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FLIRE DSS: A web tool for the management of floods and wildfires in urban and periurban areas

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Abstract: A web-based Decision Support System, named FLIRE DSS, for combined forest fire control and planning as well as flood risk management, has been developed and is presented in this paper. State of the art tools and models have been used in order to enable Civil Protection agencies and local stakeholders to take advantage of the web based DSS without the need of local installation of complex software and their maintenance. Civil protection agencies can predict the behavior of a fire event using real time data and in such a way plan its efficient elimination. Also, during dry periods, agencies can implement "*what-if*" scenarios for areas that are prone to fire and thus have available plans for forest fire management in case such scenarios occur. Flood services include flood maps and flood-related warnings and become available to relevant authorities for visualization and further analysis on a daily basis. When flood warnings are issued, relevant authorities may proceed to efficient evacuation planning for the areas that are likely to flood and thus save human lives. Real-time weather data from ground stations provide the necessary inputs for the calculation of the fire model in real-time, and a high resolution weather forecast grid supports flood modeling as well as the development of "*what-if*" scenarios for the fire modeling. All these can be accessed by various computer sources including PC, laptop, Smartphone and tablet either by normal network connection or by using 3G and 4G cellular network. The latter is important for the accessibility of the FLIRE DSS during firefighting or rescue operations during flood events. All these methods and tools provide the end users with the necessary information to design an operational plan for the elimination of the fire events and the efficient management of the flood events in almost real time. Concluding, the FLIRE DSS can be easily transferred to other areas with similar characteristics due to its robust architecture and its flexibility.

Keywords: DSS System; on-line simulation; fire; flood; natural disaster

1 Introduction

A Decision Support System is a computer-based information system which has the efficiency to support business or organizational decision-making activities. In this environment, the computer is the "silent partner" as the key factor, responsible for engagement of the computers in the decision-making process. Through the computers, the information is treated as the sixth resource besides the machines, the money, the people, the materials and the management [1]. Such systems can provide services for the planning, operation and management of an organization in order to aid decision making. Thus, DSS introduces multiple interdisciplinary aspects into the planning process in complex decision environments by adding the geospatial domain [2]. The basis of such systems is the Geographic Information System (GIS) that includes data management, graphic display, spatial modeling and spa-

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tial analysis functions. Across these common GIS decision utilities, special features may also be included like model optimization as well as statistical and spatial interaction functions [3]. The fundamental components of a DSS are the database or the database management system (DBMS), the model (the decision context and user criteria) or the model based management system (MBMS) and the user interface, which is usually a standalone software on a personal computer (PC) or nowadays, a web - based Graphical User Interface (GUI) which is accessible via any web browser from any platform [4]. The revolution in communication networks (3G, 4G cellular networks) and digital media (smartphones, tablets) has changed the original concept of modules implemented within Commercial-Off-The-Shelf (COTS) software or closed software which includes all the components of a system. Yet the elements of a system can be distributed in components in different geographic remote locations and by implementing this architecture, the use of iconic structures is apparent. This allows the use of models and information from their original storage devices (hardware), reducing expenses for data capture and analysis, integration and management. Web-based DSS systems remain less common, especially in the field of natural disaster management, while the World Wide Web technologies can provide integrated platforms for the design, development, implementation and deployment of such Decision Support Systems. Current systems provide the end users with a broad range of capabilities and decision tasks, including information gathering and analysis, model building, sensitivity analysis, collaboration, decision implementation, spatial analysis and spatial visualization [5]. Also, by using the web-based approach, DSS systems become more flexible as all the components of the system are located on the web, distributed in different locations, while the calculations for the outputs and the results of the models are running "on the fly". Therefore, the models have been designed with optimizations in order to provide real time information. Thus, the information provided to the person responsible for the confrontation of natural disasters will be available in a manner of real-time response. DSS are popular in several fields like water resources management [6], renewable resources management [7], environmental management [8], fire management [9, 10]) and flood management [11]. Moreover, the application of a DSS is considered vital in the areas of fire and flood management where the early detection of the ignition of the fire or the early warning of a flood event is crucial for the protection of human lives, properties and assets. Forest fires and flash floods has be classified among the most destructive natural disasters, the occurrence of which is related with severe socioeconomic impacts, including loss of human lives, health and quality of life degradation, loss of private and public property and destruction of economic activities. At the European level, flood events are the most frequently reported natural disasters, affecting 25% more people than any other type of natural disaster [12] while Price *et al.* [13, 14] recognised that flash floods are among the costliest natural hazards around the globe and used lightning data to better understand and predict flash floods in the Mediterranean. Papagiannaki *et al.* [15] presented a database which includes the weather events that have high-impact in Greece during 2001-2011. They found out that almost the half of the weather events were the flash floods. These constitute the most frequent type of the examined phenomena during this decade. From 51 prefectures of Greece, Attica was among the more often influenced areas, mostly from flash floods. Regarding the seasonality of flash floods, autumn in Greece is actually the season with the higher frequency of rainfall and the highest accumulated rainfall, particularly in the mainland [16–19]. As well, economic damages resulting from wildfires (*i.e.*, the reduced ability of a burnt forest to offer recreation opportunities) are also significant, especially in Mediterranean regions, where their frequency is considerably high. This ecological degradation becomes even more severe in the case of combined action, *i.e.* a flood event becomes more probable and more catastrophic when occurring in a formerly forested area that has been devastated by wildfire. The occurrence and the extent of both natural disasters strongly depend not only on the existing weather conditions in an area, but also on human intervention, which is particularly pronounced in peri-urban areas and can magnify the environmental impact. Typically, these phenomena have been investigated separately, with different systems collecting information and modeling the resulting risk. This approach overlooks two significant facts:

- The field data required in both cases are essentially the same, and hence a "*collect once – use for many purposes*" paradigm can be adopted resulting in increased accuracy and economies and,
- The phenomena are tightly interrelated, with forest fires exacerbating the risk of flooding and preceding floods drastically reducing the risk of fires.

This implies that a combined approach to manage flood and fire risk would achieve better, more realistic results at a decreased cost and thus have considerable added value beyond current practice. The fact that end-users, in the form of emergency services (*e.g.* civil protection) are more often the recipients of both warnings only strength-

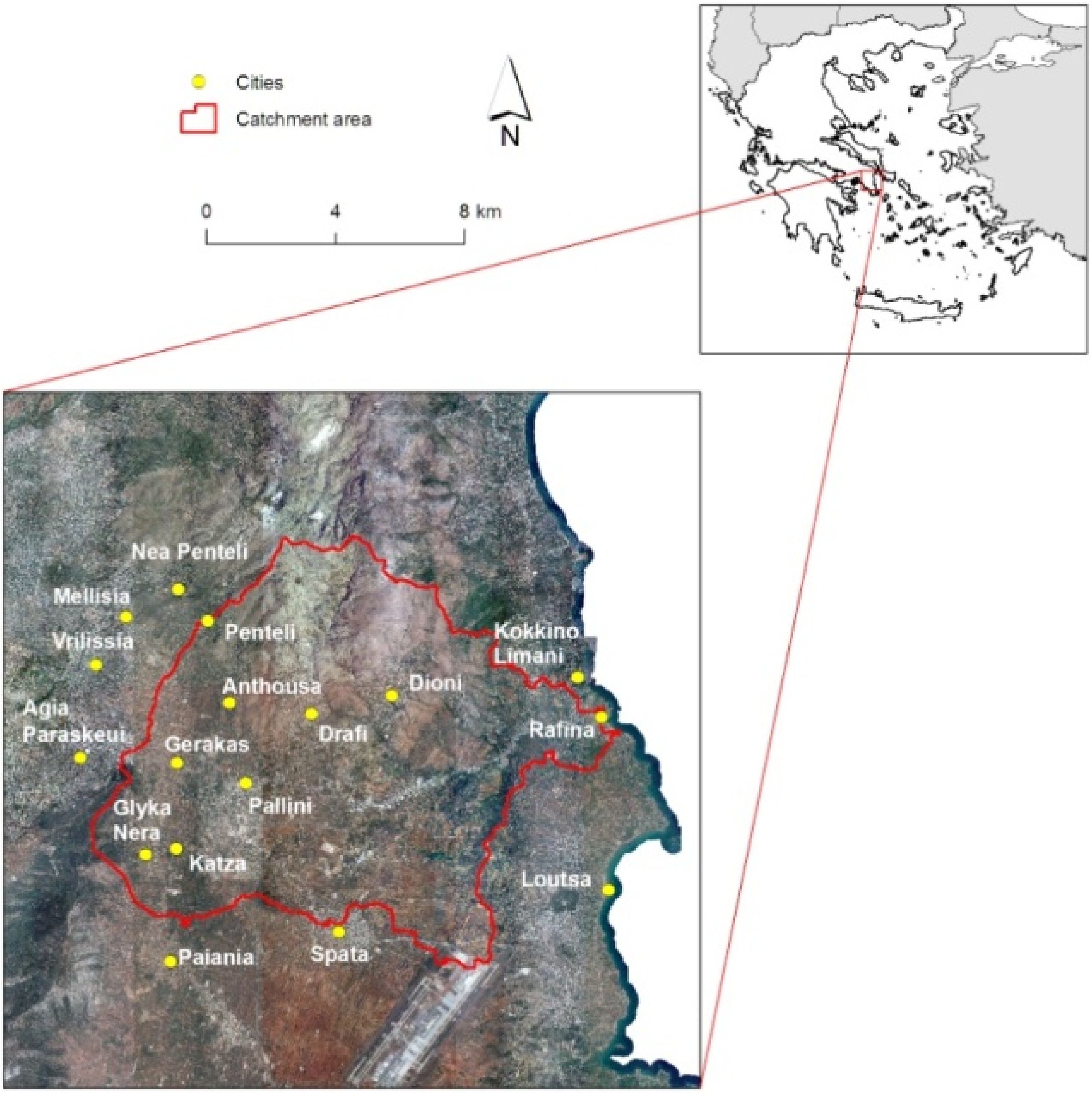

Figure 1: The boundaries of Rafina catchment.

ens the case for a combined risk assessment and management.

The aim of the FLIRE DSS system is to change the paradigm for the coupled, effectual and strong risk assessment and management of both flash floods and forest fires. This will be achieved by using state of art tools, technologies and methods, taking into account prevention, adjustments and interaction issues. Meanwhile this system is based and built on the platform of the World Wide Web.

2 Project area and datasets

The project area located in the hydrological runoff basin of Rafina, a suburban area with an extent of 123 km^2, in the region of Attika, Greece. It is a typical Mediterranean area with mixed land uses. The area has been subjected to a fast and unregulated urbanization in the last decade. It is close to "Eleftherios Venizelos" Athens International Airport, as well as to the A6 highway (Attiki Odos) (Figure 1). A6 highway connects the project area with Athens city, favoring urban sprawl [20]. Seasonal crops, sparse cultivations of vineyards and olive trees characterize the vegetation in the southern part of the project area. Low vegetation plateau can be found at the northern part of the area. Rill networks, which host riparian vegetation and pine forests, are tracked at its western and eastern part. Some small patches of pine forests can be spotted between the buildup areas, mainly in the margins of the towns. Given that its vegetation is particularly flammable, the area is prone to wildfires. The northern hills have been affected by consecutive wildfires that have burnt the natural vegetation repetitively in the last decade. Due to the lack of natural vegetation as well as the extended urbanization in the area, strong rainfalls have turned into flash floods with catastrophic reverberations to the citizens' lives and properties, especially those properties located on the banks of the seasonal creeks. In addition, the fact that the study area is apt to forest fires and flash floods results in its gradual but dire ecological degradation. These areas have been traditionally used by the citizens of Athens for recreation activities including swimming, fishing, trekking and contact with the nature. The degradation of the environment causes significant decline to these activities.

An extended network of meteorological and hydrological stations equipped with state-of-the-art sensors exists in the area. Since 2005, the Laboratory of Hydrology and Water Resources Management of the National Technical University of Athens (NTUA) operates a network of fully automatic hydrometeorological stations that covers adequately the greater Athens area (Hydrological Observatory of Athens – HOA, [21]). Meteorological datasets are complemented by measurements from the dense meteorological network operated in the greater area by the National Observatory of Athens (NOA), as well as weather forecasts for the area, also provided by NOA [19]. Extended fieldwork has been done to collect field data for the preparation of the base data like the updated landcover dataset [22].

3 The FLIRE DSS System

FLIRE DSS is the web based decision support system (web-DSS) for integrated weather information management, forest fire management and floods information management. It uses service-orientation architecture (SOA) and is based on IT sources (Information Technology) and Geoinformation (GI). Fire propagation modeling and floods case scenarios based on weather forecasts (Figure 2) are used as web services. FLIRE DSS is accessible from the web (www.flire-dss.eu) with no prior installation of any add-on software for support on the browser. It is a password

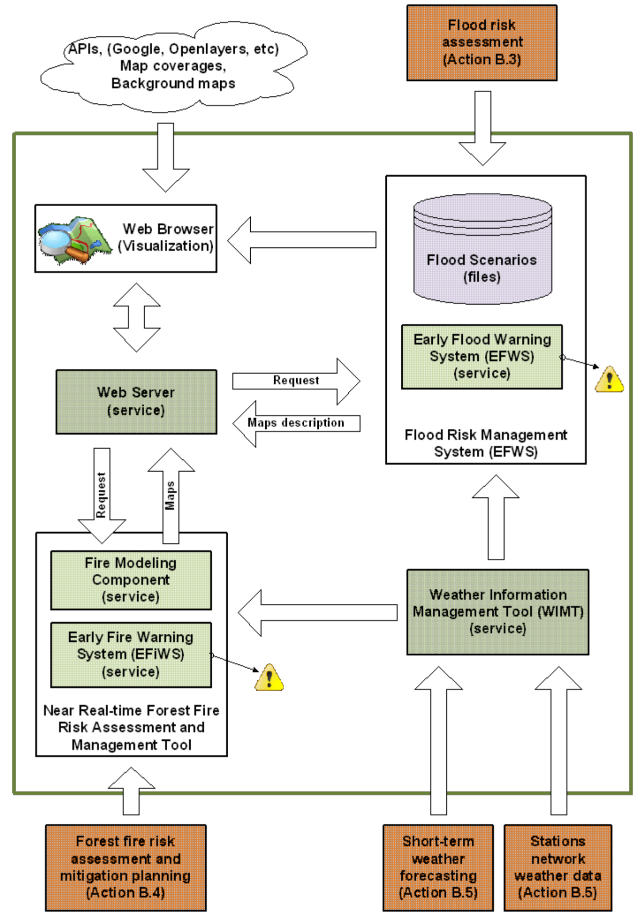

Figure 2: FLIRE DSS flowchart.

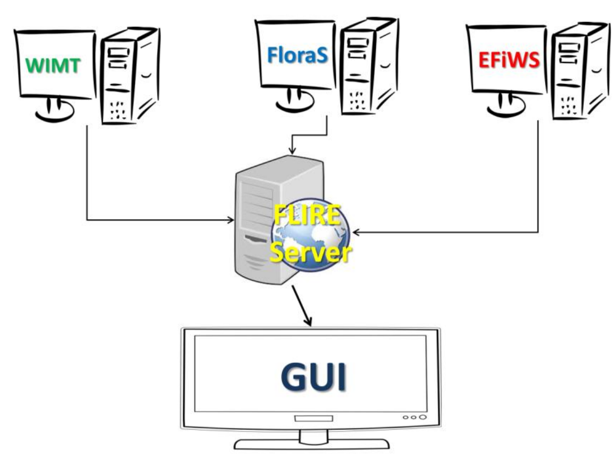

Figure 3: The architecture of the FLIRE DSS.

protected system, in which only authorized users can have access for security reasons. The components of the system are used as web services via a Graphical User Interface (GUI). The FLIRE web-DSS consists of three different modules (Figure 3) under the FLIRE Server. The server uses

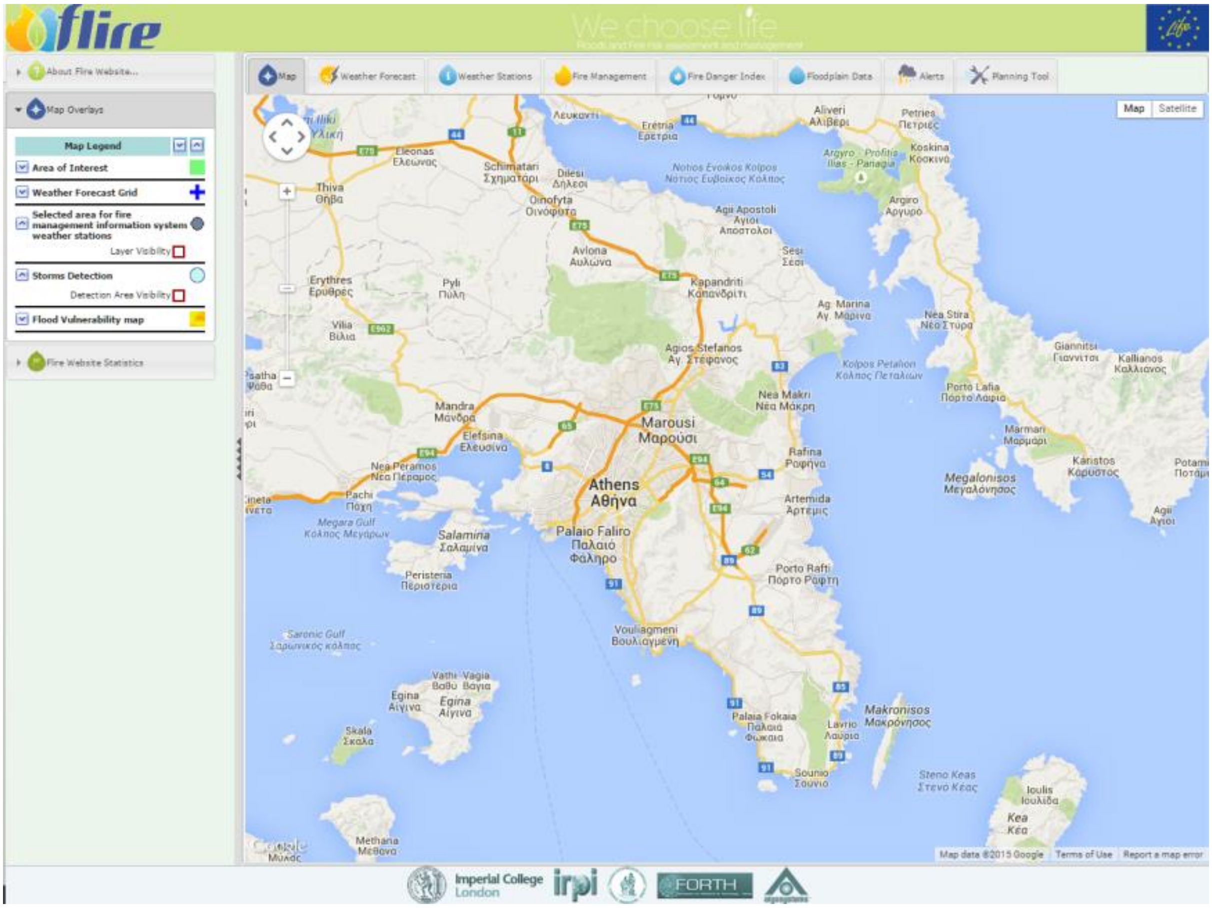

Figure 4: The Spatial Data Visualization Board.

FTP and *HTTP* communication protocols as well as web service technologies, while a GUI (Graphical Users Interface) has been designed and developed based on the user's requirements. The FLIRE DSS consists of five applications, described in the following sections:

1. Weather Information Management Tool (WIMT): It handles, manages and provides to the DSS the available weather information data. As previously mentioned, these data are coming from two sources (a) weather ground stations data & (b) weather forecast data.
2. Storms Early Warning System: It serves information about storms in the study area.
3. Early Fire Warning System (EFiWS): It provide control of the Fire Management System and the Fire Index (KBDI index).
4. Flood Risk Assessment System (FLORAS): It provides the user with flood maps based on weather forecasts and flood maps for different rainfall scenarios. It also includes smart alerts and scenarios for future planning.
5. FLIRE server: Unifies the aforementioned modules.
6. GUI: The user interface.

3.1 The FLIRE Server and the GUI

The FLIRE Server unifies the parts of the system and which can be accessed from the GUI. Users have access to the FLIRE DSS web site under a password protected system in order to prevent its use by non-authorized personnel. The backbone of the FLIRE Server is a Microsoft Windows Server and the DSS tools are implemented in six different tabs: (A) Map, (B) Weather Forecast Data, (C) Weather Stations Data, (D) Fire Management System, (E) Fire Danger Index and (F) Floodplain Data, (G) Alerts and (H) Planning tool.

Tab A act as the Spatial Data Board (Figure 4) where the users can visualize data including geospatial information, the output of the fire model, results of the flood model, the weather forecast data, and the weather observations from the deployed surface station network as well as other available spatial data like satellite images provided by Google Earth. For the needs of the monitoring of the performance of the system, statistics for each action in each tab are collected and presented in the tree menu of the DSS.

These statistics are related to the successful and failed requests of the Weather Stations Data, the Fire Management System Data, the Available Weather Forecast Data, the Fire Danger data, the Storms detection data and the data in the Floodplain Catalog. Tabs B and C are parts of the WIMT. In tab B, users have access to the weather forecast data. These data are used as input to the fire models in the cases of the scenario building ("*what-if*" approach), while they are also provided in *XML* and *KML* format for download and further use in other applications (redistribution protocol).

Tab C provides access to the weather stations data in real time. These data are used in the fire modeling tools in order to examine the spread of a fire from a given point (ignition area) in a predefined time. Tabs D and E are parts of the EFWS. Tab D provide the control of the Fire Management System. For this tab, the options are related to:

1. The flash point(s) of a fire, through tab A,
2. The weather data from the station's network through tab C,
3. The potential to use forecast data as input in the process of "*what-if*" fire scenarios.

The last one is necessary when users need to analyze what can be predicted to occur in the case of a fire at a given location of the study area when forecasted data imply increased fire risk. Tab E gives to the users the ability to visualize the Fire Danger Index values for the project area by implementing either meteorological measurements or weather forecasts. By using Voronoi polygons, the Fire Danger Information is given in the spatial extend of the area. Tab F gives access to probable floodplains for the present and the following day. Floodplains are produced for three different soil moisture conditions:

1. Probable floodplain based on rainfall forecast from NOA (assuming normal soil moisture conditions) forecasts
2. Probable floodplain assuming wet soil moisture conditions
3. Probable floodplain assuming dry soil moisture conditions

All floodplains are available either for loading and examining in tab A or for download in KML format for further analysis, such as time series analysis, impact on properties, etc.

3.2 Weather Information Management Tool (WIMT).

WIMT is implemented in two different tabs (B & C) and has been designed in order to control the weather data from four different sources:

- Weather forecast data through the National Observatory of Athens (NOA).
- Real-time weather observations from the meteorological stations operated by the National Observatory of Athens (NOA).
- Real-time weather observations from the meteorological stations operated by the National Technical University of HOA operated by NTUA.
- Storm information from National Observatory of Athens (NOA).

MM5 numerical prediction model is used for the weather forecast chain. It is a non-hydrostatic model, which use terrain-following coordinates [23]. It includes three nested grids (24, 8 and 2 km of spatial resolution) and the innermost grid cover the Athens area and the surrounding water bodies. MM5 runs one time per day with initial time at 00:00 UTC based on the Global Forecast System (GFS) gridded analysis with a 6 hour intervals forecast [24–27]. It runs with a 72-hours forecast lead time, except for Grid 3 that runs for 42- hours (initialized at 06:00 UTC).

For the needs of the FLIRE DSS, the forecasts at 1-h interval from the high resolution grid (2 km × 2 km) of the requested meteorological parameters, including near surface temperature, relative humidity, 10-m wind speed, wind direction and rainfall are stored and used in the WIMT. These parameters are necessary for the estimation of the risk related to fires and floods. The produced forecast data are stored in text files every hour in the server of the National Observatory of Athens (NOA) and are retrieved by implementing FTP communication protocol. The forecast data are handled using the *NoaForecastData* tool, an internal module operating in the DSS server that was developed by FORTH for this purpose. It is executed automatically as a "Scheduled Task" at specific times (when forecast data are available) while all parameters (urls, folder names etc.) needed by the program are stored once in NoaForecastData.ini file. This automatic task prepares all the available

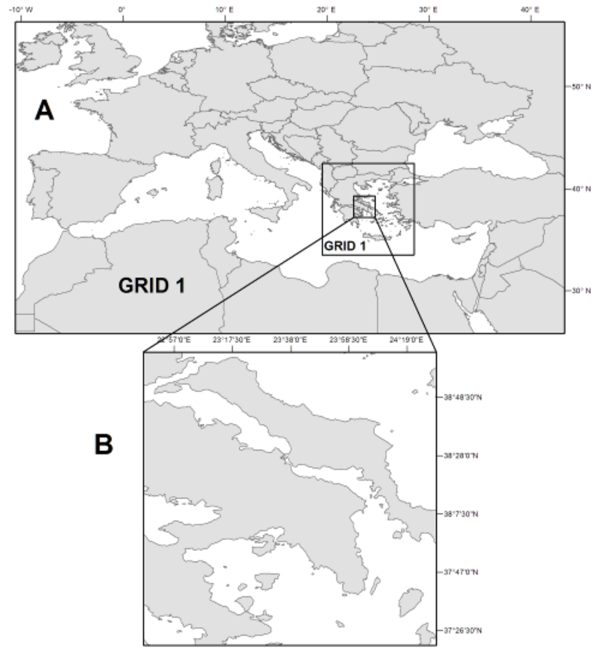

Figure 5: (a) The extension of MM5 grids. The polygons define the position of the nested grids (Grid 1 and B - intermediate and fine). (b) Athens area - Grid b.

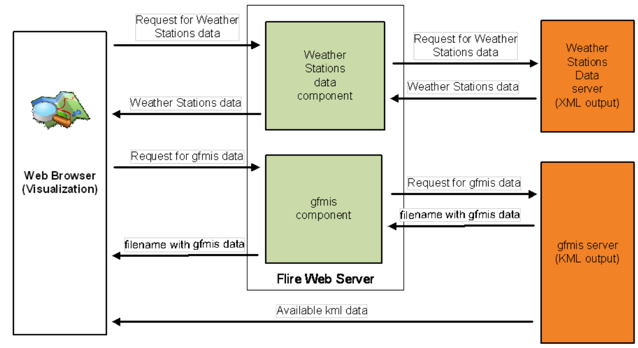

Figure 6: Flowchart on the use of GFMIS web service using weather stations data.

forecast data in the format that are needed for the models and then serves these to the FLIRE DSS system.

Weather forecast data are utilized in order to run "*what-if*" fire scenarios for the G-FMIS as well as on the calculation processes for the Fire Danger Index. In addition, the WIMT incorporates the weather observations of the surface weather stations that are deployed and operated within the study area by both NOA and NTUA. These automated weather stations provide real-time measurements of the following meteorological parameters:

- air temperature (in °C)
- Relative humidity (in %)
- wind speed (in km/h)
- wind direction (in °)
- rainfall (in mm)
- height of station (in meters)

Meteorological observations are provided every 10 minutes from HOA. NTUA homogenizes, manages and stores data from the stations network of NOA and HOA. Data are recovered by the WIMT by applying *FTP* communication tool in *XML* format. The data are stored and managed by the weather management module of the DSS database. Weather data from the stations are used as input in the fire models. NOA provides information about storms, detected in an area of 20 km around the study area, every 15 minutes. When FLIRE DSS "storms detection option" is activated and storms detection information is available, the FLIRE DSS system provides the user with an alert message, describing the area where the storms are detected, and it automatically focuses the map to that area.

3.3 Early Fire Warning System (EFiWS)

EFiWS consist of two components for fire management:

- The Geographic Fire Management Information System (G-FMIS): Is the model for the prediction of the propagation of the fire;
- The Keetch-Byram Drought Index (KBDI): Is the indicator on the Fire Danger risk.

3.3.1 G-FMIS (Geographic Fire Management Information System)

G-FMIS is a Fire Management model, mainly for the forest fires [28–31]. It incorporates a simulator on the forest fire, based on the BEHAVE model [32]. It uses the shortest path algorithm modified by Dijkstra [33] adapted to the simulation of the forest fire spread. G-FMIS has been redesigned to be used as a web-service and has been incorporated in the DSS in order to provide assessment on the fire risk and simulations on the fire propagation (Figure 6). It employs fuel maps, based on forest fuel mapping, as it is a precondition for the forest fire propagation simulation and the fire behavior assessment. An update fuel map has been made for the project area, based on satellite image analysis for the extraction of the land cover/use [22].

The Northern Forest Fire Laboratory (NFFL) fuel model system [34] and the Prometheus [35] have been combined for use in the project. Prometheus is a classification system, developed for a better understanding and representation of the typical elements of the Mediterranean for-

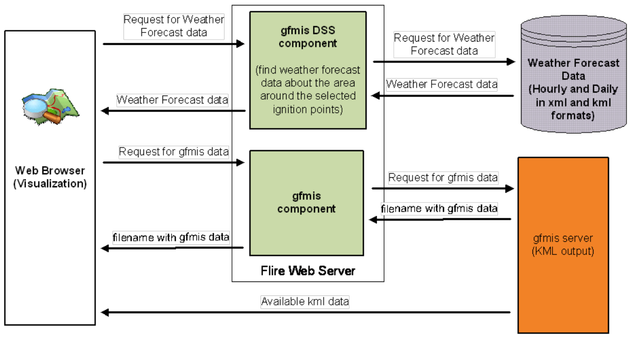

Figure 7: Flowchart on the use of GFMIS web service using weather forecast data.

est ecosystems. The fuel model, comprised by seven fuel types, is based on the height and density of fuel. These two have a direct influence to the intensity and propagation of fire. Each fuel type is associated with parameters that are used in the fire propagation modeling.

The user has two tabs to select for the use of the G-FMIS, the standard and the advanced. The standard tab is the simple approach for users who do not need to parameterize the system for the request time or for the simulation duration and the simulation step duration, as these values are fixed (120 seconds, 180 minutes and 60 minutes respectively). The user has to provide the fire ignition point (or points) in the form of click on the map at the area of interest and then has to update the system with the last 10 minutes of data from the weather stations in the project area. The advanced tab provides the user a set of parameterizations of the G-FMIS, where the user can change the request time, the simulation duration and the simulation step duration. This is crucial when low speed network connections are used. Also, from this control board, user can feed the model with the weather forecast data for the implementation of fire case scenarios. These can be designed for the present and the next day or by using the previous day's datasets, in order to prepare the simulation for the behavior of the fire that occurred in the area and has efficiently eliminate (Figure 7).

The aforementioned parameters are necessary for the execution of the models. Subsequently, after the described steps, the user has to send the request to the G-FMIS system and within the predefined time, the fire model runs and returns a simulation on the spread of the fire for the given timestep (Figure 8).

For each given point of the fire front, parameters such as the length of the flame and the step of the fire frontal are calculated and presented. The user can have access to these via the popup balloon at each point. Due to AJAX cross-domain policy, FLIRE web application cannot make a request directly to GFMIS server located in a different domain. Therefore, the GFMIS component has been created on the FLIRE web server in order to process requests to GFMIS server. The GFMIS component receives requests from the FLIRE web application and forwards the requests to GFMIS server (Fig. 7). The GFMIS component processes the response of GFMIS server and creates an *xml* response either with an error message (describing the problem) or the results of GFMIS server.

3.3.2 Fire Danger Index

The Fire Danger Index is based on the KBDI index [36]. It is calculated by using the station's data or the forecast data to support "*what-if*" analysis based on the drought conditions (Figure 9).

The initial date for the KBDI index and the number of the days for which the information is needed are the data that the user has to provide to the system. Following, by pressing the appropriate button, the table with the information appears. For each station or per weather forecast point (grid centroid), the data appear per date. For the KBDI index by the forecast data, a colored grid is created within the project area. Four colors have been used in order to denote the values of the index: Green for values with range from 0 to 25, yellow from 25 to 100, orange from 100 to 150 and red over 150. These values represent how severe the fire could be in case of a fire case.

3.4 Flood Risk Assessment System (FLORAS)

FLORAS continuously monitors hydrometeorological information coming from the monitoring stations and short-term predictions for the area. All data are assessed and compiled by the Scenario Management System feeding a catchment hydrological model, a catchment hydraulic model and an urban hydraulic model, producing information relevant to the flood risk assessment and flood alerts. The hydrological model selected for this application is HEC-HMS [37], while the models selected for hydraulic simulations are HEC-RAS [38] catchment hydraulic modeling and SWMM [39] for urban hydraulic modeling. All three models used for this task are efficient, widely applied and well established models. Their combined operation in an integrated framework has been documented in research [40]. They are usually accessed over a user interface as stand-alone applications. For the current project, this interactive approach is not an option, since all procedures, from the creation of the hydrologic scenario to the produc-

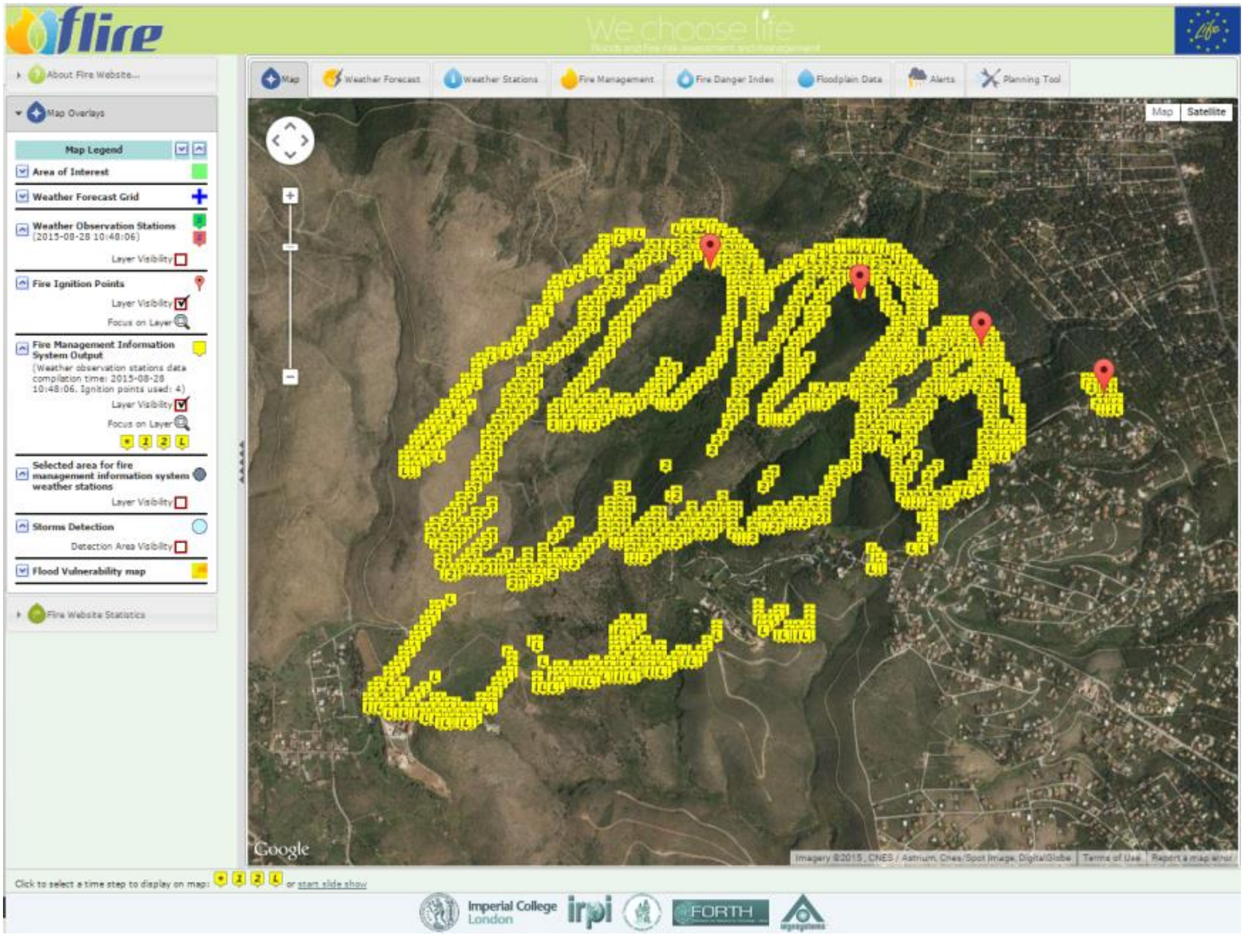

Figure 8: Fire spread during 4 hours, by using four start points.

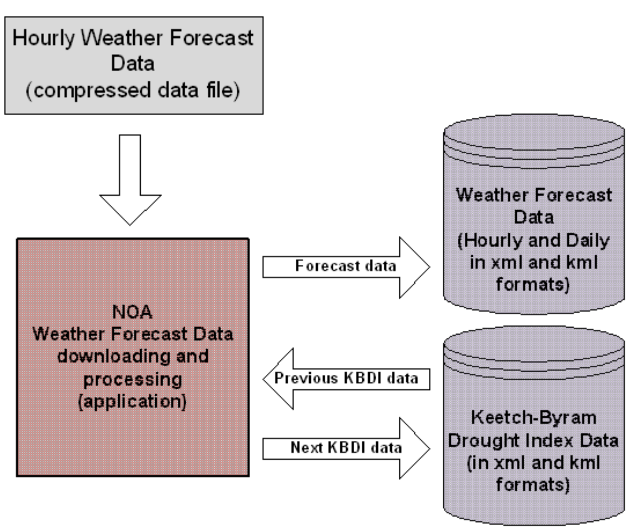

Figure 9: Weather forecast data downloading and processing and calculation of KBDI data.

tion of flood inundation maps, have to be automated and processed in batch mode. FLORAS applies scripting and other techniques offered by these models in order to feed them with the relevant data, run the scenarios and extract simulation results. Although it is not planned to be applied to areas other than the one specified in this Project, FLORAS can be adapted to other areas with modest effort by modifying the configuration files. The procedure follows the steps below (Figure 10):

- Preparation of the hydrological scenario:
  Hourly areal rainfall forecasts in a spatial discretization of 2 × 2 km produced by NOA for the next 48 hours are downloaded and compiled. Grid points are matched to the sub-basins of the study area. The time series are disaggregated from 1 hr to 10 min time-step creating continuous time series for each catchment for the time period of three days.
- Run of the hydrological model and the catchment hydraulic model:
  All files comprising a HEC-HMS project for event-based simulations are created from scratch. Precipitation time series are prepared using the script-

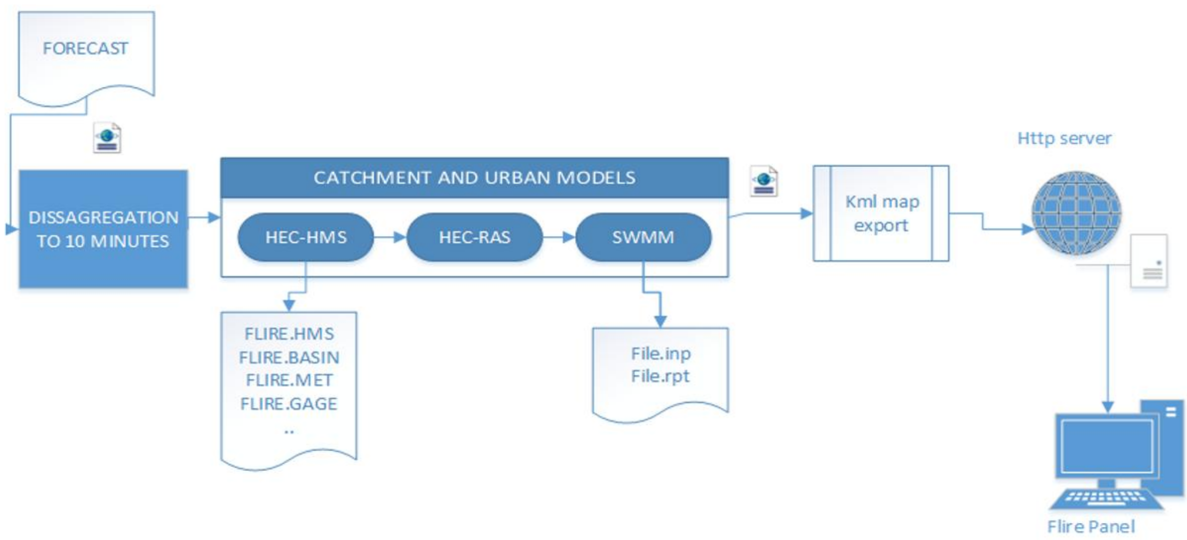

Figure 10: Flowchart on the on the production of flood results in KML.

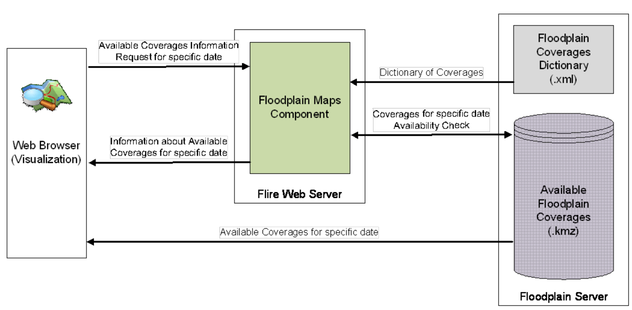

Figure 11: Flowchart on the communication of the FLIRE DSS with the Floodplain repository.

ing functionality of HEC-DSS Vue [41]. The project is run by HEC-HMS in batch mode and the resulting discharge is evaluated. Peak flow from each discharge time series representing the "worst case scenario" for steady flow is identified. The maximum discharge for selected locations of the river network (*e.g.* sub-basin outlets) is calculated and used as input of HEC-RAS. The resulting water elevations at the cross sections of each reach are stored in a spatial data file

- Run of the urban hydraulic model SWMM:
  The Storm Water Management Model (SWMM) is used for the hydraulic simulation of the urban area. After the execution of HEC HMS and HEC-RAS, a simulation of SWMM is triggered. The required input is the discharge time series from the HEC-HMS model and rainfall input. The model provides water depths at specific points in the urban area. Every output point of SWMM model is matched to an area-polygon of the urban zone and all these polygons are stored into a shapefile. Water depth is attributed to each polygon according to the output of SWMM simulation and different water depths are depicted with different color classes in order to be easily readable on exported maps.
- Post processing and visualization of the results:
  The water depth at specific locations is calculated from the DTM and the simulation results. The flood inundation area is calculated and stored in form of KML files.

The resulting KML files are stored in the FLIRE files in kml format, where an automatic schedule stores them in an http server from where they can be retrieved using the HTTP protocol. A dictionary containing all stared floodplain KML files is automatically updated.

Each entry of this dictionary describes the output of a specific hydrological/hydraulic scenario in one of the available languages (English or Greek). Whenever a new scenario runs, a new entry is inserted in the dictionary for each of the available languages and at the same time the output of the new scenario can be accessed through the FLIRE web application. When these are generated, a pull function is activated and the flood data are transferred to the FLIRE DSS, stored internal and are prepared for the visualization upon request (Figure 11). In case no new data are available at the time the user requests to visualize the information, an appropriate message informs that no data are available up to now. In the Floodplain Data tab, the

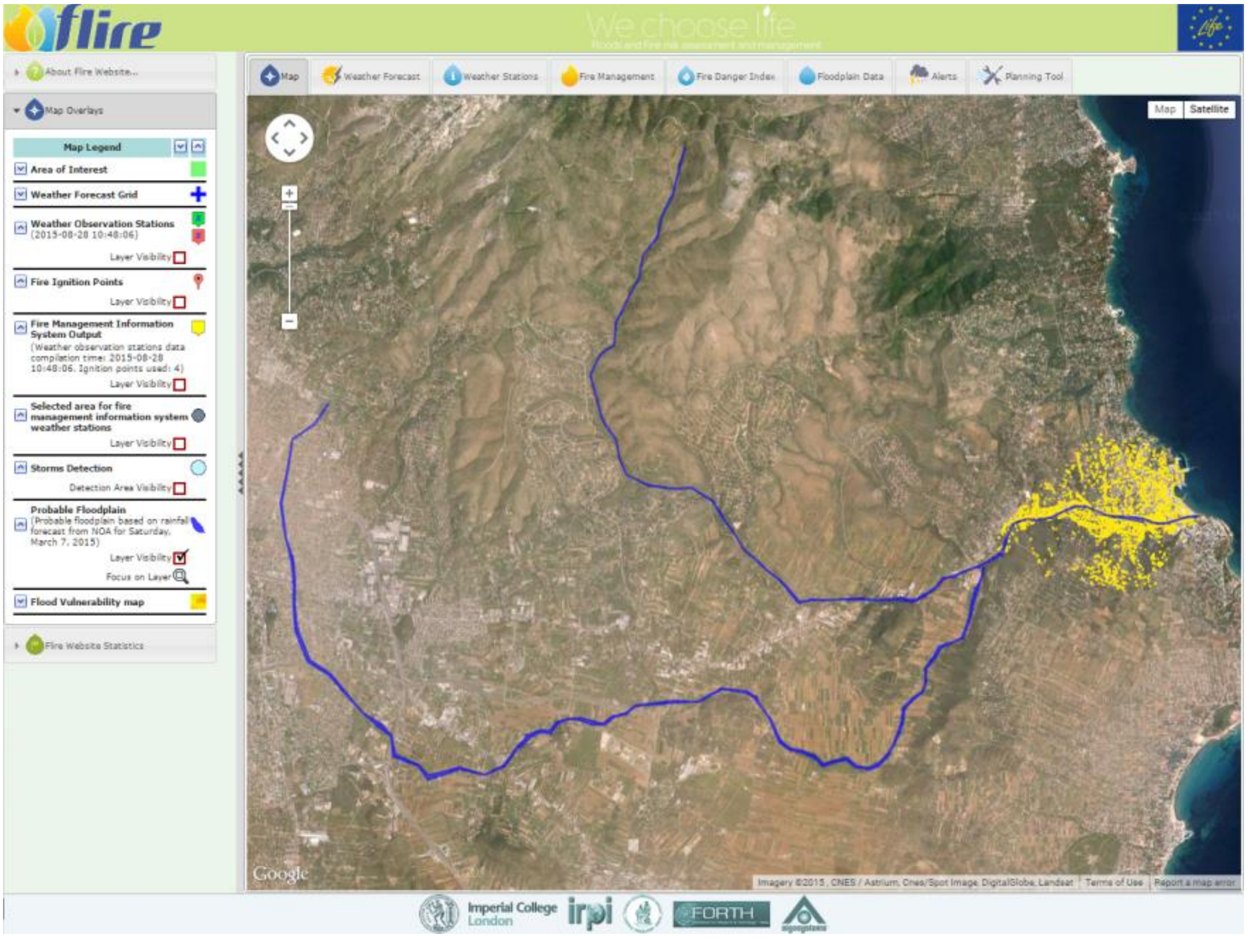

Figure 12: Visualization of a flood case in the spatial data visualization board.

user has access to the data in order to visualize them (Figure 12).

Here, the user can view the spatial extend of a flood event and identify areas that are prone to flooding in the urban (with yellow) and peri-urban areas (with blue). In this way, the service can support relevant authorities to take the necessary measures in vulnerable areas in order to reduce flood impact and also assist in the identification of locations for the evacuation of the vulnerable to flood areas.

3.5 Alerts

Three different smart alerting levels are provided by the system (Figure 13). The alerts are available from the tab "Alerts". The 1st alerting level is based on observed water levels at specific flow gauges in the study area and is useful for the period several minutes prior to a potential flood occurrence. The 2nd alerting level is based on lightning detection in the greater study area and is useful for the period of a couple of hours prior to a potential flood occurrence. The 3rd alerting level is based on forecasted data and simulations performed from the hydrological model of the FLIRE system and is useful for the period several hours up to 48 hours prior to a potential flood occurrence. Each alerting level is described in detail below.

3.5.1 1st Alerting level

The 1st alerting level is provided by NTUA and is based on real-time stage recordings from flow gauges installed in appropriate locations the study area. More specifically, four flow gauges (Drafi, Spata, Rafina and Rafina2) installed in the area send measurements of water levels to the platform. These measurements are compared against preselected threshold values for three different smart alerts: yellow (lower level), amber (medium level) and red (higher level) alert. The green color represents no Alert. When the

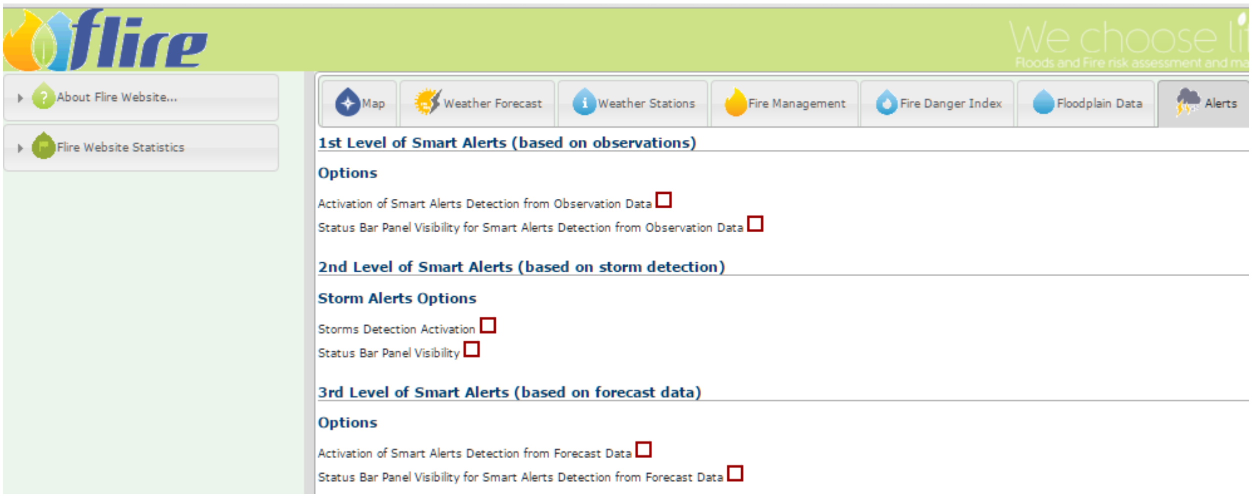

Figure 13: The Smart Alerts tab with the three levels.

threshold values for any of the three levels are exceeded, then the Flood Early Warning System (FEWS) of the platform is triggered and appropriate warnings are issued.

3.5.2 2nd Alerting level

The 2nd alerting level is provided by NOA and is based on the production of smart alerts for thunderstorms with a regular update approximately every 15 minutes. In particular, every 15 minutes an automated procedure is executed at NOA, scanning ZEUS lightning detection network data for lightning occurrence within a radius of 10 km and 20 km around the city of Rafina. A warning is issued and transferred to the FLIRE online tool when lightning is observed through this procedure within a radius of 10 km from Rafina city (red alert), or within a radius of 20 km from Rafina city (amber alert).

3.5.3 3rd Alerting level

The 3rd alerting level is provided by NTUA and is based on weather forecasts provided by NOA. The hydrological (HEC-HMS) model of the FLIRE system automatically receives the weather forecasts and is run for normal soil moisture conditions. As mentioned in Section 3, weather forecast data are available every day for the current and the following day. Therefore, the simulations are performed every day for the current and the following day as well. Simulated discharges at appropriate locations (Drafi, Spata, Rafina and Rafina2) are compared against preselected threshold values for three different smart alerts: yellow (lower level), amber (medium level) and red (higher level) alert and evaluated. The green color represents no Alert. When the threshold values for any of the three levels are exceeded, then the Flood Early Warning System (FEWS) of the platform is triggered and appropriate warnings are issued.

3.6 Planning Tool

This tool performs detailed cost-benefit and environmental analyses, as well as runs of the flood model chain and eventually suggests sets of measures-interventions for flood risk management in Rafina catchment. More specifically, a list of structural and non-structural measures that have been properly selected to be efficient for application in the study area has been established. These measures were incorporated in the hydrological model (HEC-HMS), hydraulic model (HEC-RAS) and the model chain ran for different scenarios-initial conditions in terms of fire occurrence, urban development and rainfall return period. It needs to be highlighted that, particularly for scenarios that concern fire occurrence, a methodology developed during the implementation of the FLIRE Project that considers floods-fires interaction has been incorporated in the hydrological model. According to this methodology, when a recent forest fire affects the study area, then different values need to be attributed to five properly selected hydrological parameters (*i.e.* Curve Number (CN), Initial Abstraction (IA), Standard Lag (TP), Peaking Coefficient (CP) and Muskingum K coefficient) in order to perform efficient flood simulations. After running these scenarios and estimating the corresponding floodplain, the

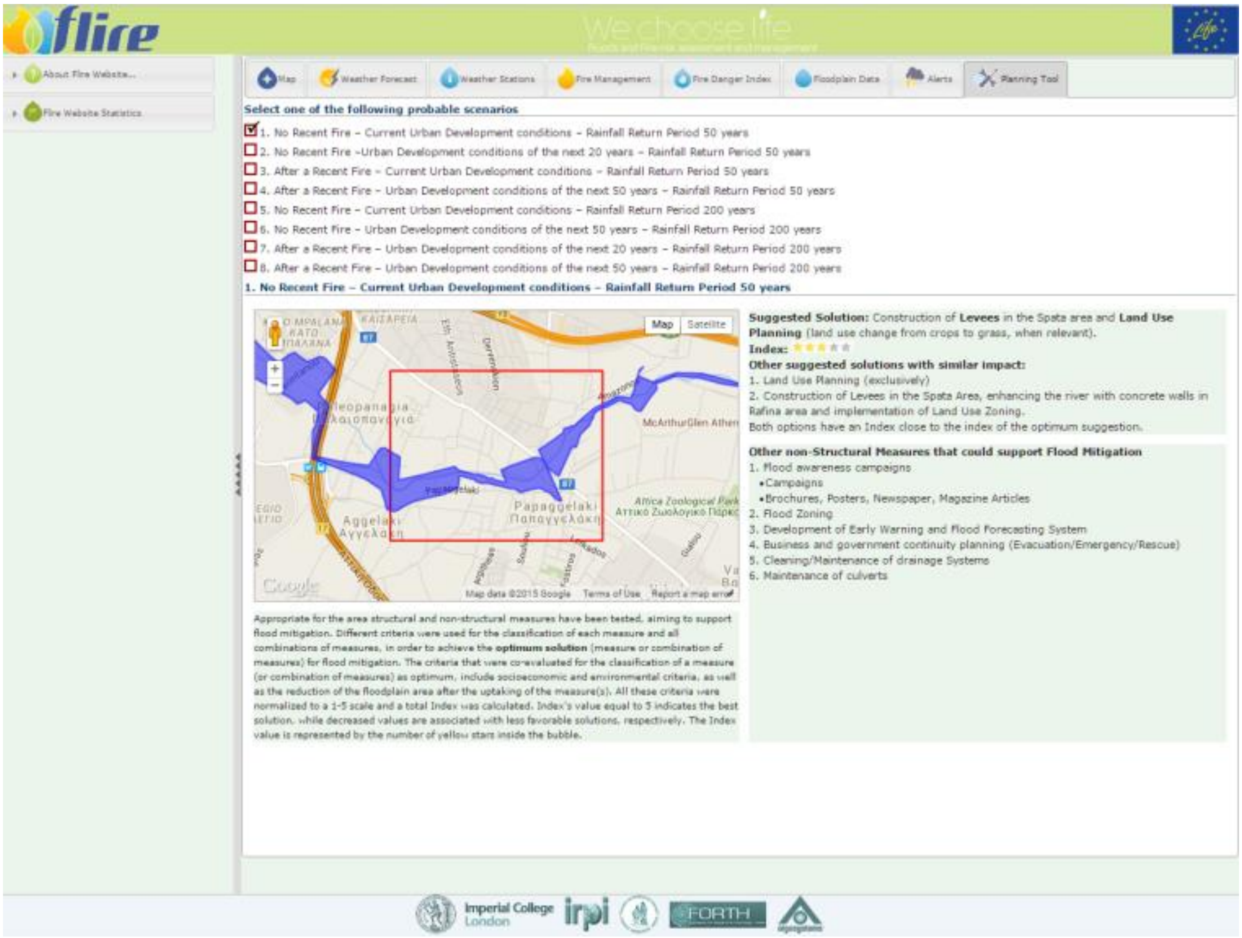

Figure 14: The planning tool with the relevant information.

suggested structural and non-structural measures as well as all the combinations of those measures were tested, model chain runs were repeated and the corresponding floodplains were estimated. The optimum solution (suggested measure(s) for each scenario) was estimated using socioeconomic criteria (construction and maintenance cost and reduction of floodplain for each measure and each combination of measures) and environmental criteria (environmental footprint of each measure and each combination of measures), to which appropriate weights were attributed. The FLIRE platform provides access to the Planning Tool for flood management by selecting the tab "Planning Tool". The user can choose one out of eight selected scenarios that correspond to different initial conditions for the model chain runs. These scenarios include the current situation in terms of urban development and fire occurrence, urban development scenarios for the next 20 and 50 years, fire scenarios in terms of fire extent, rainfall return periods that correspond to rainfalls of medium (T = 50 years) and high (T = 200 years) probability of occurrence and several combinations of these criteria. Once the desired scenario is selected, the platform presents: (1) a map of the study area and (2) three different text boxes. The map depicts the floodplain (blue color) for the selected initial conditions and one or more red rectangles indicate the area where suggested measure(s) can be applied. The text box on the right of the map, presents the optimum selected solution and an Index estimated using the aforementioned socioeconomic and environmental criteria, which represents the impact of the implementation of the particular solution (presented as the number of stars from 1 to 5, with increasing number of stars representing better solutions). Just below this text box, other suggested solutions and primarily nonstructural measures that can be applied for the specific scenario are suggested. Finally, a text box that describes in brief the functionality of the Planning Tool is presented below the map (Figure 14).

Table 1: Results for the calculated statistical scores for various thresholds of 24-h accumulated rainfall.

	Rain Thresholds in mm				
	1	***2.5***	***5***	***10***	***20***
Areal Bias	0.90	0.83	0.73	0.65	0.51
POD (Probability of Detection)	0.89	0.82	0.72	0.63	0.42
FAR (False Alarm Ratio)	0.01	0.01	0.01	0.04	0.17
CSI (critical success index)	0.88	0.82	0.72	0.61	0.39

4 Discussion

The FLIRE DSS is an integrated system which combines an easily expandable web application as frontend and a backend with several web services, large volume of real and non-real time data from different providers and applications for data processing and map coverages tiles creation. The frontend is a Javascript web application that is based on Google Maps API (to display static maps and dynamic map information) and uses Ajax requests to retrieve data from the system web services. The backend data are organized in xml and kml data files and the applications are written in Visual Basic. The developed web services provide the web application (or any other authorized user or application) with both real and non-real time data and data dictionaries. FLIRE DSS has been intensively checked for its performance and reliability by accessing it from different technological sources. It has been accessed and tested by office computers and laptops with wired and wireless network connections and different operation software (Microsoft Windows, Linux, Apple Mac OS), tablet and smartphones with 2G/3G/4G network and various operation systems (Apple iOS 8, Android) from remote areas. Meanwhile, the system has been demonstrated to the Civil Protection in order to have an interplay for improvements on the design and the presented tools.

The FLIRE DSS is a promising tool for the fire brigade agencies, the Civil Protection and the local stakeholders. Usually, these agencies have the knowledge and the funds in order to operate and manage their own IT systems. The FLIRE DSS provides natural disaster management departments with the advantages of the GIS abilities without the challenge of the installation of complicated and expensive software. The platform provides the users with real time information on the current weather conditions in the area as well as high resolution imageries which support the identification of the shortest paths to reach the areas of fire or flood and other important information for the surrounding terrain. Important component of the FLIRE DSS is the potential of the users to use weather forecast data in order to analyze and plan "*what-if*" scenarios during dry seasons for the fire services or during wet seasons for flood services. For the case of the fire, the user has to provide weather forecast data to the fire model for a specific date (instead of the real time weather data) and then to set the ignition point of the fire. These could be valuable in areas that are prone to fire due to flammable vegetation. By sending the data to the model, the results appear on screen in few seconds. The results of the model can be used for analysis in an efficient planning in this area. Floods are calculated daily by using the forecast data and datasets are available for visualization in the system. FLIRE DSS provides easy access to the system's components via a website that hosts the platform instead of a classic desktop application. Moreover, all the components of the system are geographically isolated, providing the system the desired distributed architecture. The fire model has been designed as a web service and has as a backbone, the well-known BEHAVE model [32] which is widely used in the era of wildfire management. The well-established models HEC-HMS, HEC-RAS and SWMM have been selected for flood modeling. The hydrological model HEC-HMS and the catchment hydraulic model HEC-RAS have already been successfully applied several times in the study area in event-based mode (*e.g.* [42, 43]). Efficient calibration of both models was achieved through the cross-validation of simulated results with observed datasets, when available. The performance of the FLIRE DSS regarding the ability of the meteorological model to quantitatively forecast rainfall has been evaluated. The verification covered the period from March 2013 up to December 2014, a period that comprises of 37 rain episodes, with at least one station recording more than 20 mm of rain within 24 hours. For the verification period, 44 rain gauges were selected, operated by the National Observatory of Athens and the National Technical University of Athens. Following the methodology widely accepted for evaluation of precipitation, a contingency table (yes/no for observed/modelled rain) was constructed for the totality of the 37 episodes and several statistical scores were calculated. The calculation of the statistical scores (Table 1) revealed a decreasing trend of the Prob-

Table 2: Results for the calculated statistical scores for various ranges of 24-h accumulated rainfall.

	Rain Ranges in mm				
	0.2–2.5	***2.5–5***	***5.–10.***	***10.–20.***	***>20.***
QB	0.28	−0.52	−1.65	−3.59	−14.36
MAE	0.66	1.02	3.05	5.97	15.95

ability of Detection (POD) with increasing rain threshold, with a POD of 0.42 for the highest precipitation amounts. This result is in agreement with the verification results of similar activities of high-resolution rain forecasts in the Mediterranean area [44–46]. On the other hand, the calculated False Alarm Ratio (FAR) was very low (lower than 0.17) for all rain thresholds, indicating that the model has no tendency to provide false alarms. Verification of the quantity of forecasted rain against observations (calculation of mean error and mean absolute errors) is provided in Table 2.

The model underpredicts the amounts of rain for all ranges (negative QB) with the exception of the first range of 0.2–2.5 mm. The greatest errors are obtained for the large amounts of rainfall (for > 20 mm the mean value of QB is −14.36 mm). The same comments apply for the MAE values that range from 0.66 mm for the lowest range, 3 mm for the medium precipitation amounts (5-10 mm range) and an error value of ~15 mm for the high precipitation amounts. The numbers reported in Table 2 are better that the values reported in previous studies over Greece [26, 44]. It should be noted however that these previous studies refer only to summer period cases (when rain forecast is in general a more demanding task) while the analysis performed in the frame of this work spans on cases throughout the year.

5 Conclusions

The performance of the FLIRE DSS (WIMT, G-FMIS, and Fire Danger Index) has been also evaluated. A series of 250 ignition point scenarios using weather data have been used in order to evaluate the response time of the model. The fire model has a response in about 27 seconds (mean value) after a cold start with a maximum at 61 seconds and a minimum at 23 seconds. In some cases, the system needs more that 35 seconds. Similar behavior has been noted by using the weather forecast data. Flood data are transferred to the FLIRE DSS system when they are available and there is no time lag for the visualization. The ultimate goal of the FLIRE DSS is the migration to a mobile platform, in order to become available to the firefighters, to the civil protection and to the stakeholders on the field. By using, it will bring onboard the fire behavior potential in order to plan the efficient elimination, satellite images for navigation and spatial information related to the flooded areas. FLIRE DSS is applied in East Attika, but due to its architecture and flexibility, can be transferred to other areas or to a broader area (region, country). The only requirements are the creation of a fuel map and a landuse/landcover map for the desired area by using accurate and updated Earth Observation data as well as information from a network of ground weather stations. Weather forecast data can be calculated by using the same technique. Minor hardware upgrade will be necessary for the storage of bigger datasets and the control of the traffic due to the accessibility of more users in cases of its transfer in a region level or country level.

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References

[1] Simonovic, S.P. 1996. Decision Support Systems For Sustainable Management Of Water Resources 2. Case Studies, Water International, 21(4), 233-244.

[2] Chrysoulakis, N., Mitraka, Z., Diamantakis, E., González, A., Castro, E. A., San Josë, R. and I. Blecic. 2010. Accounting for urban metabolism in urban planning. The case of BRIDGE. Proc. 10th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, organized by the Technical University of Einhoven, in Eindhoven, The Netherlands (July 19-22).

[3] Nyerged, T. 2010. Regional and urban GIS: a decision support approach, A Division of Guilford Publications, Inc, New York, USA.

[4] Böhner, C. 2006. Decision-support systems for sustainable urban Planning. International Journal of Environmental Technology and Management, 6, 193–205

[5] Bhargava, K.H., Power, J.D. and Sun D. 2007. Progress in Web-based decision support technologies. Decision Support Systems 43(4),1083-1095.

[6] Koutsoyiannis, D., Karavokiros G., Efstratiadis A., Mamassis N., Koukouvinos A. and A. Christofides. 2003. A decision support system for the management of the water resource system of Athens, Physics and Chemistry of the Earth, 28 (14-15), 599–609.

[7] Giupponi, C. and Sgobbi, A. 2013. Decision Support Systems for Water Resources Management in Developing Countries: Learning from Experiences in Africa. Water 5, 798-818.

[8] McIntosh, B.S., Ascough II, J.C., Twery, M., Chew, J., Elmahdi, A., Haase, D., Harou, J.J., Hepting, D., Cuddy, S., Jakeman, A.J., Chen, S., Kassahun, A., Lautenbach, S., Matthews, K., Merritt, W., Quinn, N.W.T., Rodriguez-Roda, I., Sieber, S., Stavenga, M., Sulis, A. Ticehurst, J., Volk, M., Wrobel, M., van Delden, H., El-Sawah S., Rizzoli A., and Voinov, A. 2011. Environmental decision support systems (EDSS) development – challenges and best practices. Environmental Modelling and Software, 26, 1389–1402

[9] Kalabokidis, K., Athanasis N., Gagliardi F., Karayiannis F., Palaiologou P., Parastatidis S. and Vasilakos C. 2013. Virtual Fire: A web-based GIS platform for forest fire control. Ecological Informatics 16, 62-69.

[10] Noonan-Wright, E.K., Opperman, T.S., Finney, A.M., Zimmerman, G., Seli, R., Elenz, L, Calkin, D. and Fiedler J.. 2011. Developing the US Wildland Fire Decision Support System. Journal of Combustion. Article ID 168473. doi:10.1155/2011/168473.

[11] Honghai Qi and Altinakar M.S. 2011. A GIS-based decision support system for integrated flood management under uncertainty with two dimensional numerical simulations. Environmental Modelling & Software 26(6),817–82.

[12] Prevention Web 2011. Disaster statistics from the Prevention Web http://www.preventionweb.net/english/countries/statistics/index_region.php?rid=3.

[13] Price C., Yair Y., Mugnai A., Lagouvardos K., Llasat M. C., Michaelides S., Dayan U., Dietrich S., Di Paola F., Galanti E., Garrote L., Harats N., Katsanos D., Kohn M., Kotroni V., Llasat-Botija, M. Lynn B., Mediero L., Morin E., Nicolaides K., Rozalis S., Savvidou K. and Ziv B. 2011b: Using lightning data to better understand and predict flash floods in the Mediterranean. Surveys in Geophysics 32(6), pp. 733–751.

[14] Price C., Yair Y., Mugnai A., Lagouvardos K., Carmen Llasat M., Michaelides S., Dietrich S., Galanti E., Garrote L., Katsanos D., Kotroni V., Llasat-Botija M., Mediero L., Morin E., Nicolaides K., Savvidou K. and and Ziv B. 2011a. The FLASH Project: Using lightning data to better understand and predict flash floods. Environmental Science & Policy, 14, 898-911.

[15] Papagiannaki K., Lagouvardos K. and Kotroni V. 2013. A database of high-impact weather events in Greece: a descriptive impact analysis for the period 2001–2011. Natural Hazards and Earth System Sciences, 13, 727–736.

[16] Jansa, A., Alpert, P., Arbogast, P., Buzzi, A., Ivancan-Picek, B., Kotroni, V., Llasat, M. C., Ramis, C., Richard, E., Romero, R. and Speranza, A.: MEDEX: a general overview. Natural Hazards and Earth System Sciences, 14 (8), 1965-1984, doi:10.5194/nhess-14-1965-2014, 2014

[17] Lagouvardos K. and Kotroni V. 2007. TRMM and lightning observations of a low-pressure system over the Eastern Mediterranean. Bulletin of the American Meteorological Society, 88, 1363–1367.

[18] Kotroni V., Lagouvardos K., Kallos G. and Ziakopoulos D. 1999. Severe flooding over central and southern Greece associated with pre-cold frontal orographic lifting. Quarterly Journal of Royal Meteorological Society, 125, 967-991.

[19] Lagouvardos K., Kotroni V., Bezes A., Koletsis I., Kopania T., Lykoudis S., Mazarakis N., Papagiannaki K. and Vougioukas S. 2016. The Automatic Weather Stations Network of the National Observatory of Athens: Operation and Database. Geoscience Data Journal (in press).

[20] Chrysoulakis, N., Mitraka, Z., Stathopoulou, M. and Cartalis, C. 2013. A comparative analysis of the urban web of the greater Athens agglomeration for the last 20 years period on the basis of Landsat imagery. Fresenius Environmental Bulletin, 22, 2139–2144.

[21] Papathanasiou, C., Makropoulos, C., Baltas, E. and Mimikou, M. 2013. The Hydrological Observatory of Athens: a state-of-the-art network for the assessment of the hydrometeorological regime of Attica. Proc. 13th International Conference on Environmental Science and Technology, 5th-7th September 2013, Athens, Greece.

[22] Poursanidis D, Mitraka Z andChrysoulakis N. 2015. Landsat 8 vs. Landsat 5: A comparison based on urban and peri-urban land cover mapping. International Journal of Applied Earth Observation and Geoinformation 35, 259–269.

[23] Dudhia, J., (1993). A non-hydrostatic version of the Penn State–NCAR Mesoscale Model: Validation tests and simulation of an Atlantic cyclone and cold front, American Meteorological Society, 121, 1493–1513, DOI: http://dx.doi.org/10.1175/1520-0493(1993)121<1493:ANVOTP> 2.0. CO;2.

[24] Kotroni V. and Lagouvardos K. 2001. Precipitation forecast skill of different convective parameterization and microphysical schemes: application for the cold season over Greece. Geophysical Research Letters, 28(10), 1977–1980.

[25] Kotroni V., Lagouvardos K. and Retalis A. 2011. The heat wave of June 2007 in Athens, Greece - Part 2: Modelling study and sensitivity experiments. Atmospheric Research, 100, 1–11.

[26] Kotroni V. and Lagouvardos K. 2004 Evaluation of MM5 High-Resolution Real-Time Forecasts over the Urban Area of Athens, Greece. Journal of Applied Meteorology, 43, 1666–1678.

[27] Akylas E., Kotroni V. and Lagouvardos K. 2007. Sensitivity of high resolution operational weather forecasts to the choice of the planetary boundary layer scheme, Atmospheric Research, 84, 49–57.

[28] Eftichidis G., Margaritis E., Sfiris A. and Varela V. 1998 Fire management information systems: FMIS. Proc. III Int. Conference on Forest Fire Research / 14th Conference on Fire and Forest Meteorology (Luso, 16/20 November 1998), Vol. II: 2641–2642.

[29] Andrews, P. L. and C. H. Chase. 1989. BEHAVE: fire behavior prediction and fuel modeling system - BURN subsystem, part 2. General Technical Report INT-260. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

[30] Andrews, P. L. 1986. BEHAVE: Fire behavior prediction and fuel modeling system — BURN Subsystem, Part 1, Gen. Tech. Rep. INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

[31] Burgan R.E. 1988) 1988 revisions to the 1978 National Fire-Danger Rating System. Res. Pap. SE-273. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

[32] Burgan, R. E. and R. C. Rothermel. 1984. BEHAVE: fire behavior prediction and fuel modeling system - FUEL subsystem. General Technical Report INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.
[33] Dijkstra, E. W. 1959. A note on two problems in connection with graphs. Numerische Mathematik 1, 269–271.
[34] Albini, F. 1976. Estimating Wildfire Behavior and Effects. USDA Forest Service. General Technical Report INT-30. 1976.
[35] Prometheus, S.V. Project, 1999. Management techniques for optimization of suppression and minimization of wildfire effects. System Validation. European Commission. Contract number ENV4-CT98-0716.
[36] Keetch, John J & Byram, George. 1968. A drought index for forest fire control. Res. Paper SE-38. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.
[37] Hydrologic Engineering Center. 2010a. Hydrologic Modeling System HEC-HMS, User's Manual v.3.5. US Army Corps of Engineers
[38] Hydrologic Engineering Center. 2010b. HEC-RAS, River Analysis System, User's Manual v. 4.1. US Army Corps of Engineers.
[39] Rossman, L. A., 2010. Storm Water Management Model User's Manual, EPA/600/R-05/040, U.S. Environmental Protection Agency, Cincinnati, OH.
[40] Robayo, O. 2005. Map to Map: Converting a NEXRAD Rainfall Map into a Flood Inundation Map. The University of Texas at Austin, Dissertation.
[41] Hydrologic Engineering Center. 2009. HEC-DSSVue. HEC Data Storage System Visual Utility Engine. User's Manual v. 2.0. US Army Corps of Engineers.
[42] Papathanasiou C., Alonistioti D., Kasella A., Makropoulos C. and Mimikou M.2012. The impact of forest fires on the vulnerability of peri-urban catchments to flood events (The case of the Eastern Attica region). Special Issue of the Global NEST Journal on Hydrology and Water Resources, 14(3), 294-302.
[43] Papathanasiou, C., Safiolea, E., Makropoulos, C. and Mimikou, M. 2009. The FLADAR Project and its contribution to the implementation of the EU Flood Directive 2007/60. Proc. 11th International Conference on Environmental Science and Technology, 3-5 September 2009, Chania, Crete, Greece.
[44] Mazarakis, N., Kotroni V., Lagouvardos K. and Argiriou A.A. 2009. The sensitivity of numerical forecasts to convective parameterization during the warm period and the use of lighting data as an indicator for convective occurrence. Atmospheric Research 94, 704-714.
[45] Sindosi O. A., Bartzokas A., Kotroni V. and Lagouvardos K. 2012. Verification of precipitation forecasts of MM5 model over Epirus, NW Greece, for various convective parameterization schemes, Natural Hazards and Earth System Sciences, 12, 1393–1405.
[46] Oberto E., Milelli M., Pasi F. and Gozzini B., 2012. Intercomparison of two meteorological limited area models for quantitative precipitation forecast verification. Natural Hazards and Earth System Sciences 12, 591-606. DOI: 10.5194/nhess-12-591-2012.