events (Ninov & Balabanova, 2021).

- Makakov, Venelin & Velichkova, Rositsa & Simova, Iskra & Markov, Detelin. (2017). FLOODS RISK ASSESSMENT IN BULGARIA. CBU International Conference Proceedings. 5. 1253. 10.12955/cbup.v5.1105.
- Draft Preliminary Flood Risk Assessment for West Aegean River Basin Management District, Executive Summary [https://wabd.bg/content/wp-content/uploads/2021/06/01\\_BG4\\_PFRA\\_Summary\\_eng.pdf](https://wabd.bg/content/wp-content/uploads/2021/06/01_BG4_PFRA_Summary_eng.pdf)
- Updated Draft Preliminary Flood Risk Assessment for East Aegean River Basin Management District Executive Summary [https://earbd.bg/files/File/PURN%20-%202/Project\\_PFRA\\_2021/01\\_PFRA\\_BG3\\_Summary\\_eng.pdf](https://earbd.bg/files/File/PURN%20-%202/Project_PFRA_2021/01_PFRA_BG3_Summary_eng.pdf)
- Julia S. Stoyanova, Christo G. Georgiev, SVAT modelling in support to flood risk assessment in Bulgaria, Atmospheric Research, Volume 123, 2013, Pages 384-399, ISSN 0169-8095, <https://doi.org/10.1016/j.atmosres.2012.07.002>.
- Ninov, P., Balabanova, S., International Multidisciplinary Scientific GeoConference: SGEM; Sofia, Vol. 21, Iss. 3.1, (2021). DOI:10.5593/sgem2021/3.1/s12.12
- FLOOD RISK MANAGEMENT PLAN OF EVROS RIVER BASIN, Executive Summary Version 1 – EN | 5.8.2016, Ministry of Environment and Energy, Special Secretariat for Water <http://thyamis.itia.ntua.gr/egyFloods/gr12/Reports/FRMP%20Evros%20Basin%20-%20Executive%20Summary%20v2.pdf>
- Bojilova, E. K. (2002). Methodology for integrated catastrophic flood-losses risk management. Hydrological study. Preliminary application for Tundja River in Bulgaria. In Proc. 5th Int. Conf. on Hydroinformatics, Cardiff, UK, IWA Publishing and the authors, ISBN 1 84339 021 3 (set), 816 (Vol. 822).
- Diakakis, M., Foumelis, M., Gouliotis, L., Lekkas, E. (2011). Preliminary flood hazard and risk assessment in Western Athens metropolitan area. In: Lambrakis, N., Stournaras, G., Katsanou, K. (eds) Advances in the Research of Aquatic Environment. Environmental Earth Sciences. Springer, Berlin, Heidelberg. [https://doi.org/10.1007/978-3-642-19902-8\\_16](https://doi.org/10.1007/978-3-642-19902-8_16)
- Alamanos, A.; Rolston, A.; Papaioannou, G. Development of a Decision Support System for Sustainable Environmental Management and Stakeholder Engagement. Hydrology 2021, 8, 40. <https://doi.org/10.3390/hydrology8010040>

- **Flood forecasting systems**

Flood forecast systems (FFS) play fundamental role in protection from floods. FFS are built on the top of knowledge about climatological, hydrographic, hydraulic, societal and industrial development and the corresponding risk from flooding of settlements and

infrastructure. Complex FFS (Kontoes et al., 2000) are maintained by professionals as hydrologists and meteorologists and incorporate meteorological forecasts several days ahead (Artinyan et al., 2016) but some light systems are based on simple sensor-level > website-alert triggering.

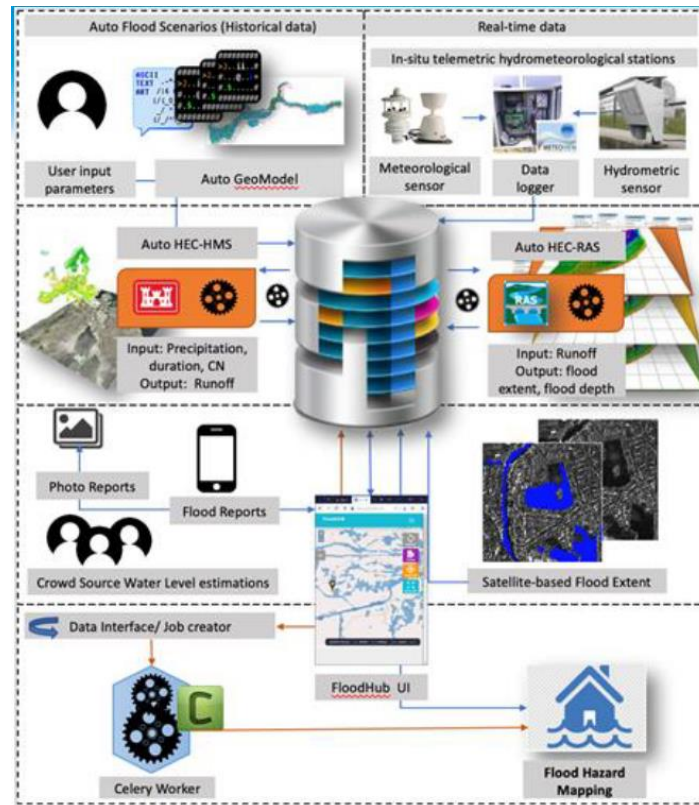


Fig. 2. Architecture of the FloodHUB system: An integrated near-real-time flood monitoring system (Kontoes et al., 2000)

- Haris Kontoes, Alexia Tsouni, Stella Girtsou, The FloodHub and FireHub systems for early warning and crisis management, National Observatory of Athens – IAASARS – BEYOND Center of Excellence MANDRA 2020: Architecture of the FloodHUB system (Fig. 2): An integrated near-real-time flood monitoring system: based on modeling, multi-source EO and crowdsourced data, with a fully scalable and transferable modular architecture, delivering a reliable operational awareness picture of the crisis every 5-15 minutes to all the relevant authorities. [https://www.un-spider.org/sites/default/files/rso-greece-floodhub-firehub\\_0.pdf](https://www.un-spider.org/sites/default/files/rso-greece-floodhub-firehub_0.pdf)
- Maritsa and Tundzha Rivers flood forecast system: Stoyanova, Minka & Artinyan, Eram. (2010). Flood Forecasting and Early Warning System for Maritsa and

Tundzha Rivers-Data Exchange Tool and Web-Site. BALWOIS 2010—Ohrid, Republic of Macedonia —25, 29 May 2010

- ARDAFORECAST: Artinyan, Eram & Vincendon, Beatrice & Kroumova, Kamelia & Nedkov, Nikolai & Tsarev, Petko & Balabanova, Snezhanka & Koshinchanov, Georgy. (2016). Flood forecasting and alert system for Arda River basin. *Journal of Hydrology*. 541. 457-470. [10.1016/j.jhydrol.2016.02.059](https://doi.org/10.1016/j.jhydrol.2016.02.059).
- Giorgos Kochilakis, Dimitris Poursanidis, Nektarios Chrysoulakis, Vassiliki Varella, Vassiliki Kotroni, Giorgos Eftychidis, Kostas Lagouvardos, Chrysoula Papathanasiou, George Karavokyros, Maria Aivazoglou, Christos Makropoulos, Maria Mimikou, A web based DSS for the management of floods and wildfires (FLIRE) in urban and periurban areas, *Environmental Modelling & Software*, Volume 86, 2016, Pages 111-115, ISSN 1364-8152, <https://doi.org/10.1016/j.envsoft.2016.09.016>.

- **Flood protection works, vulnerability assessment**

Flood protection works are so called hard measures consisting of structural changes in the hydraulic conditions in order to mitigate flooding effects. Such works are building of dams, dikes, clearing of river bed from sediments and vegetation, or in case of floods setting up temporary flood barriers. As most of these works are very expensive (<https://climate-adapt.eea.europa.eu/en/metadata/case-studies/european-funds-for-flood-protection-measures-in-smolyan-bulgaria/#websites> ) and require further maintenance in some cases floodplains are used that must be flooded instead, to control the floods amplitude.

- Mitsopoulos, G.; Diakakis, M.; Bloutsos, A.; Lekkas, E.; Baltas, E.; Stamou, A. The Effect of Flood Protection Works on Flood Risk. *Water* 2022, 14, 3936. <https://doi.org/10.3390/w14233936>
- Mitsopoulos, G., Diakakis, M., Panagiotatou, E., Sant, V., Bloutsos, A., Lekkas, E., ... & Stamou, A. I. (2022). “How would an extreme flood have behaved if flood protection works were built?” the case of the disastrous flash flood of November 2017 in Mandra, Attica, Greece. *Urban Water Journal*, 19(9), 911-921.
- Gramatikov, Plamen. (2009). Bulgarian Policy for Water Resources Management and Flood Protection. *10.3233/978-1-58603-948-6-51*.

- **GIS and geo-information technologies**

GIS tools and technologies are key part of hydrological information systems. They are used to represent in clear way the spatial extent of hydrological features as elevation, slope, soil

hydraulic properties, soil erosion, land use, river network at catchment scale. Combining these features (Mentzafou et al., 2018) is an efficient tool to better estimate flood risk and to predict floods (Fig. 3).

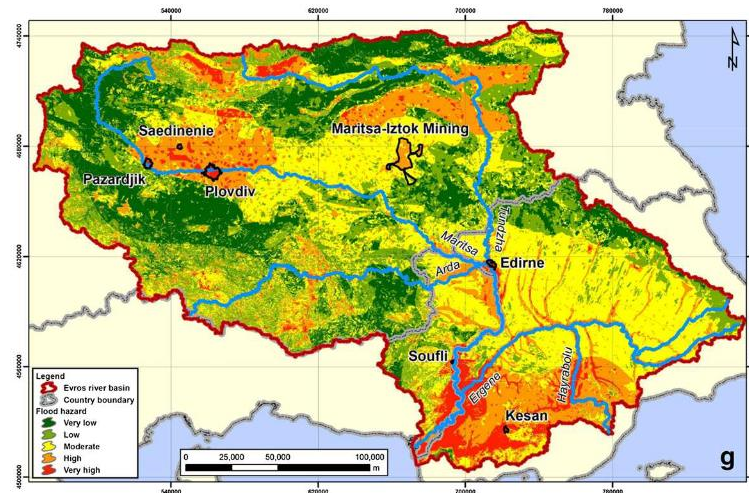


Figure 4

Flood hazard maps of each factor (a: topography, b: slope, c: flow accumulation, d: land use, e: geology, f: rain intensity MFI) and final flood-hazard map for Evros river basin (g)

Fig. 3. Flood hazard map of Evros/Maritsa Basin (Mentzafou et al., 2018)

- Stamellou, E., Kalogeropoulos, K., Stathopoulos, N., Tsesmelis, D. E., Louka, P., Apostolidis, V., & Tsatsaris, A. (2021). A GIS-Cellular Automata-Based Model for Coupling Urban Sprawl and Flood Susceptibility Assessment. *Hydrology*, 8 (4), 159. <https://doi.org/10.3390/hydrology8040159>
- Fotis, M., Georgia, V., & Apostolos, V. (2012, May). Estimation of the prefecture of Evros vulnerability in flood cases using GIS and fuzzy set algebra. In 16th international water technology conference, Istanbul, Turkey (pp. 7-10).
- Perrou, Theodora & Papastergios, Asterios & Parcharidis, Is & Chini, Marco. (2017). Spatiotemporal Hazard Mapping of a flood event "migration" in a Transboundary River Basin as an operational tool in Flood Risk Management. 8. 10.1117/12.2277746.
- Mentzafou, A., Markogianni, V., Dimitriou, E. (2018). The Use of Geospatial Technologies in Flood Hazard Mapping and Assessment: Case Study from River Evros. In: Niedzielski, T., Migala, K. (eds) *Geoinformatics and Atmospheric Science*. Pageoph Topical Volumes. Birkhäuser, Cham. [https://doi.org/10.1007/978-3-319-66092-9\\_12](https://doi.org/10.1007/978-3-319-66092-9_12) (Fig. 3)

- **Hydrology, hydraulics, river routing models of Maritsa \ Evros, and Arda \ Ardas basin**

Knowledge of river hydraulics and river routing is essential to understand how flood is propagated along the watershed. Hydrology solves the water balance in order to compute water available to the river flow (Artinyan et al., 2008). This knowledge is further employed in automation of hydrological forecasting and decision support systems.

- Angelidis, P., Mystakidis, G., Lalikidou, S., Hrisanthou, V. and Kotsovinos, N.(2010) Computation of Hydrographs in Evros River Basin. *European Water*, 31, 33-42.
- Angelidis, Panagiotis & Maris, Fotis & Kopasakis, Kyriakos & Vasileiou, Apostolos & Kotsovinos, Nikolaos. (2018). Overflow Discharges and Flooding Areas from Flood Hydrographs Routing in Arda River, Greece. *Hydrology*. 5. 31. 10.3390/hydrology5030031.
- Artinyan, et al.(2008). Modelling the water budget and the riverflows of the Maritsa basin in Bulgaria. *Hydrology and Earth System Sciences*. 12. 10.5194/hessd-4-475-2007
- Paralska, Katia & Tsarev, Petko & Stefanova, Rositsa & Koshinchanov, Georgy. (2022). ANALYSIS OF HIGH WAVE DURING HYDROLOGICAL EXTREME EVENT ON 10-15 DECEMBER 2021 WITH SIGNIFICANT RAINFALL IN SOUTHERN BULGARIA. 33-40. 10.5593/sgem2022/3.1/s12.04.
- Tsarev, Petko & Artinyan, Eram & David, Cédric. (2021). Assessment of three hydrological routing models coupled to the SURFEX land surface model (ISBA scheme): an example of Varbitsa River basin in Bulgaria. 10.5593/sgem2021/3.1/s12.08.
- Naldzhiyan, Andrey & Tsarev, Petko. (2021). REMOTE MEASUREMENT OF THE RIVER FLOW SURFACE VELOCITY AT HIGH WATER WITH LARGE SCALE PARTICLE IMAGE VELOCIMETRY METHOD. 10.5593/sgem2021/2.1/s10.72.

- **Databases and inventories of floods**

Databases and inventories of flood are prepared in order to assess regional vulnerability to floods and better understanding causes of floods. Often these databases are using GIS technologies and incorporated in flood risk maps ([https://bsdi.asde-bg.org/data/Floods/Dolno\\_Lukovo/pdf/Dolno\\_Lukovo\\_05\\_m.pdf](https://bsdi.asde-bg.org/data/Floods/Dolno_Lukovo/pdf/Dolno_Lukovo_05_m.pdf) ) and flood risk management plans.



Fig.4. Flooding at Evros River, 16.03.2006. The need for an integrated approach in flood risk assessment remains obvious due to the high pressure in land-use (Karagiorgos, et al. ,2013).

- Karagiorgos, K. et al. (2013). A flood hazard database for Greece. *Wildbach- und Lawinenverbau*. 77.Jg.. 264-277. (Fig. 4)
- Diakakis, M., An inventory of flood events in Athens, Greece, during the last 130 years: Seasonality and spatial distribution, *Journal of Flood Risk Management*, 10.1111/jfr3.12053, 2013
- National Data Bank of Hydrological & Meteorological Information, which was assigned to N.T.U.A. by the Ministry of Environment, Planning & Public Works, provides the required infrastructure for the implementation of the E.U. Water Framework Directive for the protection, rational management and exploitation of the water resources in the national level  
<http://ndbhmi.chi.civil.ntua.gr/en/about/general.html> (Fig. 5)

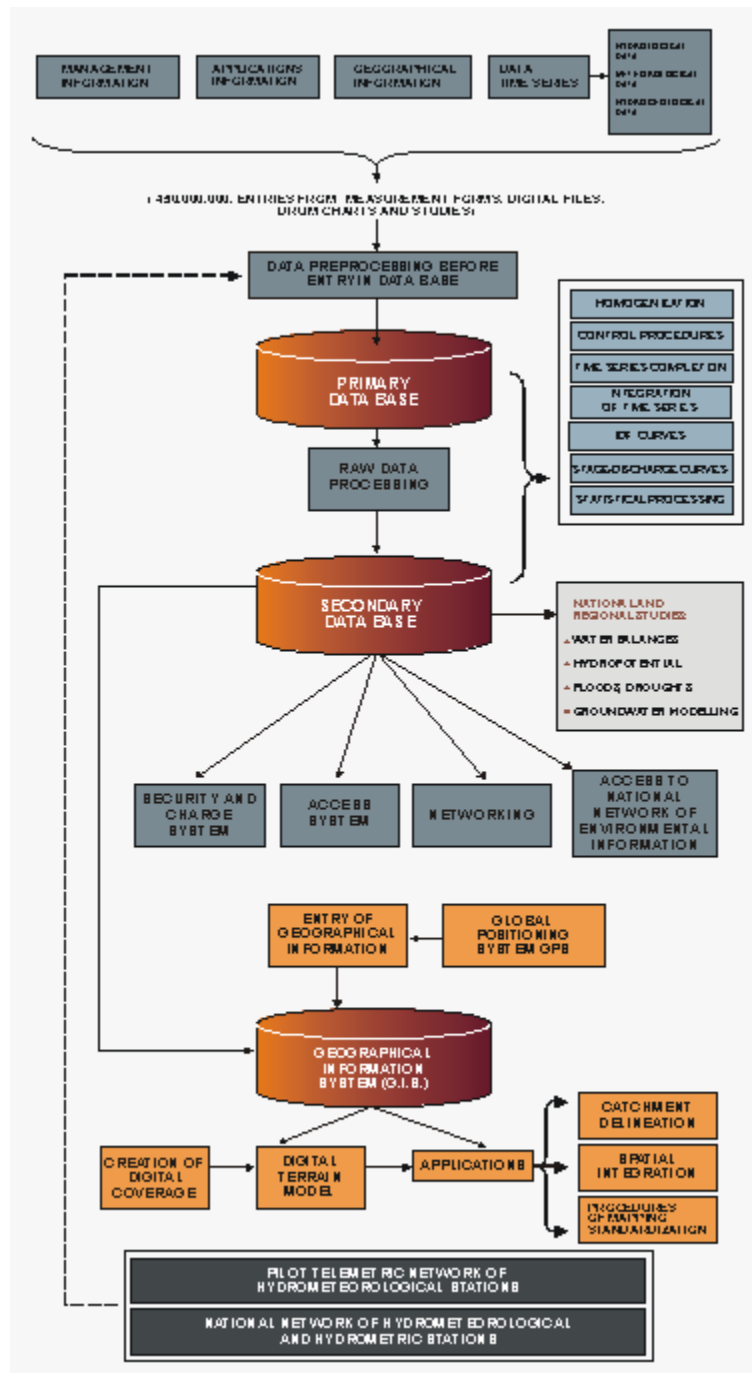


Fig. 5 National monitoring databases in Greece

- **Flash floods risk assessment, management and forecasting**

Among the variety of floods the most dangerous and causing human losses are flash floods. Their frequency is increasing related to climatic changes (Fig. 6) (Diakakis et al., 2022) but in the same time they are the most difficult to predict. Flash floods are often caused by stationary cyclones that create intensive convective precipitation reaching hundreds of mm rain over relatively small river basins. Those events trigger powerful storms and flooding that puts in danger infrastructure, human life, industry and agriculture.

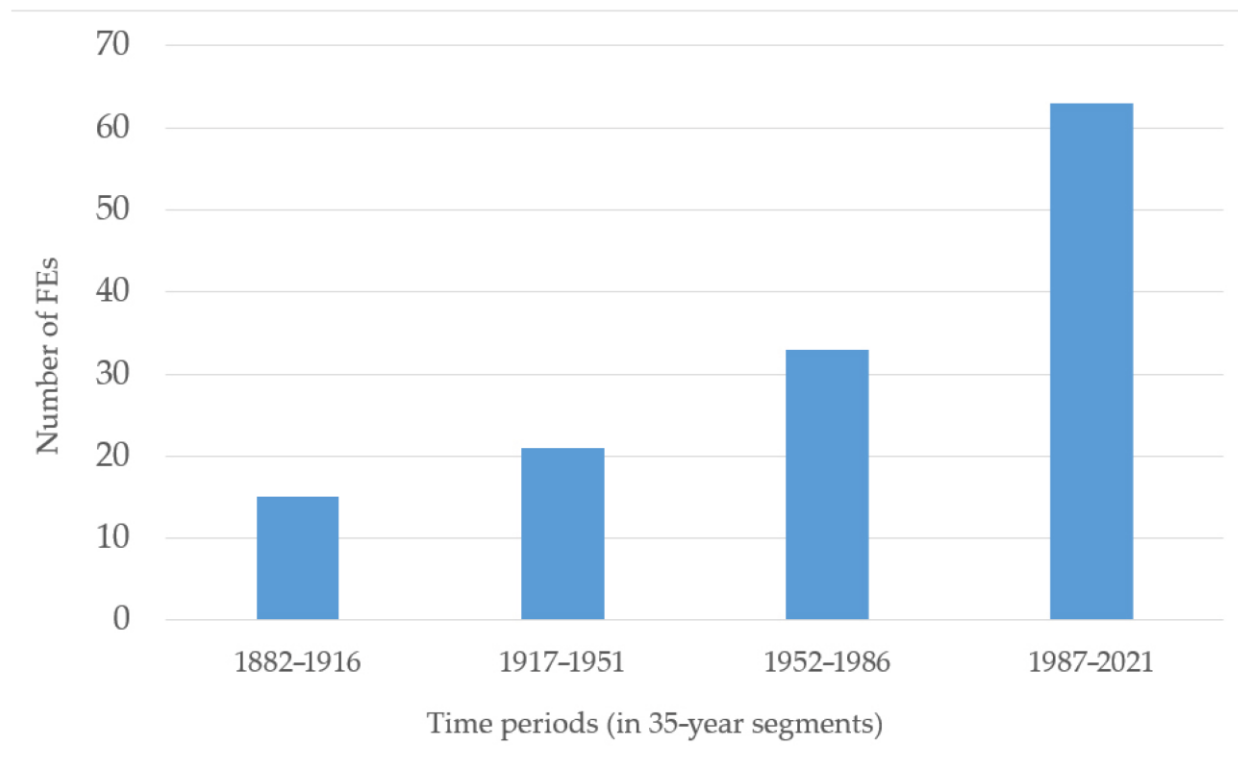


Fig. 6. Number of flash flood events by periods of 35 years for the period 1882-2021 (Diakakis et al., 2022) in Mediterranean region.

- Karagiorgos, K., et al. (2016). Multi-vulnerability analysis for flash flood risk management. *Natural Hazards*. 82. 1-25. 10.1007/s11069-016-2296-y.
- Flash flood forecasting using the Black Sea Middle East Flash Flood Guidance (BSMEFFG) System – [https://www.hrcwater.org/wp-content/uploads/2017/12/FFG-Gazette\\_August\\_2013.pdf](https://www.hrcwater.org/wp-content/uploads/2017/12/FFG-Gazette_August_2013.pdf)
- NIMH – Bulgaria, (2004) STUDY OF HISTORICAL FLOODS IN CENTRAL AND EASTERN EUROPE FROM AN INTEGRATED FLOOD MANAGEMENT VIEWPOINT, BULGARIA, submitted for WMO/GWP Associated Programme on Flood

Management

[https://www.floodmanagement.info/projects/pilot/europe/Flash\\_Flood\\_Bulgaria.pdf](https://www.floodmanagement.info/projects/pilot/europe/Flash_Flood_Bulgaria.pdf)

- Spyrou, C.; Varlas, G.; Pappa, A.; Mentzafou, A.; Katsafados, P.; Papadopoulos, A.; Anagnostou, M.N.; Kalogiros, J. Implementation of a Nowcasting Hydrometeorological System for Studying Flash Flood Events: The Case of Mandra, Greece. *Remote Sens.* 2020, 12, 2784.  
<https://doi.org/10.3390/rs12172784>
  - Varlas, George & Anagnostou, Marios & Spyrou, C. & Papadopoulos, Anastasios & Kalogiros, John & Mentzafou, A. & Michaelides, Silas & Baltas, Evangelos & Karymbalis, Efthimios & Katsafados, P.. (2018). A Multi-Platform Hydrometeorological Analysis of the Flash Flood Event of 15 November 2017 in Attica, Greece. *Remote Sensing.* 11. 45. 10.3390/rs11010045.
  - Diakakis, M., et al. "Proposal of a flash flood impact severity scale for the classification and mapping of flash flood impacts." *Journal of Hydrology* 590 (2020): 125452.
  - Mitsopoulos, G., Panagiotatou, E., Sant, V., Baltas, E., Diakakis, M., Lekkas, E., & Stamou, A. (2022). Optimizing the Performance of Coupled 1D/2D Hydrodynamic Models for Early Warning of Flash Floods. *Water*, 14(15), 2356.
  - Diakakis, Michalis & Papagiannaki, Katerina & Fouskaris, Meletis. (2022). The Occurrence of Catastrophic Multiple-Fatality Flash Floods in the Eastern Mediterranean Region. *Water.* 15. 119. 10.3390/w15010119. (Fig. 6)
- **Social aspects of flood risk**
    - Fuchs, S., Karagiorgos, K., Kitikidou, K., Maris, F., Paparrizos, S., & Thaler, T. (2017). Flood risk perception and adaptation capacity: a contribution to the socio-hydrology debate. *Hydrology and Earth System Sciences*, 21(6), 3183-3198.
    - Diakakis, Michalis, Giorgos Deligiannakis, Emmanouil Andreadakis, Katerina N. Katsetsiadou, Navsika I. Spyrou, and Marilia E. Gogou. "How different surrounding environments influence the characteristics of flash flood-mortality: The case of the 2017 extreme flood in Mandra, Greece." *Journal of Flood Risk Management* 13, no. 3 (2020): e12613.
    - Skouloudis, A.; Tsalis, T.; Nikolaou, I.; Evangelinos, K.; Filho, W.L. Small & medium-sized enterprises, organizational resilience capacity and flash floods: Insights from a literature review. *Sustainability* 2020, 12, 7437
  - **Dam management in relation of flood protection and climate change**

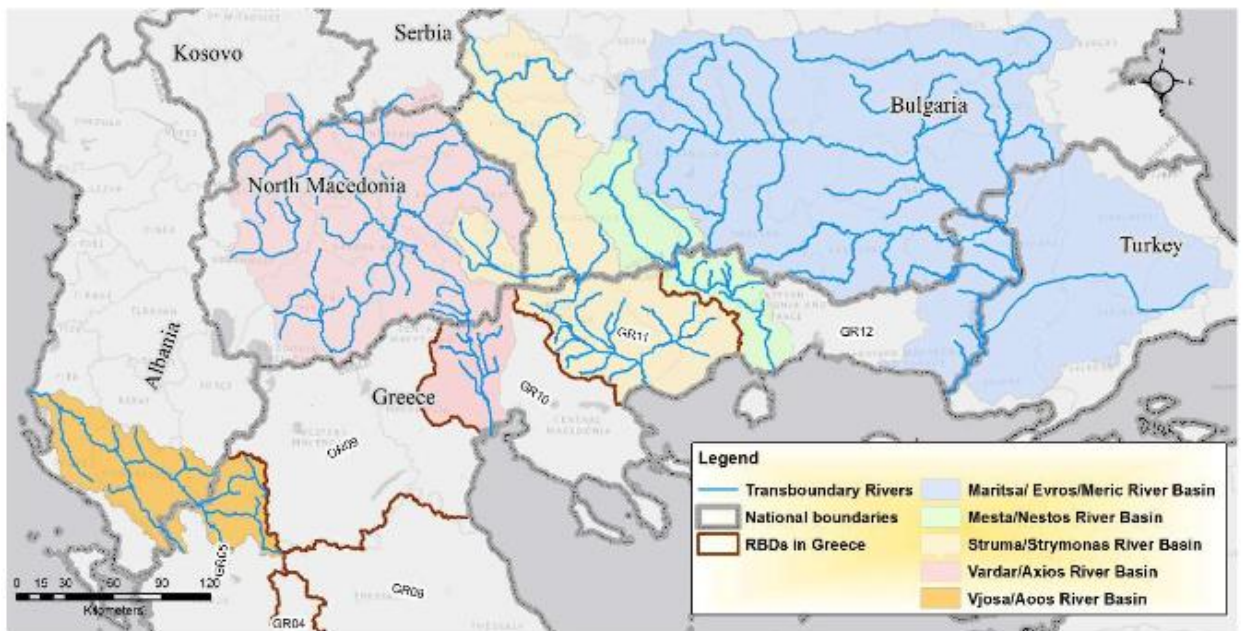
Dam management is essential for the management of floods. Where available dam reservoirs can store large amounts of water in order to mitigate and protect downstream areas. Dam storage is often used in complex energy producing, irrigation and fish farming purposes, so their capacity is only partially available for flood mitigation. Nevertheless well maintained big reservoirs with concrete wall and managed outflow are a strong factor when downstream watershed is in danger of floods (Tsarev et al., 2019). In opposite small unmanaged dams can often be source of problems because their capacity is overwhelmed, dam breaks occur and downstream areas are flooded very fast.

- Angelidis, P., Kotsikas, M., and Kotsovinos, N. (2010): Management of upstream dams and flood protection of the transboundary river Evros/Maritza, *Water Resour. Manag.*, 24, 2467–2484
- Tsarev, P., Artinyan, E., 2017: Reservoirs cascade simulation add-on for riverflow forecasting of Arda and Tundzha Rivers - XXVII Conference of the Danubian Countries 2017 [https://www.danubeconference2017.org/images/e-book\\_full\\_texts\\_dc\\_2017.pdf](https://www.danubeconference2017.org/images/e-book_full_texts_dc_2017.pdf)
- Angelidis, P. , Kotsikas, M. , Kopasakis, K. , Maris, F. and Kotsovinos, N. (2018) Flood Routing Simulation and Management in Hydrologic Basins with Artificial Reservoirs—The Case of Arda River. *Computational Water, Energy, and Environmental Engineering*, 7, 51-68. doi: 10.4236/cweee.2018.72003.
- Tsarev, Petko & Artinyan, Eram & Naldzhiyan, Andrey. (2019). IMPROVEMENTS OF THE HYDROLOGICAL MODELLING, SOFTWARE APPLICATIONS AND DAM OVERFLOW COMPUTING IN ARDAFORECAST PROJECT FOR ARDA RIVER BASIN. Conference: Eighth Bulgarian-Austrian Seminar “Hydrological hazards and related problems”, May 30 – 31, 2019At: UACEG, Sofia, Bulgaria Volume: ANNUAL OF THE UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY SOFIA, 2019, Vol 52, Issue S1

- **Transboundary rivers management under climate change**

River management is often a problem when river basins are covering two or more countries (Fig. 7). Upstream countries are often under pressure in opposite directions: to ensure safety of downstream parts of the basin against floods and to provide enough water for irrigation and industrial application. Therefore it is important to achieve sustainable exploitation of water resources in neighboring states that will ensure both safety and water availability on both sides of the country’s borders.

- Stefanopoulou, D. & Skoulikaris, Charalampos. (2022). Assessment of hydrodiplomacy effectiveness under climate change: The case study of the transboundary river basins of Greece. IOP Conference Series: Earth and Environmental Science. 1123. 012089. 10.1088/1755-1315/1123/1/012089.
- Kolokyhta E. and Skoulikaris C. 2019 Dependencies in transboundary water management in Greece in the face of climate change E-Proc 38 IAHR World Congress (Panama) pp 1466–1474. (Fig. 9)
- Skoulikaris C. 2021 Transboundary Cooperation Through Water Related EU Directives' Implementation Process. The Case of Shared Waters between Bulgaria and Greece. Water Resources Management, 35, 4977–4993.
- Skoulikaris C. and Zafirakou A. 2019 River Basin Management Plans as a tool for sustainable transboundary river basins' management Environ Sci Pollut Res, 26, 14835–14848.



**Figure 1.** Illustration of the transboundary river basins that Greece shares with other riparian [14].

Fig. 7. Transboundary river basin of Greece and neighboring countries (Skoulikaris et al., 2019).

- **Climate change aspects of river runoff, land use change aspects**

One of main results of climate change is the deeply changed way how precipitation is distributed during the year. It is enough well documented that more frequently occurring flash floods are succeeded by long periods of dry weather. The flash floods and long periods of dry weather are both harmful for the human life and the country economy. Although climate change analysis results are indicative they show possible reduction of yearly streamflow discharge for East-Aegean River basin in Bulgaria up-to 16%. (Fig. 8)

- Maria Mimikou, et al. (1991). Regional hydrological effects of climate change, *Journal of Hydrology*, Volume 123, Issues 1–2, 1991, ISSN 0022-169
- Paparrizos, S., Maris, F. and Matzarakis, A. (2016) Integrated Analysis and Mapping of Present and Future Responses of Precipitation over Selected Greek Areas with Different Climate Conditions. *Atmospheric Research*, 169, 199-208. <https://doi.org/10.1016/j.atmosres.2015.10.004>
- Artinyan, Eram & Tsarev, Petko & Kroumova, Kamelia. (2021). Variations of the yearly runoff in Bulgaria up to the end of 21st century at the basis of three climatic scenarios, *Bul. J. Meteo & Hydro*, 25/1 (2021), ISSN 2535-0595. 25.
- Alexandrov V and Genev M 2003 Climate variability and change impact on water resources in Bulgaria *European Water*, 1(2), 25-30.
- Chang H, Knight C G, Staneva M P and Kostov D 2002 Water resource impacts of climate change in southwestern Bulgaria *GeoJournal*, 57(3), 159–168
- Davidovski I, Atanassova M and Simeonov V 2009 Assessment of climate impact on the transboundary Struma River flow in Bulgarian territory using integral indices. *Ecological Chemistry and Engineering. A*, 16(3), 181–200
- Niagolov I et al 2012 Analysis of climate change impact on water resources in the Struma river Basin *Proc. Int. Conf. BALWOIS (Ohrid)*
- Panagiotatou, E., & Stamou, A. (2022). Mathematical Modelling of Nature-Based Solutions for flood risk reduction under Climate Change conditions. In 7th IAHR Europe Congress: Innovative Water Management in a Changing Climate. Athens, Greece, September 7-9, 2022. (pp. Session-FDCC).

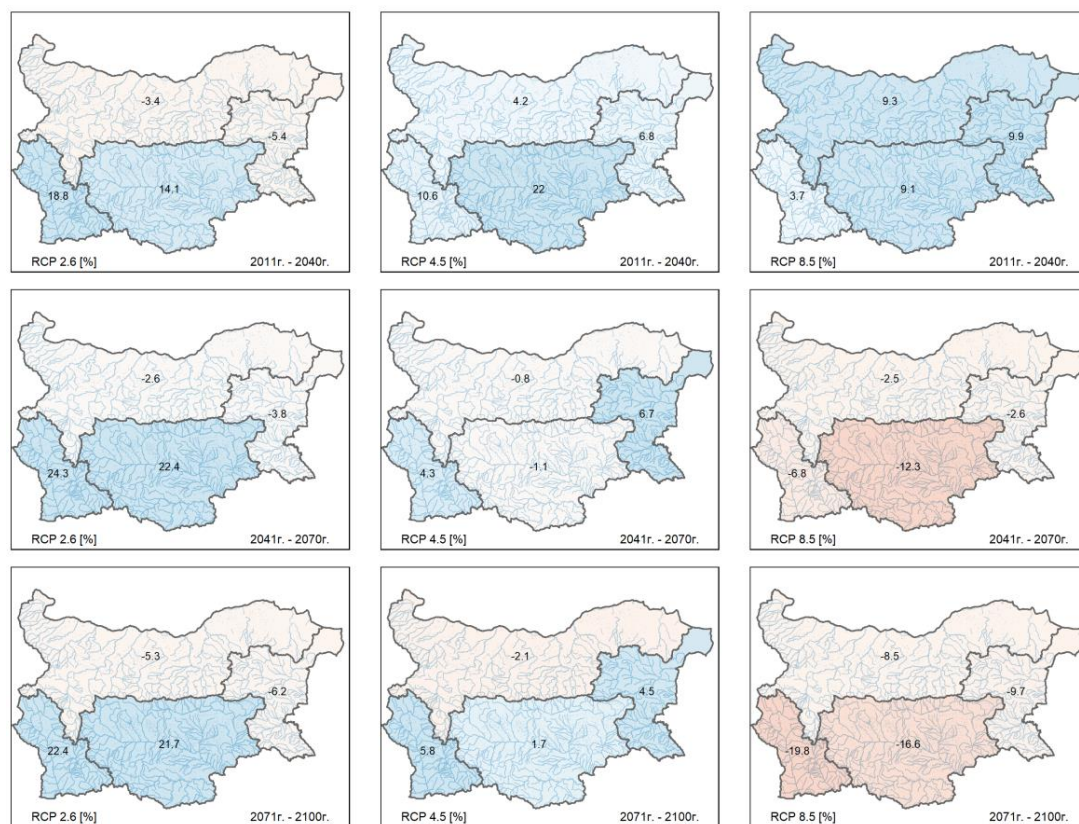


Fig. 8. Maps of relative change of the multiannual average runoff in the four main river basin districts, for the three 30 year periods 2011-2040, 2041-2070 and 2071-2100 in [%] compared to the reference 2071 – 2000. At the left: relative change for RCP 2.6; in the middle – for RCP 4.5 and to the right for RCP 8.5.

- Stefanopoulou, D & Skoulikaris, Charalampos. (2022). Assessment of hydrodiplomacy effectiveness under climate change: The case study of the transboundary river basins of Greece. IOP Conference Series: Earth and Environmental Science. 1123. 012089. 10.1088/1755-1315/1123/1/012089.
- Stamou, A., Mitsopoulos, G., & Baltas, E. (2022). Identification of the weak points in the application of a methodology for the design of Flood Early Warning Systems in Climate Change Conditions–The case of the town of Mandra, Attica, Greece. In 7th IAHR Europe Congress: Innovative Water Management in a Changing Climate. Athens, Greece, September 7-9, 2022. (pp. Session-FDCC).
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- **Emerging technologies in flood protection**

New technologies incorporated in flood forecasting systems can create promising tools for flood warning and mitigation. Such technologies are the use of GNSS (Fig .9) and Earth Magnetic Field to assess water availability in the atmosphere and in the Earth.

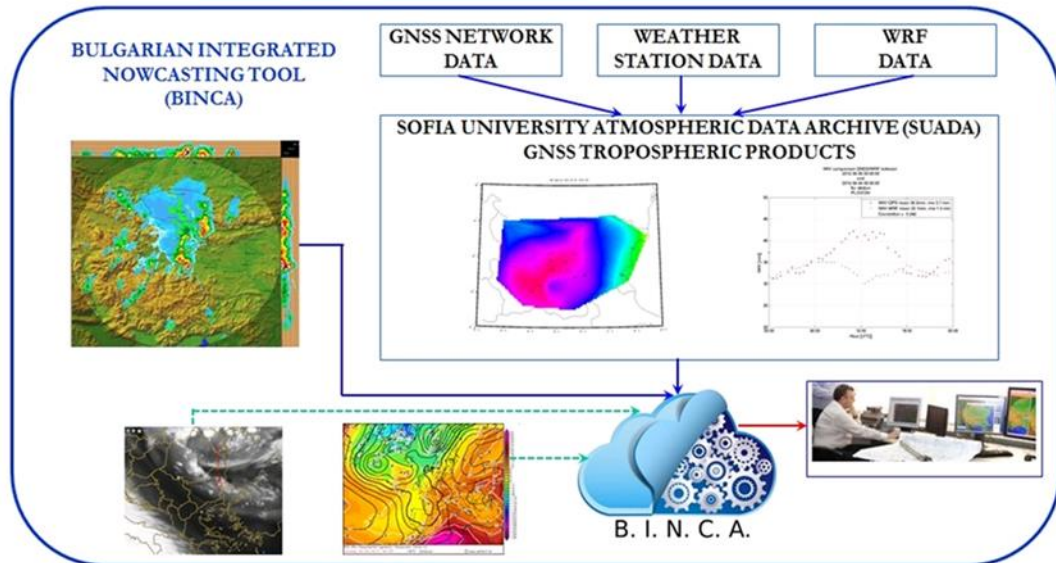


Fig.9. BINCA system: Bulgarian Integrated NowCasting tool (BINCA)

- Bulgarian Integrated NowCasting tool (BINCA) (Fig.9) <https://iabg.government.bg/index.php?nid=13> based on Global Navigation Satellite System (GNSS)
- Guerova G, Douša J, Dimitrova T, Stoycheva A, Václavovic P, Penov N. GNSS Storm Nowcasting Demonstrator for Bulgaria. Remote Sensing. 2022; 14(15):3746. <https://doi.org/10.3390/rs14153746>

- **Sediments, water pollution in Evros and Arda**

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# Report on existing hydrological technologies - technical preparation

## 1.1. General notes about the need of hydrological measures, models and forecasting

Measures to reduce the impact of river floods on life and economic activities and to limit damage include floodplain activities. These include land use regulation, levee protection, and flood forecasting and short to medium term flood warnings

To reduce damage from flash floods, apart from ultra-short-term "nowcasting" warning systems involving meteorological radars, unpopular and expensive local measures are needed, such as banning economic activity near natural drainage routes including dry gullies, construction of drainage ditches and shafts at the end of the forest roads at the entrance to the settlement, carrying out only sanitary felling to strengthen the forests, removing dead stems and logs from the slopes above settlements, raising the elevation of bridges and road network in the most endangered settlements .

### Flood forecasting

Flood forecasting allows society to ascertain the future states of hydrological phenomena, when a river may flood its flood plain, to what extent and for how long. Flood forecasts formulated and issued with sufficient advance allow authorities to respond in time: to check operating dams; regulation of prison authorities; anticipatory actions to increase the free capacity of water reservoirs; issuing preventive instructions, such as bans on shipping and fishing; taking emergency measures, such as raising alarms; evacuating and providing assistance to the population in high-risk areas or carrying out planned dike breaches. It is essential for the development and operation of flood forecasting and warning systems that they have sufficient advance to predict the expected extent and duration of flooding. Flood forecasting involves continuous monitoring of information system performance regardless of frequency of use.

Purpose of flood forecasting – to provide time for:

- inspection of operating dams;
- regulation of prison authorities;
- anticipatory actions to increase the free capacity of water reservoirs;
- issuing preventive instructions, such as bans on shipping and fishing;
- taking emergency measures, such as raising alarms;
- evacuating and providing assistance to the population in high-risk areas or carrying out planned dike breaches

Of utmost importance is the formulation of the forecast, its dissemination to the users or interested public as a warning transmitted by telephone, radio/wireless/television bulletins,

telegrams, e-mail and other systems and media for which a robust and well-maintained communication system is required.

A hydrological forecast is an assessment of the future states of hydrological phenomena. They are important for the efficient functioning of water infrastructure and the mitigation of natural disasters such as floods and droughts. In addition, they are becoming increasingly important in supporting integrated water resources management and reducing flood losses. Describing and predicting future states of a water resource can be categorized based on how far into the future the event is expected to occur. A forecast of various hydrological elements such as wave volume and speed can be made from the very beginning of the forecast to various points in the future.

### Operational forecast

A regular hydrologic forecasting service is composed of trained hydrologic forecasters working with a combination of real-time and historical data, which may include the use of radar and satellite data, communications hardware and software, hydrologic modeling systems, weather models and their data and computer hardware. There are many ways to configure a hydrological forecast service. However, there are a critical number of factors that are necessary to provide a reliable service that meets the needs of a diverse user community. The Hydrological Forecast Operational Concept defines how the operational forecast service will operate continuously.

The primary users of warning products are national, regional, and local government emergency or civil defense organizations, the media, agriculture, industry, hydropower organizations, water supply organizations, and the public. The requirements for hydrologic data, forecast products, and warnings vary depending on the purpose of the user community. This is essential for the hydrologist to understand user requirements so that data and forecast products can be tailored to meet their needs. There are many segments of the national economy, such as transportation, emergency management, agriculture, energy, and water supply that have unique needs for such information. Recognizing these needs and providing data, warnings, and products that meet them ensures that hydrologic forecasting is of greatest benefit to the community.

The following classification applies:

- ultra-short-term - a few hours ahead
- short-term hydrological forecasts covering a period of up to three days;
- medium-term hydrological forecasts, which apply for a period of 3 to 10 days;
- long-term hydrological forecasts that refer to a period of more than 10 days.

An operational hydrological forecast covers the following points:

- mission and legal framework of the organization;
- a list of users and required products or services;
- distribution deadlines;
- how the hydrological forecasting service is organized;

- how the network of hydrometeorological stations and data collection works;
- how the hydrologist will interact with weather forecasters;
- used communications hardware and software to receive data and information and disseminate forecasts;
- how predictive products are produced;
- what policies and rules in the standard operating procedure will be followed to ensure best practices in routine and emergency situations;
- providing coverage of hydrological forecasting through education to policy makers, emergency personnel and the general public.

Today's hydrologic forecasting systems are an affordable and powerful tool. The degree of success in using these systems generally depends on the training received by hydrologists. These systems are capable of producing flood forecasts that range from a few hours ahead to seasonal probabilistic forecasts for larger river basins. Creating a viable hydrological forecast and warning procedure requires a combination of meteorological and hydrological data, forecasting tools and trained forecasters. Such a program must provide sufficient response time. In the event of a flood forecast, advance notice can be critical in reducing damage and loss of life. Predictions must be accurate enough to promote confidence so that users take effective action when alerted. If the forecasts are inaccurate, the credibility is reduced and, accordingly, the confidence in the forecasts is also reduced.

The interaction of the technological components of a complete integrated hydrological forecasting system can be represented as a chain composed of many links. Each link must be fully functional to benefit the user group or population at risk. If just one link doesn't function properly, the whole system falls apart. In other words, if a perfect flood forecast is generated but it does not reach the population at risk or there is no capacity to take preventive action, then the forecasting system is not serving the desired purpose.

#### Comprehensive hydrological forecasting systems

An end-to-end hydrological forecast and response system consists of the following steps that must be linked to achieve flood loss reduction:

- Data collection and communication;
- Hydrological forecast and forecast product generation;
- Dissemination of forecasts to users;
- Decision making and assistance;
- Actions taken by users.

Sample products should be readily available to potential customers. The mission and legal framework of the hydrological forecasting service should be clearly defined. It is important that the official of a specific department as a source of forecasts and warnings is authorized by law. Multiple sources of forecasts can lead to conflicting information that creates confusion and reduces the ability to respond effectively.

#### Types of numerical models for hydrological forecasting

- Black box models - self-learning neural networks
- Conceptual models – precipitation – runoff
- Distributed models – and for flash floods
- Hydraulic models, levels and velocities are calculated
- 2 D models, flood area is calculated

#### **1.2. Assessment of the existing bases for flood forecasting in Bulgaria**

- **Early warning system for the Maritsa River and Tunzha River watersheds**  
<https://maritsa.meteo.bg>

The official name of the project is "Technical Assistance for Flood Forecasting and Early Warning System for the Maritsa and Tunja Watershed". It was implemented by an international consortium with a Mike 11 type rainfall-runoff hydrological model (NAM) and hydrodynamic model (HD). The system was completed in 2009 with funding from the PHARE programme. The water levels of the rivers in 15 settlements in the Maritsa river basin and 6 settlements in the Tunzha river basin are forecast for up to 5 days ahead with a step of 1 hour. The system is used by the Ministry of Environment and Water (MoEW), civil protection, regional and municipal administrations, and by neighboring countries in the Maritsa river basin, Turkey and Greece. For the operation of the HD models, multiple profiles were captured in the main course of the rivers during the operation of the system.

## Processes that can be simulated by MIKE11

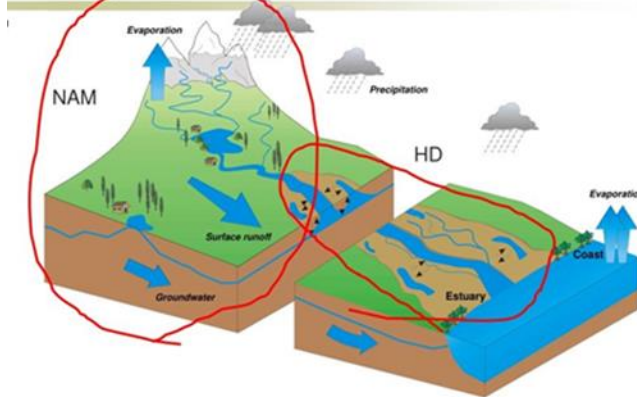


Fig. 10 Schematic diagram of DHI models – NAM and HD

As a side project, 12 telemetry stations for water level and precipitation and 17 stations for precipitation, air temperature and humidity, solar radiation and snow weight were purchased and installed, the data from which feed the operation of the NAM models (Fig. 10), the forecasting software Mike11 FLOODWATCH, a dual-processor database server and workstation.

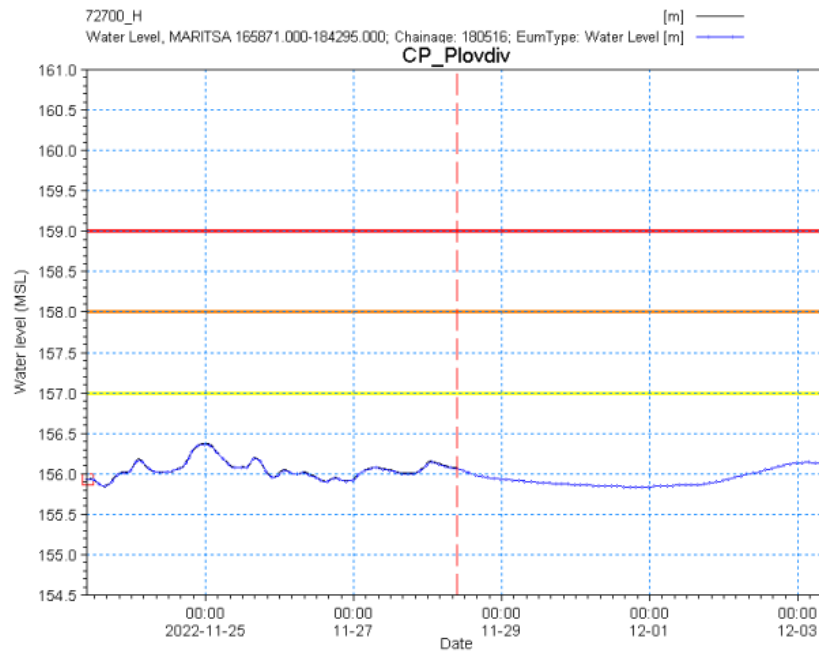


Fig. 11 Forecast of the Maritsa River levels in Plovdiv for the next 5 days

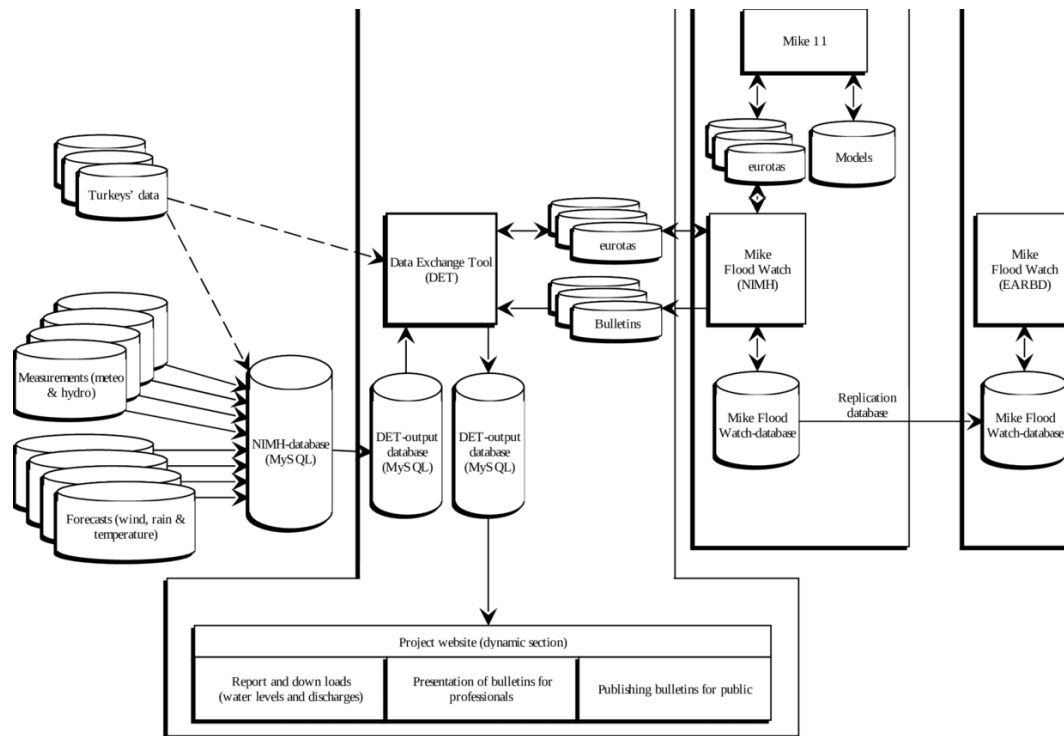


Fig. 12. Data flow and databases of Maritsa-Tundzha forecasting system

#### ARDAFORECAST Flood Early Warning System

ARDAFORECAST: The system was built independently by NIMH in 2012-2014 within the framework of a Bulgarian-Greek project with the official name "Establishment in the Arda River Basin Flood Warning System to Minimize the Risk in the Transboundary Region". The system uses SURFEX-TOP developed by the French National Center for Meteorological Research - CNRM to Meteo – France: SURFEX - TOP and the source code of the FORTRAN language is freely accessible. Real-time input data is provided by over 15 rain gauge and 16 hydrological stations, one of which we lost on December 12, 2021 along with the pedestrian bridge to the village of Kitnitsa in the tail of the Karzhali Dam. Forecast weather data comes from ALADIN - BG and ECMWF. The model time step is 3 hours and the lead time is 5 days. Water quantities in  $m^3/s$  are predicted for 19 points near settlements in Bulgaria and one point on the border with Greece, including the retention influence and possible overflow of the dams from the Arda cascade. The forecast is published every 12 hours (Fig. 13) on the website <https://arda.hydro.bg>

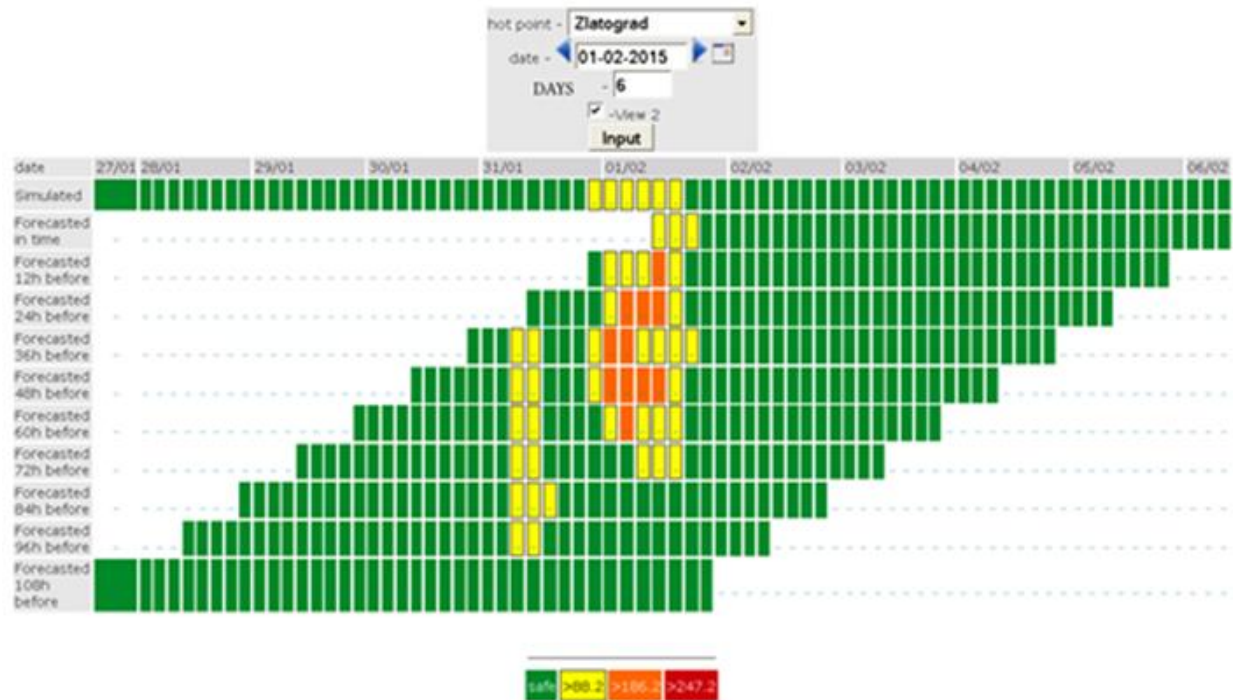


Fig. 13 Runoff forecast with step 3 h for 5 days ahead

- **River basins in Northern Bulgaria and the Black Sea basin: Yantra, Ogosta, Rusenski Lom, Iskar, Aitoska River and Fakiyska River**

For these basins at NIMH, 7 separate forecasting systems (Fig. 14) have been developed, based on various conceptual models, including those with the participation of neural networks. Forecasts are issued in the form of a daily bulletin in the form of a PDF file for each stream for three days ahead, indicating the crossing of a certain warning threshold. <https://hydro.bg>

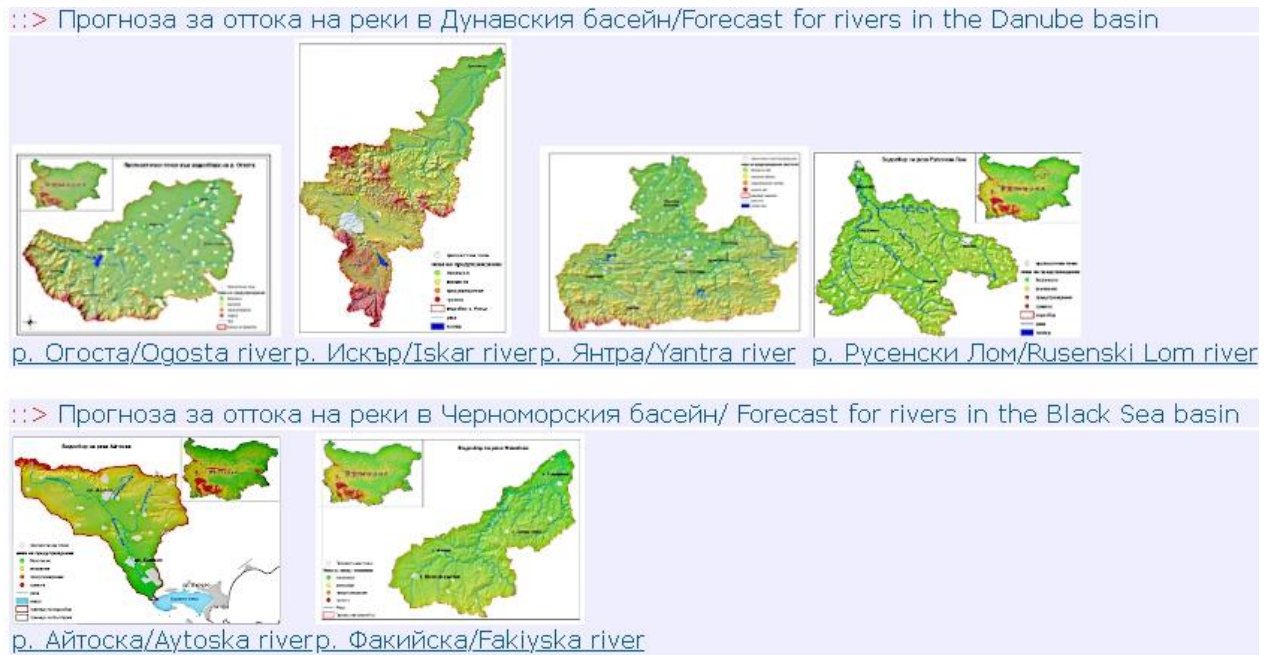


Fig. 14 Forecasting systems for rivers in northern Bulgaria

- **FLASH FLOOD FORECASTING SYSTEM IN USE FOR THE BLACK SEA REGION**

Flash flood forecasting systems - the Black Sea forecasting system has been implemented in Bulgaria and Middle East Flash Flood Guidance (BSMEFFG) which uses data on soil moisture, recent rainfall and forecast rainfall to calculate a flash flood hazard index. In addition, NIMH has the possibility to use the product of ECMWF – ERIC (EFAS Runoff indicator)

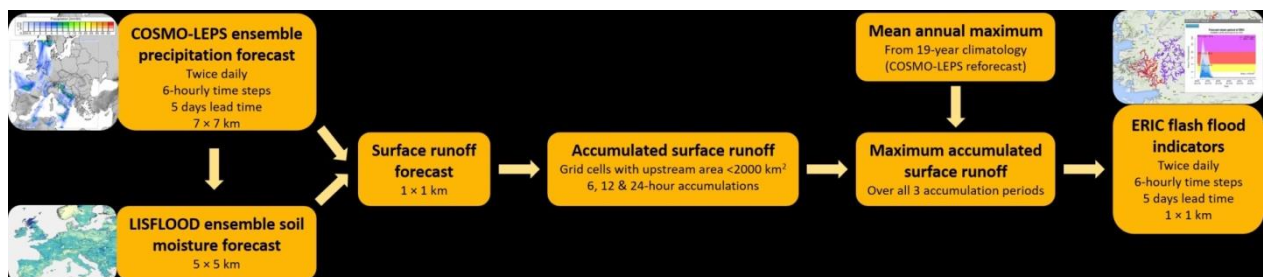


Fig. 15 Schematic of ERIC operation and sample output

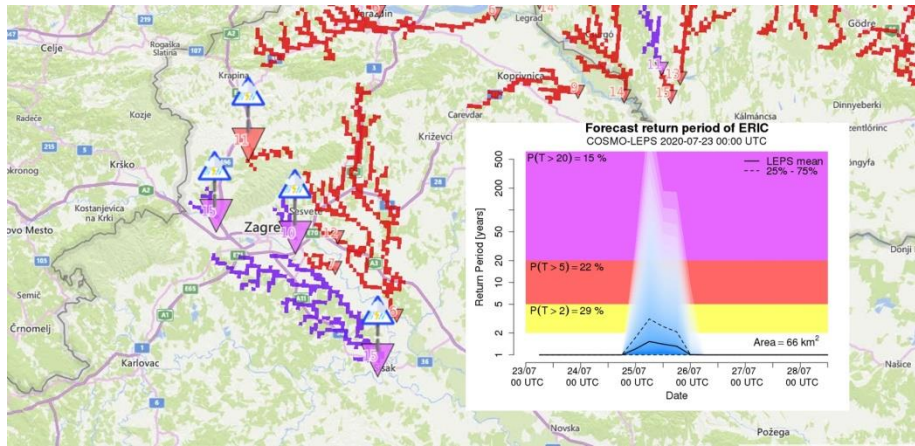


Fig. 16. Output of the operation of ERIC forecasting system