Faculty of Environmental Sciences
Chair of Geoinformatics

Master Thesis

Design of a spatial decision support system for the mitigation of damage caused by flash flood events

submitted by **Maia Zumbulidze**

submitted for the academic degree of
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TECHNISCHE UNIVERSITÄT DRESDEN

Assignment of a Master thesis topic

Course of study: International Cartography
Student name: Maia Zumbulidze

Topic: Design of a spatial decision support system for the mitigation of damage caused by flash flood events.

Objectives:

Hydro-meteorological extreme events have a huge impact on human life. Accordingly, a wide range of methods and tools are already available for their analysis, assessment and prediction. Moreover, a number of legislative initiatives, e.g. the EU Floods Directive and the INSPIRE directive, address the need for time-critical environmental information to support effective decision making in this context.

The thesis shall determine the requirements, challenges and restrictions for effective flood risk management within a Spatial Data Infrastructure (SDI). Therefore, a spatial decision support system (SDSS) for the mitigation of damage caused by flash flood events shall be designed, developed and evaluated in a service-based environment. Particular emphasis shall be put on flood risk management and decision making in the context of hydro-meteorological extreme events in small and medium sized catchment areas, which are characterized by rapid response times in the case of an event. A prototypical implementation of the core components and services shall demonstrate the feasibility of the approach.

The following shall be submitted:

- Three printed versions of the thesis,
- Three CDs/DVDs with a digital version of the thesis (pdf) and the developed applications (including source code, documentation, etc.)
- A summary of the findings of the thesis for presentation on the Web (approx. 1000-2000 characters)

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Handed out: 10.04.2018
Submission date: 10.09.2018

Prof. Dr. Michael Soffel
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Statement of Authorship

Herewith I declare that I am the sole author of the thesis named

„Design of a spatial decision support system for the mitigation of damage caused by flash flood events“

which has been submitted to the study commission of geosciences today.

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Dresden, 10/09/2018 Signature

Abstract

Over the last few years, flooding is likely to occur more frequently which has a huge impact on people, environment, economy. Flood risk management process manages an existing flood risk situation and tries to reduce the flood risk. In this research, a spatial decision support system (SDSS) in a service-based environment is designed for mitigation of damage caused by flash flood events. The legislative initiatives such as the EU Floods Directive and the INSPIRE directive are considered as the legal framework and bounding conditions for this work. Since it is not possible to abolish flooding completely, recently more efforts are made to manage the risks of floods than to protect against flood. This approach refers to the EU FD, that is the first European directive which deals specifically with flood events and establishes a framework for the assessment and management of flood risk. SDSS in a Spatial Data Infrastructure (SDI) context is considered an ideal mean of support for efficient flood risk management since SDI enables the distribution and sharing of the most up-to-date geodata and geoprocessing functionality. The various workflows of SDSS are designed and implemented based on aggregated web services using Web Processing Service (WPS) interface. The workflows consider and include the potential stakeholders could be involved in the flood risk management process. This research attempts to determine the possible requirements, challenges and restrictions for flood risk management within SDI and to demonstrate the feasibility of SDSS in a service-based environment for effective flood risk management and decision making process.

Keywords: flood risk management, Spatial Decision Support System (SDSS), Spatial Data Infrastructure (SDI), geoprocessing, web services, decision making

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List of acronyms

CSW	Catalogue Service Web
DSS	Decision Support System
ERS	Emergency Route Service
ETL	Extract Transform Load
GDSC	Geospatial Data Service Centre
GML	Geographic Markup Language
GI	Geographic Information
GIS	Geo-Information System
HTTP	Hypertext Transfer Protocol
IFRM	Integrated Flood Risk Management
INSPIRE	Infrastructure for spatial information in Europe
ISO	International Organization for Standardisation
KVP	Key Value Pair
MCDA	Multi-Criteria Decision Analysis
MADM	Multi-Attribute Decision Making
MODM	Multi-Objective Decision Making
O&M	Observations and Measurements
OGC	Open Geospatial Consortium
OpenLS	Open Location Service
RS	Route Service
SDI	Spatial Data Infrastructure
SDSS	Spatial Decision Support System
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SOS	Sensor Observation Service
SPS	Sensor Planning Service
SWE	Sensor Web Enablement
The EU FD	European Floods Directive
The EU WFD	European Water Framework Directive
UDDI	Universal Description Discovery Integration
WCS	Web Coverage Service
WFS	Web Feature Service
WMP	Web Map Service
WPS	Web Processing Service
WSDL	Web Services Description Language
XML	Extensible Markup Language

1. Introduction

1.1. Motivation and problem statement

Flood is a natural disaster that can cost the loss of life and damage to the economy. It is important to provide sufficient protection for people and properties. Due to climate change and urbanisation, flooding is likely to occur more frequently. In order to cope with the future flooding in a sufficient way the change of traditional approaches and planning new strategies are required.

Flood risk management is aimed to reduce flood damage on people, the environment and the economy. According to Simonovic (2002), the flood risk management can be considered as a spatial problem. The flood risk management process consists of three phases: pre-flood planning; flood emergency management and post-flood recovery (Ahmad and Simonovic 2006). In order to reduce flood damage, in pre-flood planning phase flood risk management options such as structural and non-structural measures are analysed and compared for possible implementation. Flood emergency management phase includes flood forecasting and updating process. Post-flood recovery phase includes the activities that lead to return to normal life from flooding period, also the implementation of flood mitigation strategies.

Since information about natural hazards (e.g. flooding) mostly has a spatial nature, using and sharing spatial data is crucial in the disaster management process in general. Decision Support System (DSS) plays a significant role in effective flood risk management. Whereas, Geo-information system (GIS) plays important role in developing and implementing interactive decision support systems for flood risk management.

As mentioned above there are three phases (pre-flood planning; flood emergency management and post-flood recovery) in flood risk management. DSS assists decision makers during these phases, it allows to produce meaningful information in decision making process. According to Ahmad and Simonovic (2006) such system has the following functions: flood control structures, flood forecasting, and operation of flood control structures. It is capable of assisting in solution of all problems (structured, semi-structured, and unstructured) using all information available on request.

In order to achieve effective flood protection structural measures (e.g. dykes, reservoirs and etc.) and non-structural measures (e.g. flood forecasting, warning system and etc.) can be used. These flood mitigation alternatives play a significant role in decision making process. Using multiple criteria different flood protection measures can be compared and their impact can be evaluated (Bouwer et al. 2009). These criteria mainly include life loss and flood damage. Reliable 2D flood modelling, GIS and remote sensing technology are capable of flood risk management since it takes into account spatial variability of flood hazard (Qi and Altinakar 2011). It is important to have the versatile environment for creation different criteria and use relevant data for decision making.

The important aspect of DSS is flood forecasting, which is one of the most effective non-structural flood mitigation measures. It leads to reduce flood damage and the loss of people's lives. According to Hafiz et al. (2013), in order to develop the flood forecasting and warning system, two methods are used, which are real time flood forecasting and flood forecasting using forecast rainfall data. The rainfall data which is used for real time flood forecasting is from either ground rainfall station or real time satellite rainfall and the lead time available for flood warning alert is not long. Opposite to the real time rainfall data, forecasted rainfall data is used for simulation and it gives more time to the people before flood occurs, but there is a problem with respect to data accuracy.

As mentioned earlier spatial data plays a significant role in flood management since natural disaster such as flood has a spatial nature. Considering this fact in this research a Spatial Decision Support System (SDSS) for the mitigation of damage caused by flood events will be designed and developed. According to Dissanayake (2014) a spatial decision support system is an interactive, computer-based system designed to assist in decision making while solving semi-structured spatial problems, it can be considered as a policy support system. SDSS consists of GIS functionalities such as spatial data management, cartographic display, analytical modelling capabilities, a flexible user interface and complex spatial data structures (Goodchild 2000). GIS and SDSS have complex nature in terms of data representation, presentation and computation, moreover, SDSS in Spatial Data infrastructure (SDI) context would be more functional and user friendly by providing intelligent interfaces (Sugumaran and Sugumaran 2007).

It is important to highlight that in spite of many efforts to protect against floods it's impossible to abolish them completely. For this reason, recently flood management has shifted from protection against floods to managing the risks of floods (Mostert and Junier 2009). The European Commission introduced Directive 2007/60/EC on the assessment and management of flood risks for managing flood more effectively and reduce the impacts of flooding on people, the economy, cultural heritage and the environment (Commission 2007).

The EU Floods Directive (FD) is closely linked to the implementation of European water framework directive (2000/60/EC). The WFD mainly focuses on water quality and ecology. According to Priest et al. (2016), the WFD's main concepts and approaches all reappear in the EU FD (e.g. river basin approach, transboundary cooperation, coordination of water quality and quantity management, coordination with other policy fields, important roles for monitoring and public participation, etc.), however strength of the obligations in WFD differs considerably, which effects legal effectiveness.

The EU FD is less complex compared to the WFD. The concept of flood risk management is crucial in the EU FD. Considering three stages in flood risk management process the EU FD requires EU Member States to perform a preliminary flood risk assessment, to prepare flood hazard maps and flood risk maps for the areas with a potential significant flood risk, and to prepare flood risk management plans for these areas. (Mostert and Junier 2009).

Spatial data and related technologies are significant in decision making process in disaster management in general and in flood risk management particularly. Therefore, there is a need to have reliable, up-to-date and accurate data, also it is very significant to have data in time. This is an important aspect in terms of disaster response. Any delay in data collection, access, usage and dissemination has negative impacts on the quality of disaster response (Mansourian et al. 2006). Considering time sensitive nature of disaster response, data accessibility for data analysis, data integration and interoperability plays important role in the flood risk management process. An appropriate framework would be used to solve this problem. This research will attempt to use a Spatial Data Infrastructure (SDI) concept as such a framework.

The principle "collect once, use many times" is very much relevant to SDI. SDIs have been defined by Groot and McLaughlin (2000) as "a set of institutional, technical and economical arrangement, to enhance the availability (access and use) for correct, up-to-date, fit-for-purpose and integrated geo-information, timely and at an affordable price, with the goals to support decision making processes related to countries' sustainable development". It is obvious that there is a need to access and share geospatial information considering some standards that can be done using SDI. It allows sharing data from different sources and helps users to save resources, time and efforts to enquire new datasets (Rajabifard and Williamson 2001). SDIs are highly organized, standardized and institutionalized, large collections of spatial data and services (Köbben and Graham 2009).

An interoperability of the components plays an important role in SDI environment. There are two types of interoperability: technical and semantic, both are a challenge, but semantic interoperability is more complicated (Köbben and Graham 2009). In general data providers don't think much of data integration with other data sets and the users considering their needs mostly require data from different sources that is always a big challenge. Using SDI is important to consider this problem that allows integration of different data sets. SDI is intended to facilitate both users and providers' needs (Aditya and Kraak 2007). It is important to mention that SDI has ability for offering decision supports and enabling geocollaboration (MacEachren et al. 2005). The main goal of SDI is the sharing, access to, and responsible use of geospatial data for a specific application domain and enterprise (Groot and McLaughlin 2000). The SDI is a place to find and use the services (functionalities and data components) (Bernard 2002). The metadata provides the capability and functionality of the services. According to Aditya and Lemmens (2003), web services are loosely-coupled functions that can be executed remotely by users on the internet regardless the platforms implemented. The concept of a service chaining allows a combination of one or more web services.

As mentioned before in order to make flood risk management and decision making process more effective, to perform effective flooding analysis and forecasting, there is a need to have easily accessible, up-to-date, interoperable spatial data.

In this research, a service-based SDSS for the mitigation of damage caused by flood events will be designed. SDSS will be based on the previous studies, findings, considering the aspects that are related the EU FD; The system will be designed for flash flood events in a small and medium sized catchment areas. The relevant modules for flood analysis, forecasting, prevention and mitigation will be developed and linked through standardized web services such as Catalogue Services for the Web (CSW) for metadata (geodata, services) access, Web Feature Service (WFS) for vector data access, Web Map Service (WMS) for display an image (gif, jpeg, png, etc.) of vector or raster data, Web Coverage Service (WCS) for raster data access, Web Processing Service (WPS) for access to remote GIS operations(e.g. buffer, coordinate transformation, distance calculation, etc.) The composite services using WPS interface will be set up to support data geoprocessing in SDI environment. The potential stakeholders will be identified and selected and various workflows will be reviewed for the flood risk management process. Some of the workflows will be implemented in a service-based environment.

1.2. Objectives and research questions

The main objective of this research is to design a spatial decision support system (SDSS) for the mitigation of damage caused by flash flood events within SDI environment. The EU INSPIRE and the EU Floods Directive and its corresponding implementations are considered as the legal framework and bounding conditions for this work. Particular emphasis for the concept and implementation is put on effective decision making for flood risk management in the case of hydro-meteorological extreme events in small and medium sized catchment areas. There are two sub objectives that could be attained by answering the research questions:

- Determination of the role of the EU Floods Directive and the EU INSPIRE Directive for effective flood risk management

- Design of a service-based SDSS for hydro-meteorological extreme events in small and medium sized catchment areas

Determination of the role of the EU Floods Directive and the EU INSPIRE Directive for effective flood risk management: To attain this sub objective the following research question to be answered:

- To which extent the EU FD and the EU INSIPRE directive support the flood risk management process?

Design of a service-based SDSS for hydro-meteorological extreme events in small and medium sized catchment areas: This sub objective can be reached by answering the following research question:

- What are the main components of a service-based SDSS for flood risk management?
- Who are the main stakeholders and what are the main workflows of a service-based SDSS for flood risk management?
- What are the main requirements, challenges and restrictions for a SDSS in service-based environment for flood risk management in small and medium sized catchment areas?

1.3. Methods

In order to investigate a research problem and to answer the research questions the following methods will be used (see Fig.1.1): The first task will be literature review on the concept of flood risk management, the concept will be discussed with respect to the EU Flood Directive and the INSPIRE directive as well, furthermore, the concept of SDSS and SDI will be reviewed. Based on the existing (S)DSS a conceptual design of SDSS will be designed in SDI environment. The requirements of SDSS aspects in SDI context for effective flood risk management and decision making will be examined and identified. The workflows of SDSSs' modules will be set up that consider hydro-meteorological extreme events in small and medium sized catchment areas. The potential stakeholders will be identified and selected for each workflow. The next step will be the implementation of the workflows including the core components and services showing the feasibility of the approach.

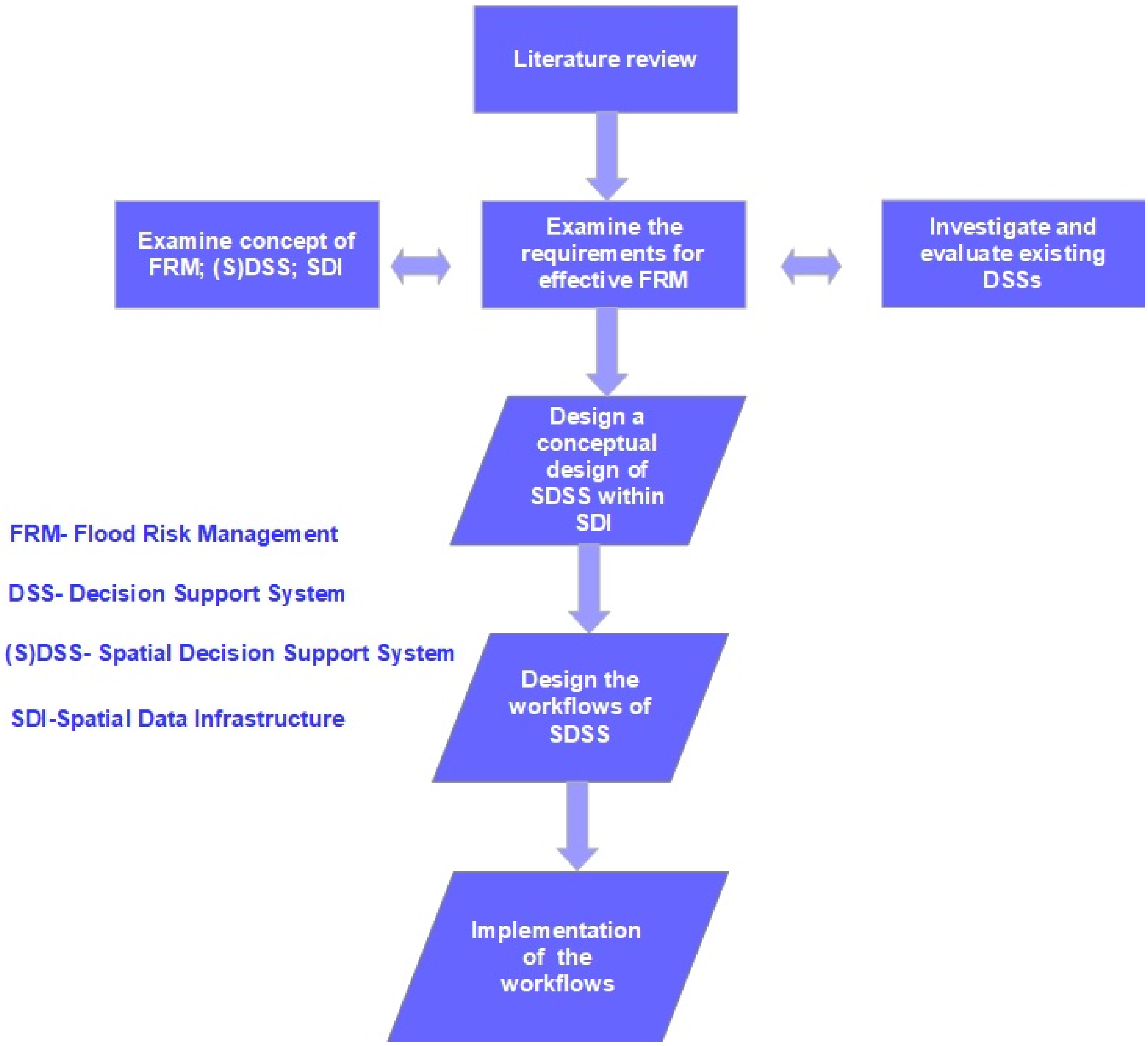


Fig. 1.1 Methodology of the research

1.4. Thesis structure

This research will be composed of six chapters. In the next chapter, the literature review will be presented. The concept of flood risk management and its role in decision making process will be introduced. For supporting effective decision making the legislative initiatives such as the EU Floods Directive and the INSPIRE directive will be reviewed. The concept of Decision Support Systems (DSS) and Spatial Data Infrastructure (SDI) will be discussed. The role of SDI in flood risk management will be examined.

In chapter 3, a conceptual design of a service-based SDSS for the mitigation of damage caused by flash flood events will be presented, which consists of SDSS and SDI frameworks. Each module of SDSS will be discussed in SDI context considering different stakeholders would be involved in the flood risk management process. In chapter4, the workflows of SDSS for effective flood risk management process will be presented. The required data, components, services will be introduced for each workflow. The chapter 5 will introduce implementation process of the workflows, that results in flood hazard and flood risk mapping. GIS processing functionalities and services will be used to accomplish the task. In chapter 6, a summary of the findings will be discussed and the recommendations for the future work will be given.

2. Literature review

2.1. Introduction

In order to answer the research questions and to expand the knowledge that is related to this research the following topics will be reviewed and discussed: flood risk management and its tasks and components, its role in decision making process, Integrated food risk management (IFRM), the EU Floods Directive, the comparison between the EU FD and Water Framework Directive, Concept of Decision Support Systems (DSS), decision support process and techniques, Spatial Decision Support Systems (SDSS), DSS for flood management, concept of Spatial Data Infrastructure (SDI), Service Oriented Architecture (SOA), components of SDI, geoportal, metadata, Web services, OGC Web Services (OWS), the EU INSPIRE Directive, the role of SDI in flood risk management.

2.2. Flood risk management

Flood is a natural phenomenon, which occurs often and can cost the loss of life and damage to the economy. Depending on the type of flood there are different approaches to deal with it, e.g. a flash flood requires different responses rather than a flood which inundates the lower part of an alluvial river (Plate 2002). Since flash floods have high velocity and huge erosive forces they may cause large loses of life of people and damage to properties. In contrast to flash floods, velocities of floods of alluvial plains of large rivers are low. This research will focus only on flash flood, which is a highly dynamic phenomenon.

According to Borga et al. (2011), flash floods are associated with short, highly-intensity rainfall rates, while runoff rates often exceed those of other flood types due to the rapid response of the catchments to intense rainfall. Flash floods events are difficult to monitor. Since flash floods have the small spatial and temporal scales relative to the sampling characteristics of conventional rain and discharge measurement networks, these events are particularly difficult to observe and to predict (Borga et al. 2008). The monitoring of flash floods is crucial in terms of observing catchments respond when hydrologic flow paths are active. Thus, it provides valuable insight into the rate-limiting processes for extreme flood response, their dependency on catchment properties and flood severity (Borga 2009). The investigation of flash flood events is important, spatially post-event surveys are significant in gathering essential observations concerning flash floods.

The term flood hazard refers to potentially damaging flood events and to probability of their occurrence. Damage caused by flood hazard related to the vulnerability of exposed elements that can be considered as inherent characteristics of these elements which determine their potential to be harmed (Schanze 2006). According to the principle of sustainability, there are three basic areas of flood vulnerability: ***Social and cultural vulnerability*** related to loss of life, health impacts, loss of vitality, stress, social impacts, loss of cultural heritage; ***Economic vulnerability*** refers to direct and indirect financial losses by damage to property, reduced productivity, relief efforts; ***Ecological vulnerability*** composes of anthropogenic pollution of waters, soils and ecological systems (Messner and Meyer 2006).

Flood risk refers to flood hazard and to flood vulnerability. It can be considered as the probability of negative consequences which caused by floods. There is the conceptual Source-Pathway-Receptor-Consequence-Model (SPRC-Model) which has been proposed by Schanze (2006). It describes the concept of flood risk (see Fig. 2.1). According to this model "source" describes the meteorological event and "pathway" represents the wave propagation. It should be stressed that the distinction between both is not easy and together cover all water related phenomena of the flood hazard. In the case of a river flood, the sources refer to the rainfall-runoff process, whereas the pathway to the wave propagation in the river catchment also covers its floodplain including the inundation process. "Receptor" and negative "consequence" together determine the vulnerability, they stand for societal matters related to the flood risk generation (Schanze 2009).

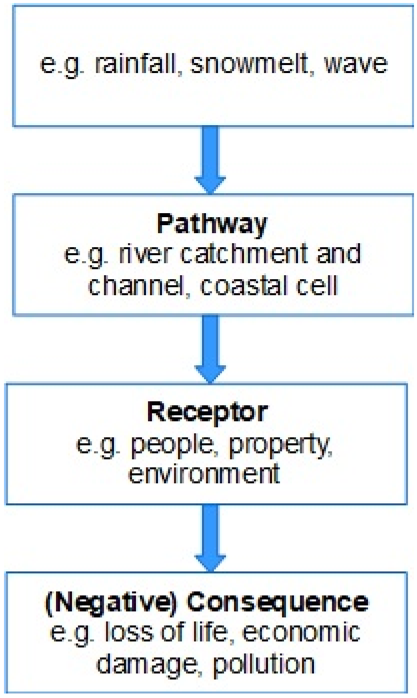


Fig. 2.1 Source-Pathway-Receptor-Consequence-Model (Schanze 2006)

This model can be used to formulate flood risk function. The "Source" is described by the probability(p) of flood events with a magnitude and other features (m). Two risk reduction factors such as early warning (w) and the retention capacity of the source areas (t) are part of this model. The "Pathway" can be determined by the inland discharge and inundation (i) with various attributes (a) and interventions for flood control (c). The "Receptor" refers to susceptibility (s) with interventions to strengthen resistance and resilience (r). The "consequence" specifies the harm to values (v) with intervention to decrease or to compensate them (d). Based on this flood risk can be expressed by the following function (Schanze 2006):

$$\text{Flood risk} = f\left((p,m,w,t)_{\text{source}}, (i,a,c)_{\text{pathway}}, (s,r)_{\text{receptor}}, (v,d)_{\text{consequence}}\right)$$

According to this author, the causal chain of the SPRC Model occurs for each element at risk and each flood hazard. A system which consists of all related elements and processes is called "flood risk system".

Flood risk management can be defined as the process of managing an existing flood risk situation (narrow sense), it includes the planning of a system, which will reduce the flood risk (wider sense) (Plate 2002). It stands for reducing the flood risk and it is a rational approach for flood disaster mitigation. According to Schanze (2006) flood risk management is "holistic and continuous societal analysis, assessment and reduction of flood risk", where "holistic" stands for the flood risk system which is comprehensive. "Continues" refers to the assessment of flood risks, their dynamic change and risk reduction activities.

Flood risk management tries to concentrate protection efforts to areas with a high expected damage by adjusting flood protection to the risk situation (Messner and Meyer 2006). In order to achieve the best management results, a risk-based approach is appropriate by using the budget and resources available. As discussed before flood risk can be considered as a product of the likelihood or chance of flooding and impact of flooding (e.g. social, economic, environmental and other impacts are part of negative consequences) (Popovska et al. 2016). In this case risk originates if the vulnerable element is exposed to the hazard (Schanze 2009). (see Fig.2.2)

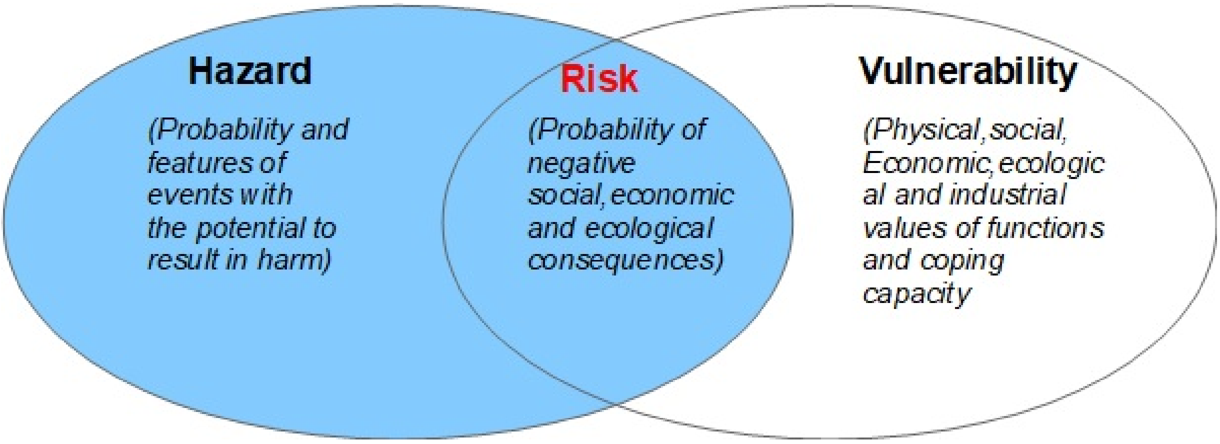


Fig. 2.2 Scheme on risk as inter-relation of hazard and vulnerability (Schanze 2009)

According to Popovska et al. (2016) four main strategies of flood risk management can be distinguished. There are elements of flood management which are related to a particular flood management strategy, which are effective for planning flood risk management measures (Popovska et al. 2016):

Reducing Flooding

- dams and reservoirs
- dykes, levees and flood embankments
- catchment management
- channel improvement

Reducing Susceptibility to Damage

- floodplain regulation
- development and redevelopment policies

- design and location of facilities
- housing and building codes
- flood proofing
- flood forecasting and warning

Mitigating the Impacts of Flooding

- information and education
- disaster preparedness
- post-flood recovery
- flood insurance

Preserving Natural Resources of Flood Plains

- floodplain zoning and regulation

The flood risk management process consists of three phases: pre-flood planning; flood emergency management and post-flood recovery (Ahmad and Simonovic 2006). In order to reduce flood damage, in pre-flood planning phase flood management options such as structural and non-structural measures are analysed and compared for possible implementation. Flood emergency management phase includes flood forecasting and updating process. Post-flood recovery phase includes the activities that lead to return to normal life from flooding period, also the implementation of flood mitigation strategies.

There is a slightly different approach regarding different modes of management in flood risk management process. According to Schanze (2006) the following modes of management can be distinguished: the pre-flood, the flood event respectively flood management and post-flood modes. Since flood risk management is considered in a broader sense, the modes are extended to risk analysis and risk assessment. Also important to highlight that there are “long term” and “operational” approaches regarding these modes with different methodological requirements (Plate 2002).

The aim of the pre-flood mode is the reduction of flood risk in the long-term. Since time and resources are available, flood risk may be examined in detail, some alternatives in terms of prevention and preparation may be discussed. In case of event management mode, response times are short and the resources are limited, this mode refers to an operational approach. Flood risk has to be estimated in the short-term, decisions should be strongly formalized and taken very fast. The post-flood mode aims to recover and to avoid the further negative consequences. According to its organizational structure, it may be seen from event management to the pre-flood mode (Schanze 2006).

According to some authors a temporal cycle of flood risk management begins with a flood event management phase, followed by the post-flood and the pre-flood modes, though Schanze (2006) states that for research and flood risk management practice important to remember that previous actions influence the future ones and also the modes can overlap in practice (e.g. including of preventions measures in recovery activities).

Considering the authors and the literature have been reviewed, according to the Directive of the European Economic and Social Committee on flood risk management, flood prevention, protection and mitigation (EUROPE 2004) it could be concluded that the following element are crucial in the flood risk management process:

- ***Prevention*:** preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding; and by promoting appropriate land-use, agricultural and forestry practices

- ***Protection:*** taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location

- ***Preparedness:*** informing the population about flood risks and what to do in the event of a flood

- ***Emergency response***: developing emergency response plans in the case of a flood

- ***Recovery and lessons learned:*** returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population

2.2.1. Tasks and components of flood risk management

According to Schanze (2006), in order to structure the management activities three tasks with specific components can be distinguished which are based on the concept of flood risk management (see Fig. 2.3). The main tasks of flood risk management are:

- risk analysis
- risk assessment
- risk reduction

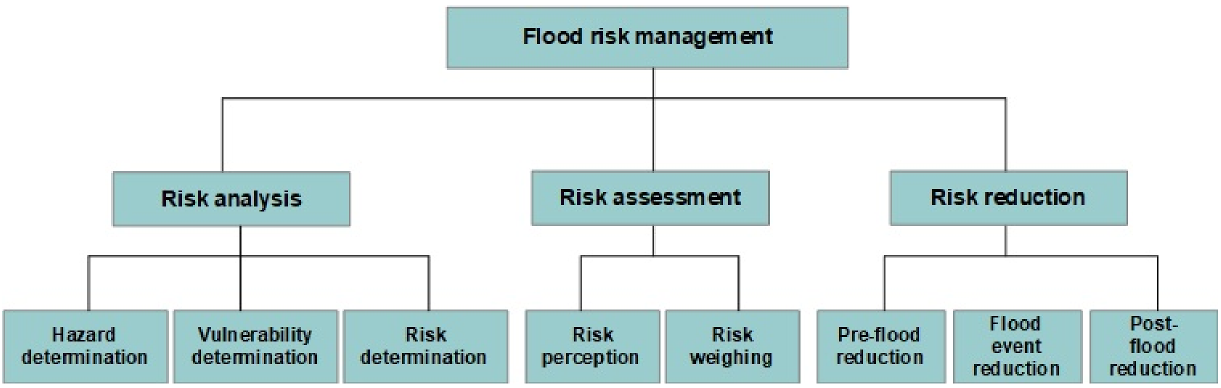


Fig. 2.3 Tasks and components of flood risk management (Schanze 2006)

Flood risk analysis comprises the flood hazard, the flood vulnerability and the flood risk. Risk analysis provides the basis for long-term management for the existing flood protection system. In order to improve the existing system, there is a need to reassess the existing risks and evaluate the hazards based on the up to date information. The vulnerability and the hazards are combined in the risk. The vulnerability of the persons or objects affected by flood is weighted with the frequency of the occurrence of that flood (Plate 2002). Flood risk analysis yields printed or digital risk maps and real time flood forecasting and warning systems. Flood maps serve to provide information about flood probability, flow velocity, water level and etc. Furthermore, they determine weak points of flood defence system and needs for the further actions to be taken in the future. Interactive and web-based flood maps are more flexible and efficient (Schanze 2006). Real time flood forecasting and warning systems use real time rainfall data, it means that the lead time for flood warning alert is not long. The main aim of such systems is to enhance the lead time in order to give time to the people for preparation.

Risk assessment consists of risk perception and risk weighing components. ***Risk perception*** may differ among people depending on their experience of flood events. According to Schanze (2006) risk perception in the construction of risk as the individual or collective imagination of a probable negative consequence which based on values, experiences, feelings and perspectives influenced by the culture of a society. ***Risk weighting*** refers to the fact that risk perception doesn't include decisions with respect to risk avoid and deal. There are options with negative and positive consequences, risk and opportunities refer to those options respectively. Weighing risk determines a degree of risk a probable "cost" which can be balanced in relation to opportunities as "benefits" (Schanze 2009).

Measures and instruments are used for ***risk reduction***. Measures are defined as "interventions based on direct physical actions", instruments are "interventions" based on mechanisms which lead to measures indirectly or influence human behaviour" (Olfert and Schanze 2005). According to these authors, measures can be permanent or temporary. Permanent measures are "direct physical interventions which lead to a durable change of the physical conditions of the flood risk system", whereas temporary measures are "direct physical interventions to reduce the risk during ongoing flood events".

2.2.2. Flood risk management as a decision making process

As discussed earlier flood risk management comprises the analysis of the flood risk system, the evaluation of such a system and the reduction of risk. It is important to stress that flood risk management refers to the societal process in order to design the measures and implement and monitor their effects (Schanze 2009). Flood risk management can be considered as a decision making process which involves stakeholders from various fields such as spatial planners, flood and water managers, emergency planners and etc.

There are several aspects which should be taken into account in terms of designing flood risks related decision making process. For example, types of waters (e. mountainous rivers, lowland rivers), flood types (e.g. flash floods, plain flood), land uses (e.g. rural, urban), planning and administrative systems (e.g. structuring according to catchments), societal (e.g. social, economic, cultural, political) (Schanze 2006).

In order to understand the relation between the three major tasks of flood risk management, which has been discussed above and their functions with respect to decision makers Schanze

(2009) has proposed a basic framework of flood risk management (see Fig. 2.4). Except for the tasks of flood risk management, the framework introduces the two important components such as the flood risk system and the decision making and development process of actors with their strategies.

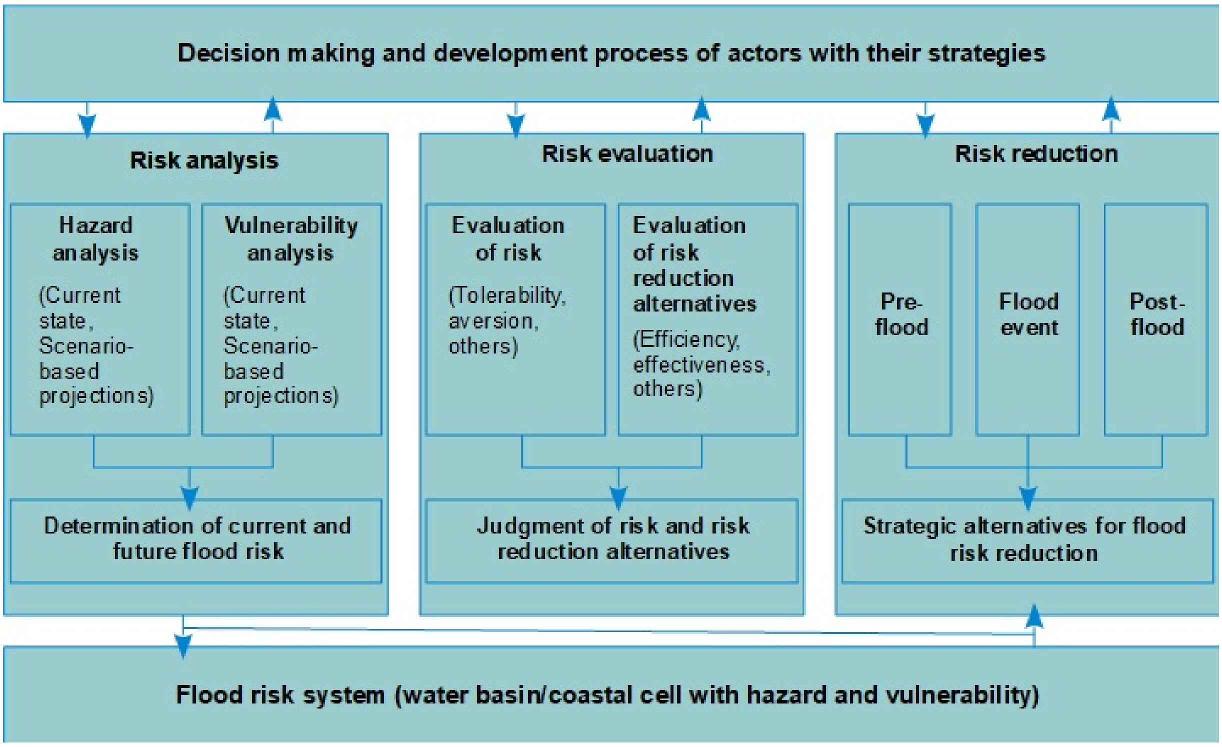


Fig. 2.4 Basic framework of flood risk management (Schanze 2009)

According to this framework, the actors perform risk analysis, moreover they evaluate and reduce flood risks. The flood analysis deals with the hazard analysis and the vulnerability analysis which based on scenario-based projections and they refer to the determination of current and future flood risk. In contrast, the risk evaluation does the evaluation of risk which refers to judgment on risk and risk reduction alternatives.

Risk reduction bears upon formalization of strategic alternatives for flood risk reduction. It comprises the pre-flood, the event and the post-flood management components, which are combined into strategic alternatives by the decision makers. After formalization of the alternatives the risk analysis and the risk evaluation deal with simulation of their effects and judgement of their suitability (Olfert and Schanze 2005).

2.2.3. Integrated flood risk management (IFRM)

Integrated Flood Risk Management (IFRM) can be considered as an extension of the concept of flood risk management. The important issues of this concept are the integration of international policy (good example of this is the role of flood risk and flood risk management in the EU Floods Directive), the integrated national policy guidance, hierarchical planning process from the national scale to regional scale, the linkage between policy and action. In order to have efficient IFRM there are some aspects to be considered: effective tools and techniques and stakeholders to integrate the knowledge and understanding (Popovska et al. 2016).

According to Samuels et al. (2010) there are the following characteristics of IFRM:

- reduce the likelihood of flooding – acting to reduce the frequency, speed, depth or duration of flooding
- reduce the harmful consequences of any flood that may occur by reducing the potential exposure to flooding or by reducing the vulnerability
- support sustainable economic growth by providing space for prudent economic development to maintain robust local and national economies
- support good ecological functioning through ensuring that any modifications of the natural processes of coasts, rivers and surface drainage systems enhance ecological potential and avoid adverse impacts
- promote sustainable development by embedding the policy and practice of flood risk management within broader sustainability objectives by enhancing the robustness and ensuring the adaptability of flood risk management policies and strategies

In order to improve flood risk management, IFRM coupled flood risk management into social, ecological, economic and political context.

2.3. The EU Floods Directive

Despite many efforts to protect against floods it's impossible to abolish them completely. For this reason, in recent years, flood management has shifted from protection against floods to managing the risks of floods (Mostert and Junier 2009). In this context, the European Directive on the Assessment and Management of Flood Risks (2007/60/EC) can make a significant contribution. The EU Floods Directive is legislation in the European Parliament introduced by the European Commission. The main purpose of the EU FD is " to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community" (Commission 2007). It is the first European directive which deals with specifically flood events. Among the definition of "river", "river basin", "sub-basin", "river basin district", there are the following definitions in the EU FD (Article 2): (Commission 2007)

- ***Flood*** – the temporary covering by water of land not normally covered by water, that includes floods from rivers, mountain torrents, Mediterranean ephemeral water courses, floods from sea in coastal areas, and may exclude floods from sewerage systems

- ***Flood risk***- the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event

According to the EU FD food, risk management comprises three main steps (see Fig. 2.5). Member states are required by the Directive to carry a ***preliminary flood risk assessment*** in order to determine river basins and associated coastal areas regarded at risk of flooding and need further risk assessment.

The second step is to provide ***flood hazard maps and flood risk maps*** for the previously defined zones with potential significant flood risks. Flood hazard maps depict the flood extent, water depths and flow directions/velocities for the following three different probability scenarios: (Commission 2007)

- floods with a low probability, or extreme event scenarios
- floods with a medium probability (likely return period - 100 years)
- floods with a high probability, where appropriate

The flood risk maps display the potential adverse consequences, they refer to the number of inhabitants, economic activity, industries, cultural heritage and natural protection areas potentially affected by flooding (Heintz et al. 2012).

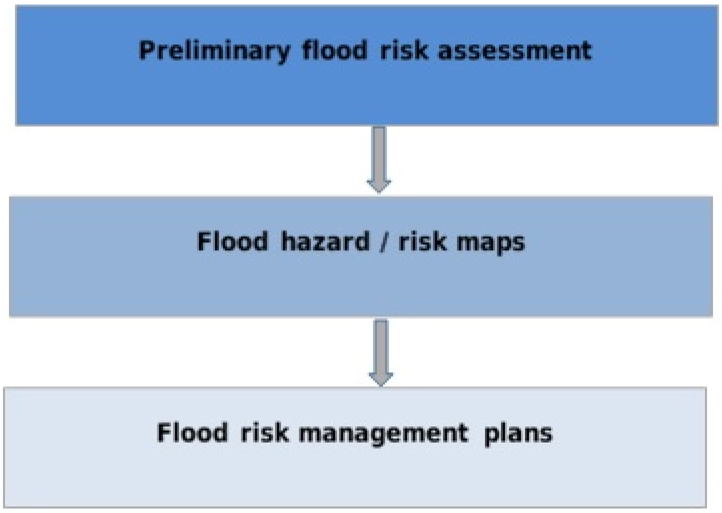


Fig.2.5 Implementation steps of the European Floods Directive

In order to provide reliable information about the area at risk of flooding by defining flood risk zones, to manage and reduce the risk to people, property, the environment, flood risk maps should be developed through co-ordination at river basin level; providing sufficient and understandable information; considering three levels of risk such as areas with frequently occurring flood events, areas with less frequently occurring flood events, very rare flood events; addressing current situation and scenarios for future flood risks (EUROPE 2004).

The third step is the preparation of ***flood risk management plans.*** The plans have to include “appropriate objective” for flood risk management in order to reduce potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity. There are the following objectives of flood risk management plans: (Commission 2007)

- to reduce the adverse impact of floods and the likelihood of floods
- to promote sustainable flood risk management measures
- to look for opportunities to work with natural processes and to deliver - if possible multiple
  benefits from flood risk management
- to inform the public and competent authorities about the flood risk and how to deal with it

The flood risk management plans have to include the measures to achieve these objectives. It is necessary to address all aspects of the flood risk management process, considering prevention, protection, preparedness, including flood forecasts and early warning systems. The risk management plans focus on long-term strategic approach which means including developments that are expected in the long-term (50-100years), another approach is interdisciplinary approach which considers all relevant aspect such as water management, physical planning, land use, agriculture, urban development, nature conservation at all levels (national, regional, local) (EUROPE 2004). It is important to mention solidarity principles, which consists of a three-step approach: retaining, storing, draining. It considers the facts that flood protection measures should not compromise the ability of other, upstream/downstream regions to achieve the level of protection the regions themselves consider to be appropriate (Commission 2007).

According to Commission (2007) the Member states have freedom in terms of setting the appropriate objectives and it is important that the objectives are binding. The Annex A.I.4 states that the plans should include a summary of the measures and their prioritization aiming to achieve the appropriate objectives.

It is important to stress that the EU FD not aiming at avoiding floods or fighting them, as discussed above the aim of the EU FD is the reduction of the adverse consequences of flooding for human health, environment, cultural heritage and economic activity. Therefore, the directive has an approach to deal with flood risks and offers the possibility to recognize flood risk policy in EU member states. According to the directive to consider and deal with extreme events systematically is crucial, but an enhancement of non-structural measures, catchment-based approaches, interdisciplinary planning, stakeholder participation is very important in flood risk management. It could be concluded that the EU FD offers an approach which shifts flood management from the prevalent flood protection to a holistic flood risk management (Heintz et al. 2012).

2.3.1. The EU Flood Directive and the EU Water Framework Directive

The European Water Framework Directive specifies (WFD) the guidelines for a coherent water policy and water management within all member states of the European Union (EC. 2000). The WFD mainly focuses on water quality and ecology. The objective of the WFD in the protection of surface waters and groundwater in order to achieve a good ecological and chemical status (Dietrich and Schumann 2004).

The EU FD is closely linked to the implementation of European water framework directive (2000/60/EC). The FD is less complex compared to WFD. According to Priest et al. (2016) the WFD's main concepts and approaches reappear in the FD (i.e. river basin approach, trans-boundary cooperation, coordination of water quality and quantity management, coordination with other policy fields, important roles for monitoring and public participation and etc.), however strength of the obligations in framework Directives differs considerably, which affects legal effectiveness.

The EU FD requires from the Member States to develop River Basin Management Plans (RBMPs) and adopts the river-basin scale as the management unit. The management units for the WFD are the same as: "river basin districts consisting one or more river basins". For the implementation of the FD, Member States can assign individual river basins to a different management unit (Daniel Hering et al. 2010). It is important to mention that the approach to international management units is comparable. In this context, producing one single international flood risk management plan is very important. There is a requirement that flood risk management planning under the EU FD to be closely linked with river basin management planning under the WFD. The EU FD guidance documents refer to WFD considering this directive as a role model in its requirements for public participation in river basin management planning (Newig et al. 2014).

As discussed earlier the coordination between the EU FD and the WFR plays a significant role in better flood risk management and better decision making. In order to achieve this coordination these two directives have been synchronized, for example, the flood hazard and flood risk maps may be integrated with the review of the river basin district under the WFD, moreover, the flood risk management plans may be integrated with the review of the river basin management plans under the WFD (Mostert and Junier 2009).

It is important to highlight the role of public participation in the FD and the WFD implementation. Public participation is key issue in the WFD planning process (Directive 2003). Three main forms of public participation are introduced in the Directive such as information supply, consultation and active involvement. Public participation in the EU FD appears less crucial compare to the WFD. There is no guidance document addressing public participation in the EU FD, but so called "common implementation strategy" (CIS) (its aim is coordinating implementation of the WFD and providing guidance on specific aspects of the directive) for WFD implementation has been extended to the EU FD (Newig et al. 2014).

2.4. Concept of Decision Support System (DSS)

2.4.1. Decision making

Decision making processes transform information into instructions that are intended to affect system behaviour in such a way that they improve system performance (Sharifi 2004). According to Mintzberg et al. (1976) a decision process is a set of actions and dynamic factors which begins with the identification of an incentive for action and ends with a specific commitment to action. Decision making process starts with identification of problem(s) (Simon

1987), afterwards the individuals or group of decision makers make alternative actions and in order to solve the problem(s) they determine priorities among the alternatives.

Simon (1987) distinguishes three phases in the decision making process: intelligence, design and choice.

- ***the intelligence phase*** – "is there a problem or opportunity for change?" the problems and opportunities are identified, also the stakeholders are defined
- ***the design phase –*** "what are the alternatives?" In this phase decision criteria are defined (formalize problem), a decision support model (decision rules) is developed
- ***the choice phase*** – "which is the best alternative?" This phase includes evaluation of the alternatives, performing sensitively analysis, formulation recommendations and choice

Considering this model Sharifi and Rodriguez (2002) define a framework for planning and decision making process (see Fig. 2. 6).

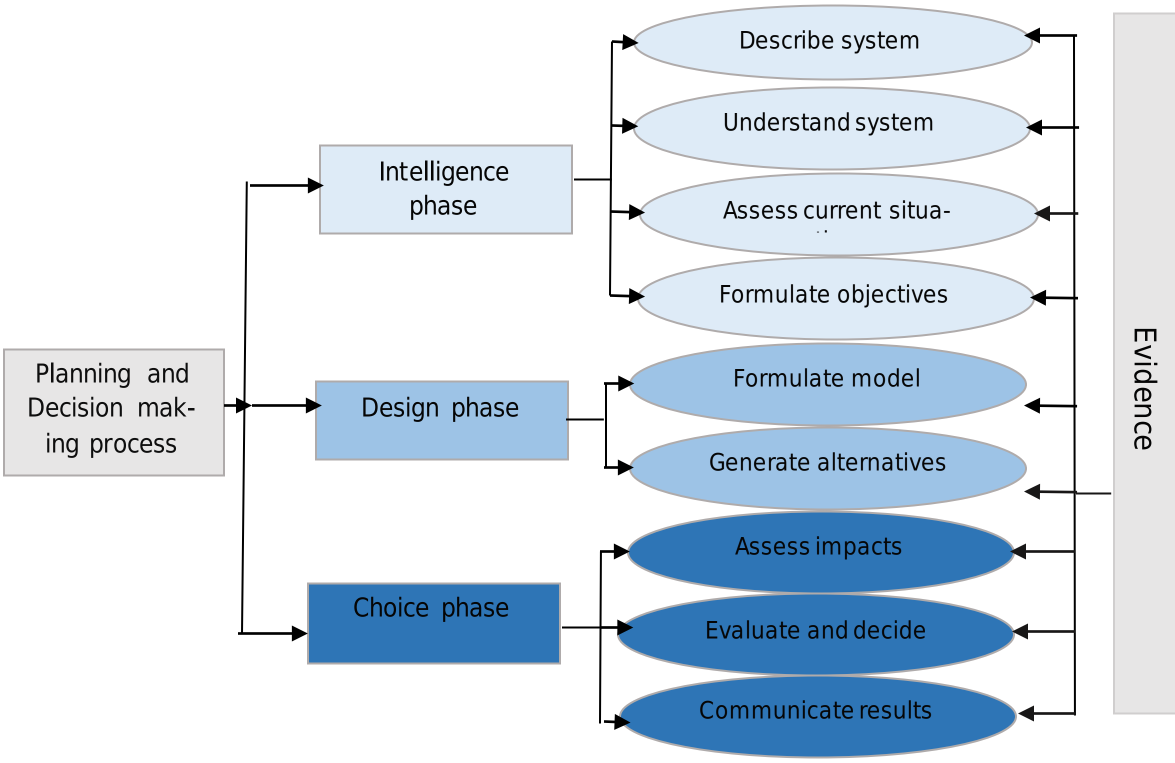


Fig. 2.6 Planning and decision-making process (Simon 1987; Sharifi and Rodriguez 2002)

2.4.2. Decision Support Systems (DSS)

Term DSS first established in the 1970's and 80's. Gorry and Scott Morton (1971) define the term of DSS as an interactive computer based system that helps decision makers to utilize data and models to solve semi-structured or unstructured problems. According to Sprague and Watson (1986) DSS is a system that makes some contribution to decision making. Whereas Loucks and Da Costa (1991) propose the following definition of DSS: "computer-based tools having interactive, graphical, and modelling characteristics to address specific problems and assist individuals in their study and search for a solution to their management Problems". Stuth and Lyons (1993) define the term as contemporary jargon for an integrated approach to the age-old problem of helping people to make better decisions, while Klosterman (1997) defines DSS as system or methodology that assists in poorly or ill-structured decisions by facilitating interactive and participatory decision processes. According to Simonovic (1999) “A decision support system allows decision-makers to combine personal judgment with computer output, in a user-machine interface, to produce meaningful information for support in a decision-making process. Such systems are capable of assisting in the solution of all problems (structured, semi-structured, and unstructured) using all information available upon request. They use quantitative models and database elements for problem solving. They are an integral part of the decision-maker’s approach to problem identification and solution”.

Mainly the definitions of DSS are developed in such a way that they are concentrated on the characteristics of the systems. Some authors present the list of characteristics that must be present in a system to be considered as DSS. According to Geoffrion (1983) such characteristics are:

- it is explicitly designed to solve complex structured problems where the objectives of the decision maker and the problem itself cannot be fully or precisely defined
- it has a user interface that is both powerful and easy to use
- it enables the user to combine analytical models and data in a flexible manner
- it helps the user to explore the solution space by using the models in the system to generate a series of feasible alternatives
- it supports a variety of decision making styles and is easily adapted to provide new capabilities as the needs of the user to evolve
- it allows problem solving to be both interactive and recursive – a process in which decision making proceeds by multiple paths, involving different routes, rather than a single linear path

An important point is that DSS doesn’t replace humans, decision makers are responsible for decision making, while DSS is a tool to provide different functions to help to make better decisions. The main characteristics of DSS are (Zarkesh 2005):

- uses flexible data as inputs, and give alternative solutions as outputs
- assists specific decision makers, individually or as groups
- allows custom design of the system, in which the decision maker can develop DSS interactively
- provides the opportunity to adopt the analytical models used in the decision making process
- allows the decision maker to systematically generate and evaluate a number of alternative solutions
- incorporate substantive knowledge of the decision maker, along with quantitative data and formalizes existing knowledge of processes
- examines the consequences of applying different information and modelling approaches, selects alternative decision criteria, objectives and constraints

Beside above mentioned main characteristics, the following DSS components can be distinguished (Zarkesh 2005): ***sophisticated database management capabilities*** (database part), ***powerful modelling functions*** (processing part), ***user interface designs*** that enable interactive queries, reporting and graphing functions.

DSSs refer to a variety of engineering tasks, including design, planning, management, operations. There are DSSs which have been designed and developed for the different applications, for example, DSS for estuarine water-quality management (Camara et al. 1990); Reservoir management and operations (Simonovic 1992); Impact analysis of catchment (Davis et al. 1991); River management (Ford and Russell Killen 1995); Reservoir management and operations (Simonovic 1992); Simonovic (1996) proposes the structure of DSS for the sustainable management of water resources. Simonovic (1999) discusses a framework for a DSS for flood management. Ahmad and Simonovic (2006) developed a DSS for evaluation of economic losses and evaluation of area flooded due to the operation of flood control structure. Since this research is dedicated to designing and development of SDSS for the mitigation of damage caused by flash flood event, a spatial decision support system (S)DSS for flood risk management will be discussed in the scope of this work.

2.4.3. Decision support techniques

Multi-Criteria Decision Analysis (MCDA) can be defined as a way to collect and process objective information, and to express and communicate subjective judgments concerning choice from a set of alternatives which affect several stakeholders (Zarkesh 2005)**.** Such approach leads to effective decisions that are made by the decision maker(s). MCDA includes a set of alternatives that are evaluated based on conflicting and incommensurate criteria, the criterion can be considered as a term that involves the concept of attribute and objective (Malczewski 1999). The main goal of MCDA is to make a comparison between alternatives and solutions.

There are objective and subjective forms used for decision criteria evaluation. Objective analysis presents an assessment of the decision event considering the potential effects and their significance. Subjective analysis consists of different approaches which lead to helping decision makers to express consistent judgment and choose rationally. The techniques using objective and analysis approaches are called multi-criteria decision methods (MCDMs) (Zarkesh 2005).

As mentioned above the term criterion includes the concepts of attribute and objective. Based on this two main classes of MCDA can be distinguished: ***Multi-objective decision making (MODM)*** refers to the selection of the best solution, it considers single or several objectives simultaneously (natural extension of mathematical programming); ***Multi-attribute decision making (MADM)*** is concerned with choice from a moderate/small size set of discrete actions (feasible alternatives), it refers to as multi-criteria analysis or multi-criteria evaluation (Jankowski 1995). Its main goal is to search for a satisfying alternative rather than for an optimal alternative. It leads to decision makers using a few alternatives to make effective and efficient decisions (Zarkesh 2005).

Keeney and McDaniels (1992) distinguish two main approaches: ***alternative-focused and value-focused approaches.*** The alternative-focused approach identifies values and criteria, develops alternative options and then evaluates an option. Whereas in the values-focused approach the value is crucial in decision analysis. Considering the specification of values, alternative options are developed and evaluated using the predefined value and criteria (Jankowski 1995). This approach focuses more on what is desired rather than on alternatives evaluation. The value-focused approach is more effective when decision problems deal with development and evaluation of alternative options, while the alternative-focused approach is more relevant when the decision problem starts with the choice of options (Sharifi et al. 2004).

Sensitivity analysis identifies the impact of changes in the priority of criteria on the suppliers' performance and order quantities (S.H. Ghodsypour and C. O'Brien 1998). In the decision making process criterion scores express prediction impacts which caused by the adoption of given alternatives, also decision making preferences may be inconsistent, subject to shifting, inaccurate in determination. These problems can be addressed through sensitivity analysis. Jankowski (1995) distinguishes two major approaches of sensitivity analysis:

- considering two alternatives at a time by calculating changes in weight values and changes in criterion scores which are required to bring the two alternatives to an equal position in the final ranking
- considering all alternatives taking part in the evaluation process and calculating changes in their ranking positions as the result of changing criterion scores and criterion weights

2.4.4. Spatial Decision Support Systems (SDSS)

The idea of a Spatial Decision Support System (SDSS) evolved in the 1980's and by the end of the decade, it was included in an authoritative review of geographical information systems (GIS) (Densham 1991). SDSS has an important link with GIS. Until the mid-1990's less attention has been paid to SDSS within the DSS research community. Afterwards, the number of research papers were dedicated to the concept of SDSS in the context of decision making. Recently SDSSs play important role in decisions making systems, they became useful tools for decision makers allowing more effective and collective use of information in addressing complex and often poorly structured questions (Booij 2003). According to Tara et al. (2016), SDSS is a tool for information dissemination which offers decision making capabilities based on the integration of information with geographical parameters. Since more GIS-based applications are considered as SDSS there is no consistency in terms of its definition, also there is no crisp boundary between GIS and SDSS, differences between those systems are not well-defined. GIS is considered as a generator for SDSS because of its power and efficient functions to store, retrieve, analyze, manipulate, and display large volumes of spatial digital data and to create maps (Pelizaro and McDonald 2006). Keenan (2003) states that the simplest perspective on the definitions of SDSS is that a GIS is implicitly a DSS, as GIS can be used to support decision making.

According to Pontius and Si (2015), SDSSs are computer-based systems that combine storage, search, and retrieval capabilities of geographic information systems (GISs) with decision models and optimizing algorithms to support decision making concerning spatial problems.

Multiple spatial criteria are applied to complex data by decision makers, which leads to complex decision making problems. Pontius and Si (2015) describes the number of challenges that may occur in decision making process when dealing with such complex structured problems:

- it may be unclear how much of the attainment of one spatial criterion should be sacrificed in order to attain a given amount of another
- the imperfection of spatial databases with respect to missing variables and erroneous data
- decision makers may choose not to accept a model's results due to concerns regarding the results' validity

In order to solve these problems decision makers may address computer-based, interactive support systems for exploring the problem(s) and searching for solutions. These solutions can be both spatial and non-spatial since solutions to all SDSS problems exist in geographic space and attribute information as well.

As mentioned above there are six main characteristics of DSS. Those characteristics are very much relevant to SDSSs, but since they deal with complex spatial problems there are some more capabilities and functions which are provided by SDSS (Densham 1993):

- provide mechanisms for the input spatial data
- allow representation of the complex spatial relations and structures that are common in spatial data
- include analytical techniques that are unique to both spatial and geographical analysis
- provide output in a variety of spatial forms including maps and other, more specialized types

These characteristics facilitate a decision making process, lead to making better decisions since they are iterative, integrative and participating.

Pontius and Si (2015) distinguishes three main subsystems in SDSS: a GIS, a model management system and a group decision support system (see Fig. 2.7). According to this author, the flow of decision making process also includes the user interface and report generator.

According to this flow of decision making process, the users define the spatial decision tasks. The interaction with the tree subsystems is made through the user interface of SDSS. ***GIS*** is used for data visualization, analysing data using spatial analysis tools, using a database management system for data storage, creating supportive data layers. In order to formalize the problems, the ***graphical interface*** of SDSS is used.

For finding a solution the ***model management system*** uses data analysed by GIS. The ***group decision support*** subsystem stands for enabling group members to observe and evaluate solutions in order to enhance SDSS. The ***report generator*** enables generate reports, based on it the users can evaluate all the alternatives. The users may accept the solutions or redefine the problem(s), also it is possible to perform the entire process again in order to find a better solution.

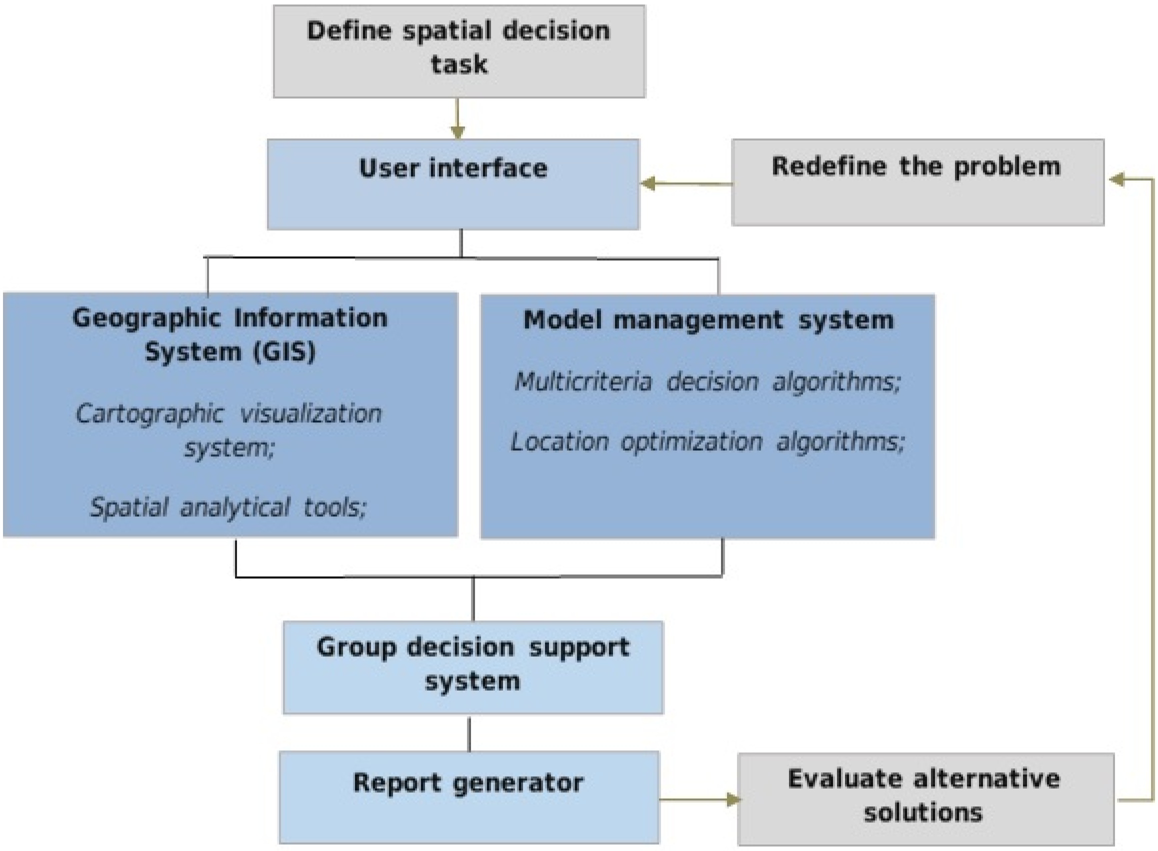


Fig. 2.7 Decision-making processes (Pontius and Si 2015)

2.4.5. Decision Support Systems for flood management

Decision support system (DSS) plays a significant role in effective flood management. As mentioned above there are three phases (pre-flood planning; flood emergency management; and post-flood recovery) in flood risk management process. DSS assists decision makers during these phases, it allows to produce meaningful information in decision making process. According to Ahmad and Simonovic (2006), such a system has the following functions: flood control structures, flood forecasting and operation of flood control structures. It is capable of assisting in the solution of all problems (structured, semi-structured, and unstructured) using all information available upon request.

Selection of appropriate scales for the DSS is important considering its objectives. For example, for flood management to choose the time step (temporal spacing scale), flood duration (temporal support scale), flood frequency (temporal extent scale), spatial resolution (spatial support/spacing scale) and research area (spatial extent scale) is important (Booij 2003). Flood DSS summarizes critical flood information by using data, analysing analytical results and model output.

In general, DSSs are closely related to information technology. With respect to it, according to Miller et al. (2004) there are some challenges for developing effective DSS: ensuring the interoperability of technologies (including computer applications, platforms, operating systems), providing the widest accessibility possible (considering GIS-internet architecture), ensuring internet security, addressing data ownership issues.

According to some authors, different approaches exist regarding components and models of flood DSS. Some of them will be discussed within this work. Booij (2003) outlines the main components of flood DSS: the integrated model systems, the objective and related measures, the scenarios and the database. According to this author, ***the integrated model system*** consists of the natural and social-economic system by proper hydrological, hydraulic and social-economic models, that leads to an evaluation of flood reducing and ecosystem upgrading measures. Within the socio-economic system and natural system, ***scenarios*** are not influenced by stakeholders (e.g. farmers, government and etc.). In the preliminary assessment phase scenarios will not be considered. The scenarios will be defined considering price development, climate change, population growth. ***The measures*** in a river basin can be dyke heightening and strengthening, retention basins and reforestation, that can be evaluated by their effects on the total net revenues in the river basin. ***The database*** includes meteorological, hydrological, hydraulic, social-economic data from several sources.

According to Ahmad and Simonovic (2006), the four components of flood DSS can be distinguished: graphical user interface, knowledgebase, modelbase and database, which stands for integration the knowledge of the problem domain with the database, modelbase, graphical tools in order to assist decision making (see Fig. 2.8).

Graphical user interface provides the functions for problem formulation, data access, presentation of results using graphics, and data visualization tools. It is linked to database, modelbase, knowledgebase. ***Knowledgebase*** (e.g. human expertise, heuristic knowledge) is crucial together with modelling tools in order to make decisions for flood management. It draws conclusions based on available data, consults modelbase, helps flood manager to select a suitable flood damage reduction option.

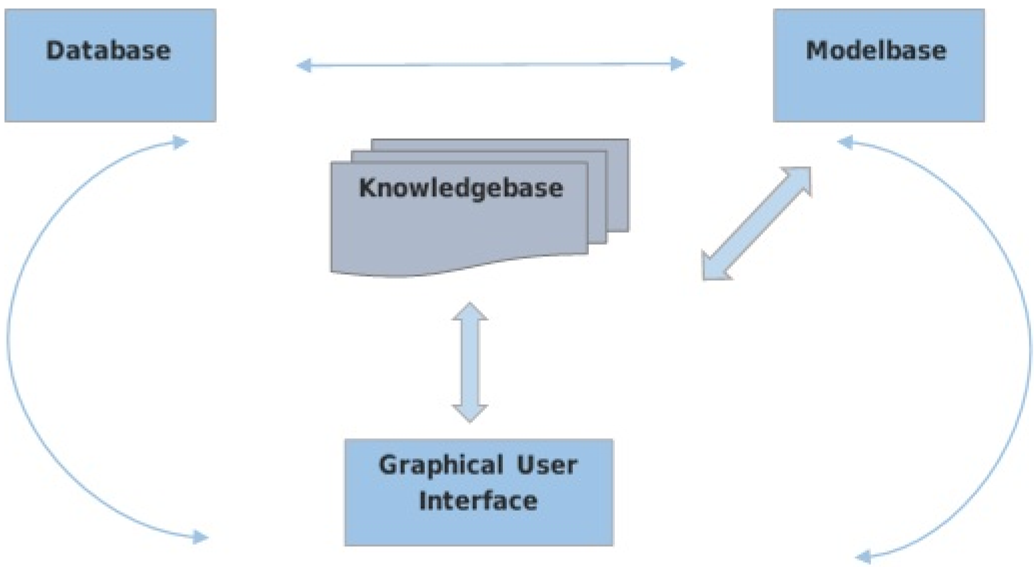


Fig. 2.8 Architecture of decision support system for management of floods

(Ahmad and Simonovic 2006)

Modelbase includes toolset for flood forecasting, hydrodynamic modelling, economic and policy analysis. The modelling tools are linked to the graphical user interface in order to formulate problem(s), obtain required data, provide results to knowledgebase and to the user. ***Database*** consists of all required data for flood management (e.g. topographic data, reservoir data, hydrologic data, infrastructure data and etc.).

The authors also discuss (Levy et al. 2005) three modules, such as selection of flood damage reduction options, flood forecasting and operation of flood control structures. These modules are supported by hydrodynamic and economic analysis models. ***Selection of flood damage reduction options model*** assists selection of a suitable flood damage reduction option. ***Flood forecasting module*** stands for forecast floods, it leads not only to provide information for flood management but also to reduce the loss of life and property. ***Operation of flood control structures module*** assists to simulate the operation of the flood control structure (e.g. reservoir and etc.).

Levy et al. (2005) discuss an overall architecture for flood DSS, which consists of three main components: a flood database, flood modelling functions, a graphical user interface (see Fig.2.9).

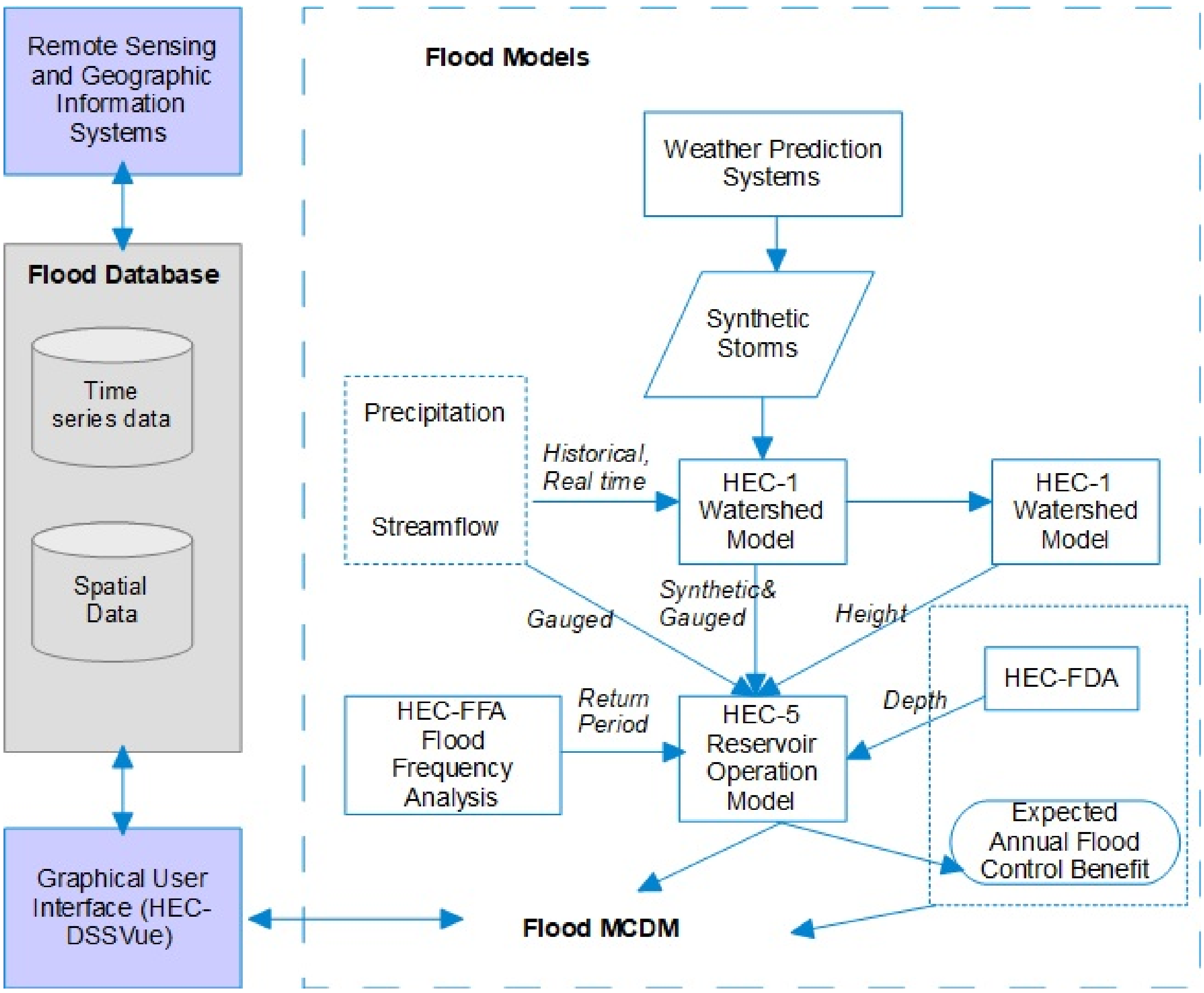


Fig. 2.9 DSS architecture for flood reservoir operation modified from (Levy et al. 2005)

Besides data that is typical for ***flood database*** (e.g. meteorological, hydro-geologic, administrative, population data and etc.), it includes remote sensing data which is an important source of data. It is often used in GIS. ***Flood modelling function*** is one of the most important components of flood DSS. It is designed considering user needs. Flood models include rainfall-run-off simulation, discharge levels, data exploration and assessment. In order to design the hydrological structures, floodplain zoning, the economic evaluation of flood management systems information about flood magnitudes and their frequencies is needed. Significant components of flood modelling function are flooding multiple-criteria decision-making (MCDM) models which leads to compare, select, rank flood alternatives. Since decision makers deal with large-scale and complex challenges, MCDM models addressing flood management problems, also they help to explore challenges. It is important to mention that DSS modules play a significant role in flood evacuation emergency planning and flood risk mitigation and control.

Graphical user interface stands for interactive flood queries, reporting, and displaying which includes spatial data handling capability, sensitivity analyses of flood model parameters, the editing function of flood inundation maps. It should be stressed that interfaces determine the scope of the interaction between the computer system and the user (Al-Sabhan et al. 2003).

Flood DSSs have the capability to mitigate flood disasters by means of improved data collection and the rapid dissemination of information to affected areas (e.g. maps of potential flood water distribution). They are able to increase the role of society to anticipate, resist, cope with, and recover from the impact of a flooding disaster (Levy et al. 2005).

2.5. Concept of Spatial Data Infrastructure (SDI)

In recent years the demand for geographic information (GI) is much increased. Due to the rapid development of spatial data capture technologies, the amount of GI is increased. There is a need to share GI. Nowadays data sharing and interoperability are crucial. The concept of Spatial Data Infrastructure (SDI) is important in determining the way in which GI is used throughout a company, a governmental agency, a nation regions and even the world (Rajabifard and Williamson 2001). In order to share GI, it is necessary to bridge the communication between data providers and users. In the 1980's many national surveying and mapping agencies initiated strategies for providing greater access to standardized GI (Groot and McLaughlin 2000). The principle "collect once, use many times" is very much relevant to SDI, it allows to access and share GI from different sources considering some standards thus enables users to save resources, time, effort to enquire new datasets (Rajabifard and Williamson 2001). GI is the most important and integral component of SDI. SDI have been defined by Groot and McLaughlin (2000) as "a set of institutional technical and economical arrangement , to enhance the availability (access and use) for correct, up-to-date, fit-for-purpose and integrated geo-information, timely and at an affordable price, with the goals to support decision making processes related to countries' sustainable development".

SDI can be considered as a tool for providing effective access to GI. According to Rajabifard et al. (2002) SDI based on a dynamic, hierarchic and multi-disciplinary concept that includes people, data, access networks, institutional policy, technical standards and human resources dimensions, its aim is to facilitate and coordinate the exchange and sharing of spatial data between stakeholders in the spatial data community. SDIs are highly organized, standardized and institutionalized, large collections of spatial data and services (Köbben and Graham 2009). It is important to highlight that a geospatial data service centre plays an intermediate role between data users and data providers in the context of a specific application domain and enterprise (see Fig. 2.10). It allows accessing data considering the administrative, data security, financial services and also data standardization activities (Groot and McLaughlin 2000).

According to Rajabifard and Williamson (2001) in order to realize the advantages of SDI and to improve it the following key factors should be considered:

- awareness of the use of Geographic Information (GI) and SDIs
- cooperation between the various stakeholders
- involvement of the politicians concerned
- knowledge about the type, location, quality and ownership of datasets
- accessibility of datasets
- the successful widespread use of the datasets

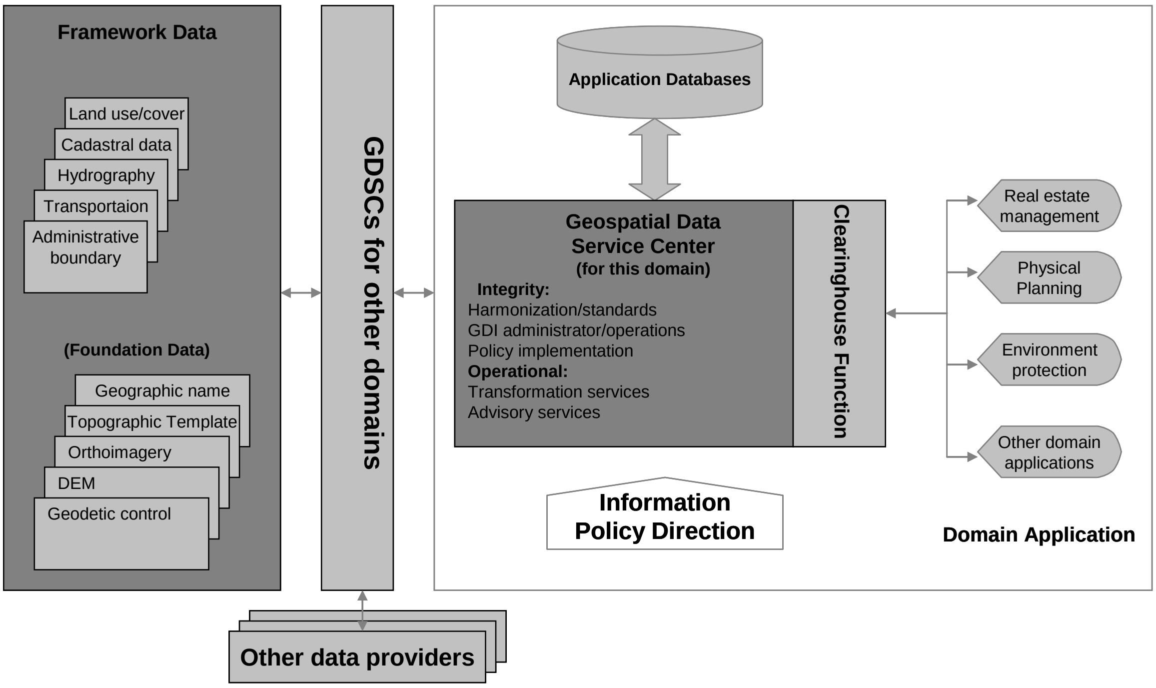


Fig. 2.10 Role of a Geospatial Data Service Centre (GDSC) (Groot and McLaughlin 2000)

As mentioned above GI is a significant and integrated part of SDI, also the cooperation and partnerships between the stakeholders are important in SDI context. It is required to be aware of data type, data structure, data quality, as well as to access and share data is crucial in SDI framework.

2.5.1. Service Oriented Architecture (SOA)

Interoperability plays an important role in SDI environment. Hu (2017) defines geospatial interoperability as the ability of different geographic information systems to share, exchange and operate geospatial data and functions. SDI is an interoperability infrastructure. Interoperability allows different applications (using different languages or concepts) can talk to each other. There are two types of interoperability: technical and semantic, both are a challenge, but semantic interoperability is more complicated (Köbben and Graham 2009). In general data providers don't think much of data integration with other data sets and the users considering their needs mostly require data from different sources that are always a big challenge. Using SDI is important to consider this problem that allows integration of different datasets. SDI is intended to facilitate both users and providers' needs (Aditya and Kraak 2007). Service-Oriented Architecture (SOA) is the most popular and widespread software architecture which is designed to implement interoperability (Akinci and Cömert 2008).

SOA is an approach to build distributed systems which deliver application functionality as services to end-user applications or to build other services (Colan 2004). Nowadays there are many services available on the internet, it is important that they meet all the service requirements of users. SOA ensures to achieve this by constructing a distributed, dynamic, flexible, reconfigurable service system on the internet. Object-oriented models were existed in the 80s, in the 90s the component-based development models were introduced. Nowadays service-oriented models are used and its key benefit is loose coupling. The main characteristic of loos coupling is that a resource is used only through its published service. Service is the key component of SOA, it is a well-defined set of actions, stateless, self-contained, doesn't depend on the state of the other services (Sahin and Gumusay 2008).

SOA consists of three components: service provider, service registry, service requester (see Fig. 2.11). In order to maintain automated discovery and the use of service, SOA uses three operations: publish, find and bind.

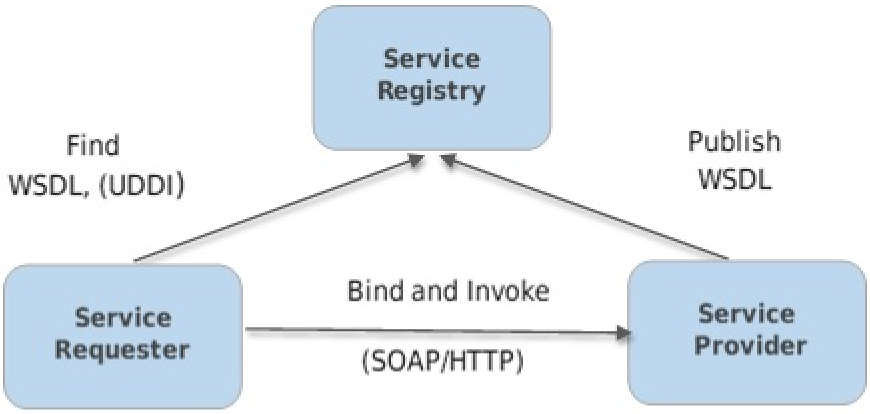


Fig. 2.11 The basic operations in SOA (Sahin and Gumusay 2008)

According to Sayar (2008) above mentioned three components can be described as the following:

- ***Service provider*** publishes services to a registry and makes it available on the Internet for the requests of the consumers

- ***Service requester*** (client) performs service discovery operations on the service registry in order to find the needed service; then accesses services

- ***Service registry*** helps service providers and service requesters to find each other by acting as a registry of the services

Sahin and Gumusay (2008) discuss the main benefits of SOA. One of the key benefits of SOA from users' perspectives is an open and interoperable environment that is based on reusable and standardized components. The applications based on SOA provide the functionalities considering the users' need. In SOA the inconsistency and repositories of data are avoided since data used for a given processing activity are not stored locally, it leads to increase the quality of the output, in cases when data from different sources are used.

2.5.2. Components of SDI

According to Rajabifard and Williamson (2001), the core components of SDI are policy, access network, technical standards, people and data (see Fig. 2.12).

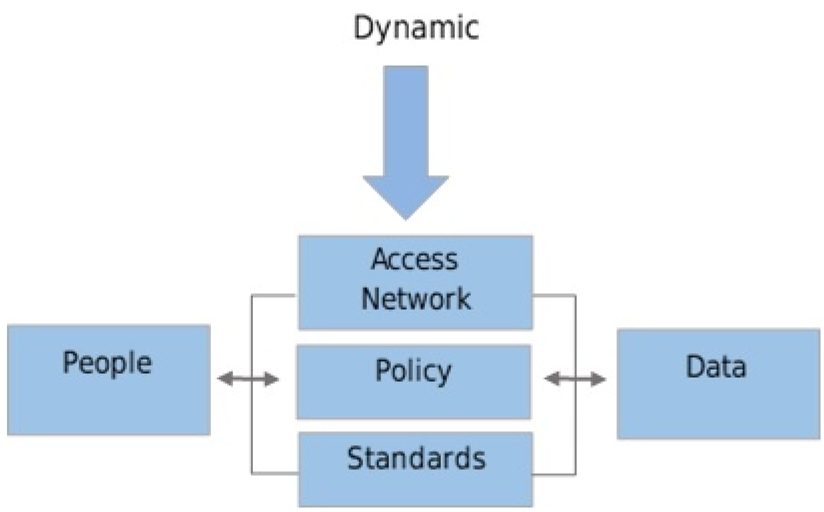


Fig. 2.12 Nature and relations between SDI components

(Rajabifard and Williamson 2001)

Considering different nature of the components' interaction in SDI environment different categories are formed, for example, people and data can be considered as one category, the second category will include network, policy and standards. The authors stress that the second category is dynamic due to rapid development of technology, and there is a need for mediation of rights, restrictions and responsibilities between people and data change. Based on nature and relations between SDI components, it can be concluded that SDI concept is dynamic, for example, dataset access requires utilization of the technological components.

Hu (2017) distinguishes three key components of SDI: geoportals, metadata and search functions.

Geoportals are the most popular and extensively used technology to implement local, regional, national and international level SDIs (Akinci and Cömert 2008). Geoportals can be considered as the most visible part of SDIs since they are the main interfaces, gateway website through which people can search, discover, access and visualize the geospatial resources within SDIs (Hu 2017).

There are different definitions of geoportal. Maguire and Longley (2005)define geoportal as "a World Wide Web gateway that organizes content and services such as directories, search tools, community information, support resources, data and applications". Whereas Tait (2005) states that geoportal is " Web site considered to be an entry point to geographic content on the Web or, more simply, a Web site where geographic content can be discovered". While Koshkarev et al. (2008) define a geoportal as " a set of tools for purposeful and deepened search of various thematic spatial data in the "geo-directory" following the request of a basic or extended search by addresses, postal codes, geographical names, coordinates, etc."

As mentioned before SDIs support the sharing of GI. Geoportals play important role in the sharing process. According to Maguire and Longley (2005) geoportals are web applications where geographic content can be discovered and they have the following characteristics:

- geo-portals organize content and services (e.g. directories, search tools, community information, support resources, data and application)
- geo-portals support to query metadata records and then link directly to the on-line content services
- geo-portals control commercial usage of services (the sale/purchase of data and services).

Similar to the definition of geoportal, there is no consensus regarding the classification of geoportals. Maguire and Longley (2005) distinguishes two groups of geoportals (see Fig. 2.13):

- catalog geo-portals enable organizing and managing access to Geographic Information GI)
- application portals provide on-line, dynamic geographic web services.

According to Tang and Selwood (2005), geoportals are divided into three groups: catalog portal, application portal and enterprise portal. While Aditya (2007) classifies geoportals into two groups:

- National or regional geo-portals (e.g. the US Geospatial One Stop-GOS; GeoConnections; INSPIRE geoportal)

- Thematic geo-portals (e.g. the Food and Agriculture Organization (FAO) portal; European Protected Areas portal; Earth Science Gateway)

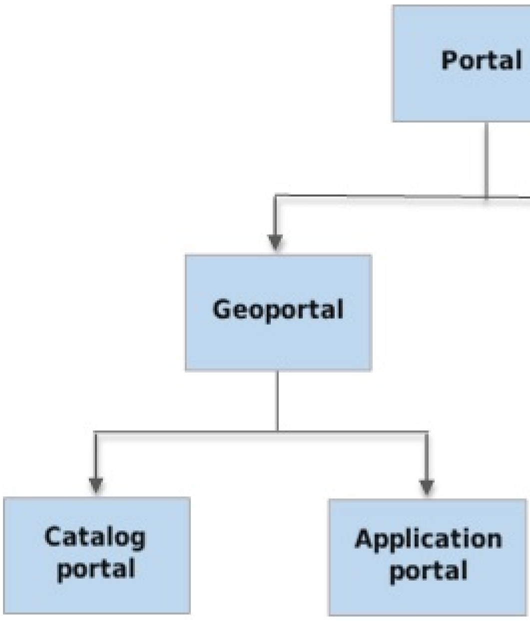


Fig. 2.13 A classification of geoportals (Maguire and Longley 2005)

Geoportals that are part of SDIs are often referred to catalog portals. In order to describe the nature and the location of resources in SDI, catalog geoportals create and maintain metadata catalog. They enable the publication and discovery of collections of geospatial resources (offline and online data services). For data publication metadata is created by data (service) providers using the catalog client. Service providers register their services and also supply metadata description. Geoportal transfers metadata records into a consistent, searchable catalog and makes the catalog available to users (Akinci and Cömert 2008). Through the catalog the users can search for services provided by service providers (Tang and Selwood 2005). For data discovery, catalog services should include tools for querying and presenting metadata records (Aditya 2007).

According to the literature about geoportal, the catalog service is a key component of SOA (see Fig. 2.14). As discussed before the catalog porta is an important part of geoportal and sometimes it is understood as the catalog service. For example, Maguire and Longley (2005) specify that a catalog is a service for publishing and accessing metadata, it is very prominent in SDI geoportals. Tang and Selwood (2005) mention that a primary focus of a geoportal is the discovery of geographical content. Considering the role of geoportals in SDI environment, its role is important in SOA and its main goal is the integration of the applications from different sources. The resource discovery process follows the publish-find-bind patter: service providers publish the metadata of their data and services to a geoportal; users perform a search on the geoportal and find data; users consume data and services from providers (Maguire and Longley 2005).

Current geo-portals have some disadvantages: lack of search capabilities and lack of appropriate navigation tools. It is important to improve the usability of geo-portals considering users' needs. There are users with different backgrounds and skills; it is obvious that their needs are various in terms of using geo-portals to discover data. Providing effective search capabilities, effective visualization (i.e. space-time plots, parallel coordinates plots and etc.), effective discover and explore spatial data is very important, however, there might be some challenges regarding data exploration from different sources and their relationships, because of the lack of search capabilities (Aditya 2007).

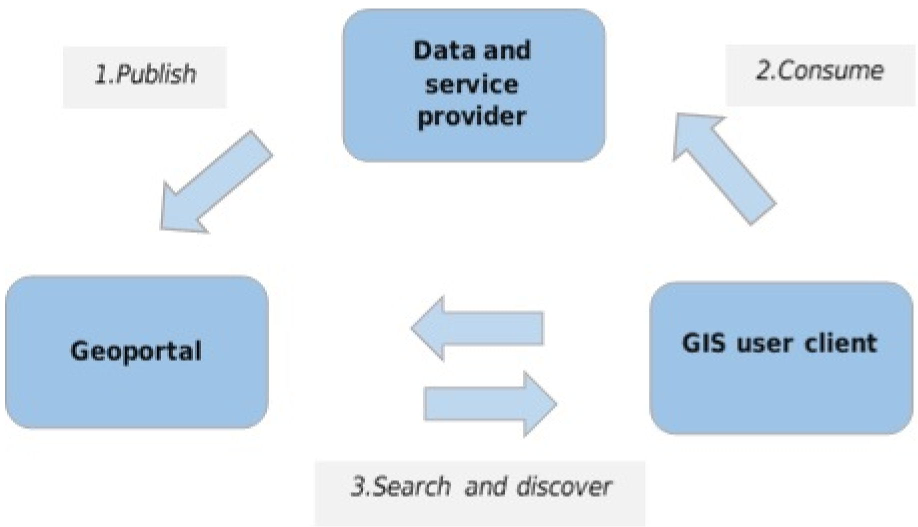


Fig. 2.14 The role of a geo-portal in a SDI (Maguire and Longley 2005)

Metadata mostly defined as "data about data" or "data which describes attributes of a resource" or "information about data". The idea of metadata is quite broad.

Metadata is an important component in SDI environment. It provides information about data and functions offered by the services, thus it describes geospatial services. When data and services are integrated into SDI, metadata helps users to understand and use geospatial resources, also it allows to reuse data and geospatial resources.

Quality of metadata is important, as it enables to discover data and resources easily. Metadata quality also links to standards that define the elements should be included in metadata (e.g. locations, time, thematic attributes, data types, data collectors, published years, coordinate systems and etc.), it ensures data and resources discovery (Hu 2017).

Roy and Das (2005) determine certain areas that hinder proper use of metadata in SDI environment:

- GI has nature which is different from conventional sources of information. So the metadata creation for a spatial resource is quite cumbersome

- the heterogeneity of metadata standards poses a considerable threat to issues of interoperability

- the use of standard vocabulary to disambiguate concepts of resources. This requires integration of the existing control vocabularies with data sets from the spatial domain

- development of crosswalks is another challenge. To achieve interoperability crosswalks are used, which provide mechanisms to transform the metadata and make it available for different standards

It can be concluded that good quality metadata in the SDI framework ensures better use of data and geospatial resources.

Search function is one of the key components of SDI. It allows users to discover data and geospatial resources. It is important to have an effective search function in order to find data and resources in an efficient way. Two types of search functions can be distinguished: text-based search and map-based search (Hu 2017). Test-based search allows a user to type keyword (s) and gets the results on the matched text. Map-based function is interactive, the user interacts with map (e.g. panning, zooming, drawing polygons of areas of interest and etc.) in order to find geospatial resources. These functions have some limitations, but there is some improvement. For example, regarding text-based function there is a translation from keyword-based search to semantic search, which based on matching geospatial resources to user queries by using the semantics of the queries, that results to identify relevant data and spatial services even in case if they are not labelled with the exact same words (Hu 2017).

2.5.3. Web Services

As discussed before SOA can be implemented at many different network environments. The implementation of SOA in the web environment is called Web Services (Sahin and Gumusay 2008). Hu (2017) defines web service as a web application that provides standardized application programming interfaces to allow remote access to data and functions over the Internet. Web services are self-contained, self-described, modular applications that can be published, located and dynamically invoked across the web (ISO 19119:2016). Web services convert an application into Web-application. They are published, found, and used through the web. Web services have several interesting characteristics (OGC Web Services 2018):

- Web services are application components
- Web services communicate using open protocols
- Web services are self-contained and self-describing

- Web services can be discovered (e.g. using Universal Description, Discovery and Integration)
- Web services can be used by other applications
- XML (eXtensible Markup Language) is the basis for Web services

The development of SDI is related to standardization bodies, for example, standards published by the International Organization for Standardisation (ISO) and the Open Geospatial Consortium (OGC) are widely accepted and implemented in SDIs (Rautenbach et al. 2013). Interoperability of web services in SDI environment requires the development and use of uniform standards. There are two types of interoperability: syntactical and semantical (ISO 19119:2016). Syntactical interoperability refers to data transfer between web services, while semantical interoperability assures that the information is processed and transferred between services since the services have a common understanding (Rautenbach et al. 2013). The interoperability is gained through a set of XML– based open standards such as WSDL, SOAP, (UDDI), that stand for defining, locating, publishing, using web services (Sahin and Gumusay 2008). Web services interact with each other by these protocols (see Fig. 2.15).

Fig. 2.15 The four-layer model of the Web services stack (Sahin and Gumusay 2008)

Aditya (2007) defines the service protocols as the following:

- ***Transport Protocol*** is responsible for transporting messages between network applications
- ***Messaging Protocol*** is responsible for encoding messages in a common XML format so that they can be understood at either end of a network connection
- ***Description Protocol*** is used for describing the public interface to a specific web service
- ***Discovery Protocol*** centralizes services into a common registry

Since there are standard interfaces and messaging protocols web services can be integrated for solving complex problems, web services can be used on different platforms, also they can be used remotely and by multiple users at the same time.

2.5.4. OGC Web Services

As discussed above GI comes in different formats and from different sources. Integration of such data is very important in general and in flood risk management process particularly. SOA approach is important regarding this issue, thus the creation of web services is necessary in order to have SOA architecture for GIS services. Sayar (2008) distinguishes three categories of GIS services:

- ***Data Services*** are tightly coupled with data sets. They offer customize data to users. It consists of the following services: Web Feature Service (WFS), Web Feature Service-Transactional (WFS-T), Web Mapping Service (WMS) and Web Coverage Service (WCS)
- ***Processing Services*** provides operations for processing or transforming data using user-specific parameters (e.g. projection and coordinate conversion, rasterization, vectorization, map overlay and etc.) The following services are part of this category: Coverage Portrayal Service (CPS), Coordinate Transformation Service (CTS)
- ***Registry or Catalog Service*** enables users to classify, register, describe, search, maintain, access information about web services, such services are: Web Registry Service(WRS) and Catalog Service for the Web (CSW)

In order to improve the interoperability among geospatial systems, Open Geospatial Consortium (OGC) introduced the OGC OpenGIS Web Services. There are OGC standards that are used for spatial data storage analysis and dissemination process (OGC Web Services 2018):

- ***Catalogue Services*** allows publishing and searching metadata about geospatial data. It is used to register metadata by data providers and also specifies an information model, that includes information about spatial references and thematic information
- ***Geography Markup Language (GML)*** is an XML grammar for describing geographical features. IT is a modelling language used in geographic systems and also for geographic transactions on the internet. There are two parts: the schema (describes the document) and the instance document (contains the actual data)
- ***Observations and Measurements (O&M)*** specifies an XML implementation for encoding observations and measurements from a sensor (archived and real-time)
- ***Open Location Service (OpenLS)*** specifies interfaces that enable companies in the Location Based Services (LBS) value chain to 'hook up' and provide their pieces of applications such as emergency response, personal navigator, traffic information service, and etc.
- ***Sensor Observation Service (SOS)*** allows querying observations, sensor metadata, representations of observed features
- ***Sensor Planning Service (SPS)*** defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor

- ***Sensor Web Enablement (SWE) Common Data Model*** defines low level data models for exchanging sensor related data between nodes of SWE framework
- ***Web Coverage Service (WCS)*** allows interoperable access to geospatial data that has values at each measurement point (e.g. satellite images, digital aerial photos, and digital elevation data)
- ***Web Feature Service (WFS)*** enables to retrieve geospatial data (vector data) using Geography Markup Language (GML)
- ***Web Map Service (WMS)*** allows displaying map images from distributed geospatial databases using HTTP interface. WMS request defines the geographic layers to be processed, and response is one or several map images (JPEG, PNG, and etc.) to be displayed using a browser application
- ***Web Processing Service (WPS)*** allows standardizing input and output for geospatial processing services. It characterizes an interface, which helps to publish geospatial processes. The data used by WPS can be available at the server

All service specifications are collectively referred to OGC Web Services (OWS) and they adhere to communication via HTTP as the distributed computing platform (Kralidis 2004). OGC Web Services architecture enables interoperability among geospatial systems that lead to effective decisions making and improvement of problem-solving process.

2.5.5. INSPIRE Directive

Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 established an Infrastructure for Spatial Information in the European Community (INSPIRE). The directive was entered in force on 15 May 2017. According to the Directive (Directive 2007), Member states shall organize “a continuous monitoring of the implementation progress with respect to the targets set out by INSPIRE” and provide “a three yearly report to the Commission to describe the approach applied by the Member States to translate the requirements set out by INSPIRE into concrete measures and describe the developments of its SDI”.

The aim of INPIRE is the development of European SDI. The main goals of INSPIRE directive are following (Directive 2007):

- supporting integrated European Environment Policies
- development of rules to establish a European SDI for environmental information
- build on national SDIs and international standards
- build on existing digital geodata and spatial data services
- following a stepwise implementation plans

In order to ensure that SDIs of the Member States are compatible and usable in a Community context, common Implementing Rules(IR) are defined in specific areas such as Metadata, Data Specifications, Network Services, Data and Service Sharing, Monitoring and Reporting (Vandenbroucke et al. 2008).

Five groups called drafting teams have been mandated to draft implementation rules regarding the following five components of INSPIRE Directive (see Fig. 2.16) (Bartha and Kocsis 2011):

- ***Interoperability of Spatial Data Sets and Services*** - enlisting 34 data topics that shall be made available in the final infrastructure
- ***Metadat***a - to allow the discovery and evaluation of INSPIRE relevant data sets and services in Europe
- ***Network Services*** - to make it possible to discover, transform, view and download spatial data and to invoke spatial data and e-commerce services
- ***Data Sharing*** - to allow an 'as easy as possible' data exchange between public bodies and to allow third parties, especially citizens to have an as much as possible free and easy access to spatial information covered by INSPIRE
- ***Coordination and Complementary Measures*** – to monitor the organizational and management aspects of the INSPIRE implementation

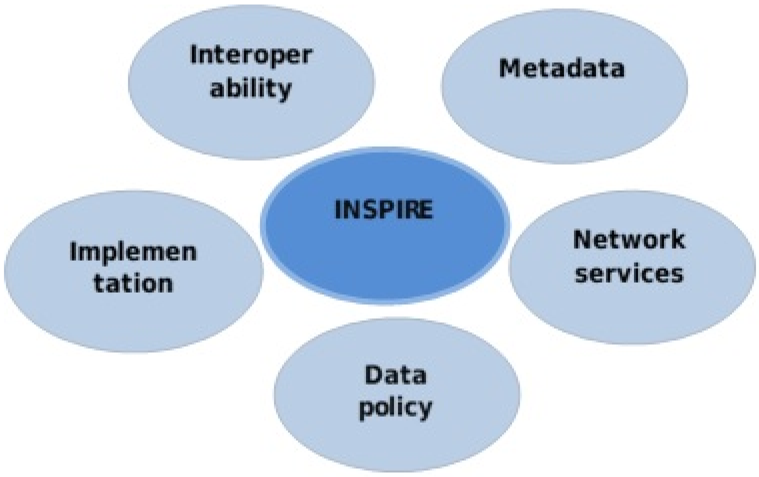


Fig. 2.16 The five components of INSPIRE (Bartha and Kocsis 2011)

As indicated before ***Drafting teams (DT)*** with Thematic ***Working Groups (TWG)*** are mandated to write the draft INSPIRE IR. There are the groups, organizations involved in INSPIRE Implementing rules: ***Spatial Data Interest Communities (SDIC)*** – comment the drafts and bring in experts; ***Legally Mandated Organizations (LMO)*** – check feasibility on national level; ***European commission*** – support, coordinates and outputs the implementing rules in the voting process; ***INSPIRE Regulatory Committee*** – negotiates and confirms the implementing rules submitted by the Commission; ***INSPIRE Initial Operational Capability Task Force (IOC TF***) – Member States test the INSPIRE specifications (Directive 2007).

INSPIRE metadata stands for discovery geodata and network services and spatial data services. It consists of details about the owners of GI, information about conformity, validity, licenses, quality, restrictions for public access and etc.

The following services for the spatial data sets and services are established and operated by the Member States, they are used metadata created accordingly the INSPIRE Directive (Bartha and Kocsis 2011):

- ***Discovery services*** making it possible to search for spatial data sets and services on the basis of the content of the corresponding metadata and to display the content of the metadata
- ***Viewing services*** making it possible to display, navigate, zoom in/out, pan, or overlay viewable spatial data sets and to display legend information and any relevant content of metadata
- ***Downloading services***, enabling copies of spatial data sets, or parts of such sets, to be downloaded and, where practicable, accessed directly
- ***Transformation services***, enabling spatial data sets to be transformed with a view to achieving interoperability
- ***Invoking services*** enable a user or client application to run them without requiring the availability of GIS services allowing spatial data services to be invoked
- ***Registry*** is in fact not a standard service, but obviously, all INSPIRE based services should provide a kind of registry for the stored data

INSPIRE network services enable to consider user requirements, they are available to the public, provide easy access to environmental geodata for the authorities of the European Commission and in the member states.

It can be concluded that the INSPIRE Directive is an initiative for having unified standards for SDI in Europe. Establishment and operation of standardized metadata and network services play a significant role in the European SDI.

2.5.6. SDI in flood risk management

As discussed earlier spatial data are crucial in disaster management and particularly in flood risk management. Since flood events have dynamic, urgent, uncertain nature, some data and functionalities may be inaccessible when they are required. In order to respond to an emergency in time and successfully, there is a need to have up-to-date and accurate spatial data, any delay in data access, usage and dissemination may have negative impacts on the quality of decision making (Mansourian et al. 2006).

The concept of SDI plays an important role with this respect. SDIs can facilitate spatial data collection, access, dissemination, usage for better decision making and for proper flood risk management respectively. Since SDI enables to integrate spatial data from different sources and to share it, it allows users to avoid duplications in data integration process and to save users' resources and time, moreover, it makes possible having collaboration and partnership between stakeholders.

Considering the core components of SDI (e.g. people, data, standard, policy and etc.) SDIs can be regarded as an appropriate framework to facilitate flood risk management (Farnaghi and Mansourian 2013). Since it is possible to integrate spatial web services in SDI environment in order to generate new spatial data and functionality, it should be concluded that the concept of SDI in flood risk management context is important for effective flood risk management process.

2.6. Summary

In this chapter, the concept of flood risk management has been discussed. It stands for managing an existing flood situation, reducing the flood risk, it is a rational approach for flood disaster mitigation. The phases of the flood management process have been highlighted which plays a significant role in flood risk management. It has been stressed that flood risk management can be considered as a decision making process that involves stakeholders from various fields. Since in recent years flood management has shifted from protection against floods to managing the risks of floods, the EU Floods Directive has been reviewed which makes a significant contribution in this context. The concept of (S)DSS is relevant to this research. It plays important role in effective flood management. Such system(s) assists decision makers in decision making process. It has the functions such as flood control structures, flood forecasting, the operation of flood control structures and it is capable of assisting in the solution of all problems using all information available upon request. Another important concept relevant to this research is Spatial Data Infrastructure (SDI). It is a large collection of spatial data and services that allows sharing geospatial data from different sources considering standards. SDIs can be considered an appropriate framework for proper flood risk management, it allows stakeholders to have collaboration and partnership.

3. Conceptual design of Spatial Decision Support System (SDSS) for the mitigation of damage caused by flash flood events

3.1. Introduction

In the present chapter, a conceptual design of a Spatial Decision Support System (SDSS) for the mitigation of damage caused by flash flood events is presented. It consists of SDSS and Spatial data infrastructure (SDI) frameworks. SDSS framework has a modular setup. It comprises several modules (e.g. hazard module, risk module, evacuation module and etc.). SDI framework includes geographical information (GI), discovery services, data access services, geoprocessing services. As mentioned earlier in this research SDSS is considered in SDI environment to make flood risk management more effective. Each module of SDSS is discussed in SDI context considering the data and services requirements, challenges and restrictions. Also, the stakeholders, decision makers, local citizens involved in flood risk management process are discussed.

3.2. Set up of a conceptual design of SDSS in SDI context

A conceptual framework is linked to the long-term planning process which addresses to answer variety of questions the different stakeholders may have with regard to their long-term planning process. Long-term planning is a significant part of developing flood risk management strategies (i.e. long-term objectives, measures, processes). As discussed earlier for effective flood risk management and decision making to design well-structured and functional SDSS is important. SDSS in SDI environment is able to make flood risk management more effective since this approach is based on a conceptual model which considers the EU INSPIRE and the EU Floods directive and its corresponding implementations as the legal framework, it complies with the interoperable standards introduced by the Open Geospatial Consortium(OGC) that presents and integrates unified information into a SDSS system for flood risk management.

The conceptual model presents an overall picture of an ideal situation of set up of SDSS for flood risk management in SDI environment to support effective decision making. The conceptual model consists of two parts: SDSS framework and SDI framework (see Fig. 3.1).

SDI framework is based on OGC implementation standards and specifications. The main components of the architecture are: Discovery service (catalogue service) provides metadata for data and services, that helps to discover which data or services are available; Data access services (e.g. WMS, WFS, SOS); Geoprocessing services (WPS).

SDSS framework has a modular setup. It consists of several modules such as: Hazard module; Exposure module; Risk module; Vulnerability module, Forecasting module, Evacuation planning module; Evacuation module, Consequence module. In flood risk management process flood risk analysis and flood risk assessment are significant, which leads to determination of risk objectively and understanding perception of risk to support effective decisions making. There are four main activities in flood risk management process: Prevention and mitigation;

Preparation; Response; Recovery (Floodsite 2008). All above mentioned modules from the conceptual design are linked to these activities.

One of the activities of flood risk management, prevention and mitigation includes and analyses hazards, risks, vulnerabilities. Since The EU Flood Directive makes the preparation for flood risk management imperative, the EU FD planning steps such as preliminary flood risk assessment, hazard and flood risk maps and flood risk management plans would be included in this phase (Flood Action 2016).

Preliminary flood risk assessment*:* action will be taken only in areas where potential significant flood risk exit or are foreseeable in the future. Member states will identify a particular river basin or sub-basin where no flood risk exists and accordingly no further action would have to be taken.

Hazard and flood risk maps: based on the preliminary flood risk assessment, flood risk maps would be produced for the river basins or sub-basins with significant potential risk of flooding. The maps may show information related to flood extent, depths and velocity of water and the potential adverse consequences.

Flood risk management plans: flood risk management plans would be developed and implemented at river basin/sub-basin level to reduce and manage the flood risk in the areas identified in the preliminary flood risk assessment. They are addressed prevention /mitigation and preparation phases in order to prevent damage caused by floods (e.g. avoiding construction of houses and industries in flood prone area) and to provide instructions to the public on what to do in the flood event.

This research focuses on the flash flooding which mainly occurs in small and medium size catchment areas. The small spatial and temporal scales of flash floods, relative to the sampling characteristics of conventional rain and discharge measurement networks result observational difficulties of flash flood (Borga et al. 2011). Flash flood forecasting is much more complex than the forecasting of excessive rainfall accumulation. The hydro-meteorological extreme events in small and medium sized catchment areas are less predictable. Flash flood occurs suddenly, within minutes or hours of excessive rainfall, its lead time is short, to reduce the exposure is crucial and difficult at the same time, it kills and damages the most. Flash flood is not caused only by meteorological phenomena, it results when meteorological and hydrological circumstances coexist (Norbiato et al. 2008). Considering the characteristics of flash flood, it is important to have dynamic, functional SDSS in order to make flood risk management more effective, to structure the modules of SDSS regarding flash flood characteristics.

Hazard module is considered as a part of prevention and mitigation phase of flood risk management cycle. It is significant to consider the possible occurrence of dyke breaches along the protective dyke rings. All river systems have a flood defence system. It is important to analyse reliability of the defence system and select the locations of failure of the defence system. The breach locations are selected in order to make flood simulation. It is an indication of what might happen if the dykes breach. Flood characteristics such as water depth, maximum flood velocity, time of inundation are calculated for each possible failure location.

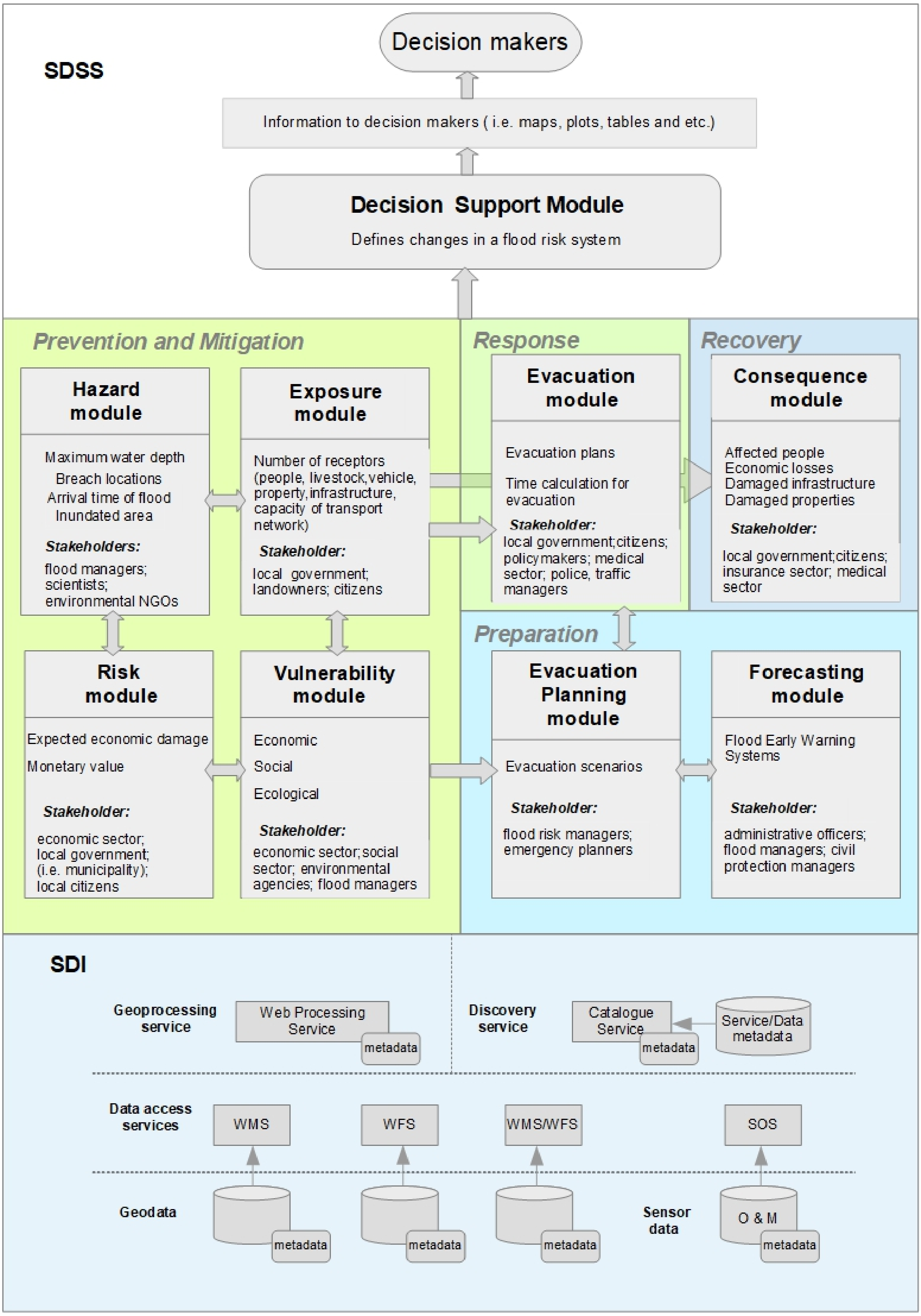


Fig. 3.1 Conceptual design of a SDSS for mitigation of damage caused by flash flood events

In order to calculate flood characteristics, rainfall data is required, that is generally observed daily and it is a measure of the total rainfall that has been received over the previous 24 hours, but more frequent observations of rainfall are available for instance in case of flash flooding.

The hazard module consists of the maps showing breach locations; inundated area (extent), water depth, flood velocity, the arrival time of flood (time of inundation). This module could refer to the flood hazard maps, that are one of the EU FD requirement to EU member states to undertake it.

The hazard module mainly focuses on the following stakeholders: flood managers, consulting engineers, the bureau of meteorology, environmental agency, local citizens. Bureau of meteorology is responsible for the provision of rainfall data. Bureau of meteorology and the authorities that are responsible for the management of flood have close communication. Consulting engineers and environmental agency are involved in flood risk management. Considering flood characteristics and failure probability (established by the stakeholders) they will create a simulation model indicated what might be happened if the dykes breach. This module considers the fact that decision maker can influence the flood characteristics by operational flood prevention measures (operation of barriers and retention areas, temporary raising of dykes with sand bags) and operational flood management measures (opening or closing sluice gates that influence the flooding pattern) (van der Vat et al. 2007).

The user group of local citizens are considered as owners of critical infrastructures and they are interested in protecting their assets against flood. It is necessary that they have access to hazard and risk maps, which is the requirement of the EU FD.

Exposure module is based on the information about receptors (i.e. people, livestock, vehicles and etc.), the module considers the distribution of people, livestock, property, utility, the capacity of infrastructure (i.e. transport network) in relation to the flood characteristics (water depths, flood velocity, inundated area and etc.). This relation defines the exposure to the flood event. In general, exposure is one of the defining components of flood risk, it answers the question ‘who and what can be harmed by flood event? The exposure module is linked to the other modules (i.e. hazard module, risk module, vulnerability module) of prevention and mitigation phase of flood risk management cycle. The module also refers to evacuation module since the reduction of exposure is possible by timely evacuation, which depends on the reliable early warning systems and effective preparedness planning.

It is important to reduce exposure and build capacity and resilience in flood prone areas. This can be achieved by effective flood risk management and decision making. For this, it is necessary to have easily accessible and up-to-date, reliable data and valuable output.

The possible output of this module is flood risk maps (including the extent of flood event) that are overlaid with other types of maps such as: distribution and number of population, number of livestock, infrastructure map, detail map of transport network (included its capacity parameters), a map showing the shelters, which will be used in evacuation module (shelters could be used to evacuate inhabitants), it will include stable and tall buildings and high areas.

Since in the exposure module the comparison is made between flood characteristics and distribution of receptors, the flood hazard maps will be combined with population distribution maps to get exposure maps as a result. Such maps also include information on age of population. The exposure maps are used in the evacuation module.

Local government (i.e. municipalities), flood managers are involved in exposure module since this module integrates information on distribution and number of receptor and as mentioned earlier the exposure maps combine flood depths and flood velocity (flood maps) with population distribution. Exposure model focuses on actual capacity of transport network under flood conditions, it means that traffic managers are connected to this module, also local citizens are incorporated in the module. It is important to highlight again that according to the EU FD flood hazard and flood risk maps should be publicly available.

The exposure maps are linked to evacuation plans which are prepared during the preparation phase. Regarding the week day (working days, weekend) and time the exposure maps can be changed. In the creation of emergency plans, the timing of the event is considered and this information is included in the exposure maps.

Exposure module enables decision makers to identify and establish the priorities for future flood risk management. It links to flood risk management plans (the EU FD) and focuses particularly on prevention or mitigation of damage caused by flood events by avoiding construction of houses and industries in the present and future flood prone areas. According to the EU FD, flood risk maps include flash floods and they distinguish three levels of risk: area with frequently occurring flood events; areas with less frequently occurring flood events; very rare flood events, including where appropriate dyke failures, also addressing the water depth and the potential damage.

Vulnerability module considers flood characteristics (e.g. water depth, flood velocity, duration and etc.) and damage (e.g. people injured, casualties and etc.) for different receptors. This module includes the information based on observation and experience which is used to establish reference damage functions. Vulnerability analysis is performed based on the following vulnerability categories: economic vulnerability (e.g. buildings, fixed assets, inventory) is determined by a damage potential analysis, it estimates the sum of existing monetary values on an object level and calculates the damage of the values considering inundation depth; social vulnerability (social hotspot, people at risk, vulnerable people) determines the social risk, for example, social vulnerability criteria people at risk considers the number of inhabitants for risk zones, also it takes into account seasonal differences (e.g. number of tourists); vulnerable people include vulnerable groups (e.g. age: <9 and > 70); hot spots (i.e. schools, kindergartens, clinics, hospitals and etc.); ecological vulnerability is assessed by describing vulnerability of ecological values, protected area. The assessment of economic, social, ecological risk criteria, performing vulnerability analysis is significant in flood risk estimation process and for risk zones determination, which links to preliminary flood risk assessment phase of the EU FD, that determines flood risk zones.

The following stakeholders participate in vulnerability module: flood managers, experts from economic and social sectors, environmental agencies (environmental NGOs). The communication between flood managers and economic, social, environmental sector is significant in order to perform the valuable vulnerability analysis, to improve the understanding about flood risk vulnerability that can support decision makers in decreasing damage and mortalities.

The output of the module helps to estimate expected damages and its spatial distribution, which is crucial in flood risk management process.

Risk module combines the results of the hazard module, the exposure module, the vulnerability module. It is logical because the components of flood risk are hazard, exposure and vulnerability. The module sums up the probability of flood damage from flash flood for each breach locations within the catchment area. It includes the information on probabilistic depth and velocity considering flood characteristics (i.e. water depth, flood velocity, duration), precipitation, defence performance to provide risk metrics, expected damaged (i.e. economic), monetary value. Expected damage is calculated for all possible dyke failure (breach) locations expressed in currency and number of people harmed.

The output of the module is the maps displaying the location of possible breaches, including the information on expected economic damages (by category: high, medium, low) and the number of people harmed. The module also includes the land use map showing land use function (e.g. residential area, transport, industries, agriculture and etc.).

The output of the module can be used for flood risk management process in the future since it includes risk estimation, risk rating and risk zoning. It refers to flood risk management plans of the EU FD. The definition of the level of protection is a part of the plans that obligates the Member States to determine the level of protection most appropriate for each locality within each river basin.

The following stakeholders participate in risk module: local government, flood managers, economic sector, local citizens. The participation of local citizens is important. Their perception and experience of flood risk should be used in decision making process. There should be communication between owners of critical infrastructures and flood managers who are responsible for the management of floods.

Forecasting module is part of the preparation phase of flood risk management cycle. It consists of a flood early warning system. In general flood forecasting is very important in flood risk management process, also flood lead time in significant in this process.

According to flood forecasting concept, flood early warning system uses real time rainfall data from ground rainfall station(s) (or real time satellite rainfall) and forecasted rainfall data which is calculated based on the historical rainfall event. In case of using forecasted rainfall data there is a lead time before actual rainfall occurs (Hafiz et al. 2013).

For flood forecasting process to have rainfall (real time or forecasted) is required. In order to produce runoff simulation rainfall is converting into runoff, that can be done by a runoff analysis model which would be integrated into SDSS. The other model which is also an integrated part of SDSS is responsible to simulate the calculated flood discharge using rainfall data; It has flood warning function that is based on threshold and warning will be issued when the calculated discharge reaches the certain value based on the threshold (Hafiz et al. 2013). The next stage of flood forecasting process is to generate flood inundation maps with estimated inundation areas.

The forecasting module generates flood inundation map within catchment area. It displays estimated inundation areas and water levels which are used in flood inundation analysis.

The administrative officers, hydrologists, flood managers and civil protection managers are involved in the forecasting module. Their close communication plays a significant role in having effective flood early warning system which leads to flood damages reduction.

Evacuation planning module is linked to the modules of SDSS that were discussed above, since it stands for creation, validation and simulation of evacuation planning (emergency scenarios) based on the analysis which is made in preparation and mitigation phase. This module is also closely linked to the forecasting module. It is important to have and simulate emergency plans in order to make the evacuation process effective if it is necessary when flash flood occurs.

Emergency plans include different type of information that helps stakeholders, decision makers and local citizens to reduce damage and disruption if flooding occurs. Before starting of emergency plans' creation, it is important to take into account who should be involved in the planning process. If a wide range of appropriate stakeholders participates in the creation of emergency plans, it would be useful for planning process because they have appropriate experience and knowledge and it makes emergency plans more efficient. After selection of stakeholders involved in the planning process, actual emergency plans are designed. The special template of the emergency plan is designed. It is necessary to develop emergency plans considering the characteristics of area, local citizens, different type of facilities and etc. It may include the following information: useful sources of information (e.g. URL links), in case if there is a need to access the information through different web sites; environment agency warning codes (with description of symbols meaning); different types of maps (e.g. map showing infrastructure and utilities; map showing evacuation routes; map showing flood extent, flood direction; map showing emergency services and etc.).

The emergency plans improve flood awareness among the population, how they should act on receiving warnings, how they understand the meaning of the warning codes. They are important in effective emergency repairs.

The following stakeholders participate in this module: flood risk managers, emergency planners (engineers, scientist and etc.), local authorities. As already discussed a wide range of stakeholders is involved in creation of emergency plans. Also, it is important to point out that in general the participation of local authorities in important since they are responsible for assessing the impact of flooding on the community.

Response phase of flood risk management cycle includes **Evacuation module**. It is linked to the evacuation plans that are part of evacuation planning module, which consist of different activities. The relationship between activities are significant in evacuation process. Having well-structured evacuation plans leads to shorter time planning which gives more time for evacuation. First of all, the actual situation is evaluated, it is based on the physical parameters of the flood such as depth of water and velocity of flow. If there is a need to evacuate people and livestock, the preparation for evacuation is started. The inhabitants getting information about necessity of evacuation, time of evacuation and the route has to be taken. At the same time, public transport is prepared and evacuation routs are cordoning and after these activities, the actual evacuation process is started. It is very important to calculate time required for evacuation and to use the best route for evacuation. Effective traffic management is crucial in evacuation process. It is important to estimate the roads capacity considering evacuation time and number of people.

In order to calculate evacuation time, there is a model in the evacuation module, which is responsible for the calculation of how much time is required for evacuation and determination of the effect of the traffic management (during the evacuation process on the required evacuation time). The input components of the evacuation time calculation model are, such as the type of departure (slow, fast); exit roads; driving velocity and etc.

The output of the evacuation module is the evacuation map, that provides the information on the existing exits, the best roads to be used (evacuation routes), average driving velocity, expected a total time of evacuation on each exit, the buildings (their function), the location of shelters. The evacuation map based on the evacuation plans which have been validated and simulated in the evacuation planning module.

As discussed before there are several evacuation plans in the module, which are displayed on the maps. Evacuation module is included the following maps: a map showing flood characteristics (water depth, flood velocity, flood extent); a map displaying number and distribution of people at risk, a map of evacuation routes, which also includes evacuation time; a map showing location and type of building at risk and shelter locations.

It is very important to have the coordinated communication between stakeholders and decision makes. The local authorities responsible for flood risk management (e.g. local government, the municipal or provincial authority) are involved in evacuation module. The policy-makers participate in making evacuation plans. The role of traffic managers, police, medical sector, local citizens is significant in the evacuation module.

Consequence module is a part of recovery phase of flood risk management cycle. The module uses the output of the exposure module and the vulnerability module and calculates the damage to population, livestock, property and utilities. Damage to population includes the number of affected people, exposed people (if no evacuation is taken place during flooding, the number of affected and exposed people equals). The module provides information on damage to livestock, property and utilities.

Besides economic and social damage, there are environmental consequences cost by flooding, for example, when factories are affected, when drinking water caption facilities or waste water treatment plants are inundated (Flood Action 2016).

The output of consequence module is a map which combines flood velocity and flood depth map with population distribution maps that results in a map showing the number and distribution of affected people. Based on flood characteristics (i.e. flood velocity, water depth, flood extent) there is a map which depicts building collapse including information on type and code of buildings, also it shows the other objects (i.e. hospitals, schools and etc.) at risk.

The local government participation is important in the consequence module, also the role of local citizens is significant. The insurance sector takes part in recovery phase. Since flooding impacts on human health, both physical and psychological, healthcare sector participation is important in consequence module.

Decision support module is linked to all modules of SDSS. In general, SDSS is a dynamic system. The changes may occur in the module(s) of SDSS. Decision support module defines these changes, for example, changes related to climate change, changes in land use. This module provides different analysis methods, techniques, information to the decision maker (e.g. calculation of damage and people at risk over assessment period, based on this benefit calculation can be done; using, for example, Monte Carlo approach for damage and people at risk robustness calculation; providing strategic alternatives, evaluate and rate the alternatives and etc.).

3.3. SSDS in SDI environment, data requirements, challenges, restrictions

In this research, an attempt is made to investigate a SDSS in SDI environment to make flood risk management more effective. There is a need for time-critical environmental information to support effective decision making for the mitigation of damage caused by flash flood events. Therefore, it is important to utilize a SDI framework to access and use of reliable, up-to-date, accurate and interoperable data and services.

Considering SDSS's modules in SDI framework, some questions might arise, for example, which SDI components are required for the implementation of the modules, which sensor data, geodata could be supported by SDI? To answer these questions, it is necessary to connect the modules to SDI framework. It is important to point out that since this research focuses on hydro-meteorological extreme events in small and medium sized catchment areas, it is required to access and use high resolution geographical information (GI) (micro scale allows a detailed representation of models, geographical features and etc.).

OGC Catalogue Services are available in SDI framework. They are used to access digital catalogues of metadata for geospatial data and services in order to discover which data, services, models are available, what kind of spatial analysis can be performed.

Flood characteristics such as water depth, flood velocity, flood extent (inundated area) are important components in flood risk management process (output of the hazard module). For calculation of flood characteristics, the rainfall data is required. Sensor Web Enablement (SWE) services are applied and integrated into SDI framework. A network of hydrological sensors such as water gauges, weather stations are used to supply sensor data (i.e. rainfall data). A data acquisition system is used to process and encode sensor data as observations and measurements (O&M) and then it is inserted to Sensor Observations Service (SOS). There is a coupled model (hydrological model/hydraulic model) in the hazard module for transforming rainfall amount into a quantity of runoff and taking a quantity of runoff to determine of water depth, flood velocity, flood extent respectively. The coupled model can be considered as a geoprocessing service. The system automatically runs the model calculation and data processing. Web mapping services (WMS) display the maps of flood characteristics (i.e. inundated area, water depth, flow velocity, the arrival time of flood). There might be some challenges regarding implementation of hydrological model/hydraulic model using WPS interface due to its complexity and accordance with OGC standards. Alternatively, a web-based GIS tool(s) would be applied and integrated into the model internally. It also might be that there is no possibility to have cooperated execution of geosimulations in SDI environment due to the restriction of their implementation, in such case the hazard module will be linked to internet sites which provide weather conditions and measured water levels.

Since the EU INSPIRE directive and its corresponding implementations are considered the legal framework and bounding conditions for this work, different datasets in the scope of INSPIRE are discussed. The datasets are used at the local level (high spatial resolution).

Besides flood characteristics, for the creation of flood maps different spatial data sets are required. According to INSPIRE directive spatial data theme ***Hydrography*** is defined in Annex I, but the additional hydrographic elements can be found within other themes, for example, names of ***water features –Geographical Names*** (Annex 1); ***water bodies -Land cover*** (Annex 2); ***water supply and discharge points- Utility and governmental services*** (Annex 3); ***hydrometric stations (water level, discharge, etc.) – Environmental monitoring facilities*** (Annex 3); ***flood risk zones – Natural risk zones*** (Annex 3).

In order to create the exposure maps (the exposure module) the following data are required: ***Population*** (the total population exposed to the flooding) refers to geographical distribution of people, including population characteristics and activity levels, aggregated by grid, region, administrative unit or another analytical unit (Directive 2007/2/EC) - ***Population distribution and demography*** (Annex 3). The theme has no direct spatial features, only contains attributes allowing to describe population phenomenon related to statistical units. Population data is linked to spatial object (statistical units) through their common identifier (Directive 2007/2/EC) – ***Statistical units*** (Annex 3); ***Essential facilities*** (hospitals, emergency centres, fire stations, police stations, schools) refers to ***Utility and governmental services*** (Annex 3) - Includes utility facilities such as sewage, waste management, energy supply and water supply, administrative and social governmental services such as public administrations, civil protection sites, schools and hospitals(Directive 2007/2/EC); ***Transportation facilities*** (airport, runways, railway, bus facilities, highways and etc.) - ***Transport networks*** (Annex 1) includes five distinct transport themes: Road transport, Rail transport, Water transport, Air transport, Cableways (Directive 2007/2/EC); ***Buildings*** (residential, commercial, industrial, public) – ***Buildings*** (Annex 3)- An important characteristic of buildings is their capability to provide services. Because this information is covered by other INSPIRE themes related to facilities (utility and governmental services, production and industrial facilities, agricultural and aquacultural facilities), this data specification only provides a simplified classification of building services. Furthermore, building theme classes share relations with addresses, cadastral parcels and geographical names themes (Directive 2007/2/EC). The data classification addresses the EU FD among the other directives such as the Population and Housing Census Directive, the Energy Performance of Building Directive and etc. The building theme includes the conventional buildings considered as generally hosting human activities (residential, industrial, commerce and services). There might arise difficulties to access shelter locations data sets, since there is no such category in INSPIRE data sets specifications. In such case, the shelter dataset can be provided by local authorities and then integrated into the system. Also, it is important to highlight that there might be some restrictions regarding accessing the historical data (“50-100-year flood”- a flood having a 50-100-year recurrence interval) since the INSPIRE directive spatial data themes don’t provide such data specifications. This historical data sets can be supplied for example, by environmental agencies or environmental NGOSs.

In order to calculate the number of exposed population and the number and values of exposed infrastructures data processing is required, which can be supplied by geoprocessing services, for example, calculation service (WPS), which calculates the of number of population and the number of structures respectively within catchment areas (small or medium sized) and within flood zones; clipping service (WPS); overlay service (WPS); union service (WPS).

There would be some restriction, limitation to perform economic vulnerability analysis (the vulnerability module) in SDI framework. The economic assets are assessed in monetary terms. Because of the complexity of a model which is responsible to perform such analysis, using WPS interface might not be sufficient in this case.

Social vulnerability analysis (the vulnerability module) is supported by SDI components. For performing social vulnerability analysis, flood hazard maps and flood risk maps are used. In order to calculate the number of people at risk and to display the hotspots dataset (schools, kindergartens, clinics, hospitals and etc.) the spatial data sets are used that are supplied by the NSPIRE directive (see above). In social vulnerability analysis should be included information on seasonal differences due to tourism (from population distribution and statistic), such information is not supported by the INSPIRE directive. The information would be provided by the local statistical bureau or tourist agencies. For classification of vulnerable groups by ages (i.e. age: <9 and > 70) classification service (WPS) can be used, that is one of the important components of social vulnerability analysis.

Ecological vulnerability (the vulnerability module) considers the susceptibility of ecological values, protected areas with respect to adverse impacts. Accordingly, vulnerability classes map showing the protected areas, the areas with high ecological values, having protections function and are impacted by inundation, which may lead to a loss of their function. For ecological vulnerability analysis the spatial data sets supported by the INSPIRE directive spatial data theme ***Protected sites*** (Annex 1) - Protected Sites have a known location, boundary and area, based on formal, legal or administrative agreements or decisions (Directive 2007/2/EC); and ***Land cover*** (Annex 2) - land cover data provides a description of the surface of the earth by its (bio-) physical characteristics (Directive 2007/2/EC).

As mentioned before risk module combines the results of the hazard module, exposure module, vulnerability module, accordingly it uses the outputs of these modules. Additional, it requires to use land use data, which are supplied by the INSPIRE directive spatial data theme ***Land use*** - (Annex 3) - Territory characterised according to its current and future planned functional dimension or socio-economic purpose (e.g. residential, industrial, commercial, agricultural, forestry, recreational) (Directive 2007/2/EC). According to the INSPIRE Land use data specification, the exact spatial dimension of all the elements of a spatial plan is given. These elements can be based on other INSPIRE spatial data themes, for example, ***Natural Risk Zones*** (Annex 3).

Flood early warning system (the forecasting module) can't be fully supported by SDI components. The module can use discharge data from the hazard module, but because of the complexity of early warning model, there might be some challenges and restrictions regarding exposing the model as geoprocessing service.

For the creation of the evacuation maps, the evacuation module uses the output of the hazard module (water depth, flood velocity). The evacuation time calculation model is supported by SDI components, the data requirements of the model are supplied by the INPIRE spatial data theme (e.g. transport networks, population distribution and demography, statistical units, buildings).

The calculation of the best route for evacuation process is supplied by Route Service (RS) using WPS interface. The evacuation time calculation is complex data analysis to be performed since the process considers many components such as people present (working hours, holidays); responded to evacuation call; distribution of people over different categories and etc.

The data requirements of the consequence module are similar to the exposure module and vulnerability module since it uses the outputs of the above mentioned modules. Furthermore, as discussed earlier if there is no evacuation takes place when the flash flood occurs, the number of affected and exposed people equals.

The image data used by the modules of SDSS is supplied by the INSPIRE directive spatial data theme ***Orthoimagery*** (Annex 2) - Geo-referenced image data of the earth 's surface, from either satellite or airborne sensors (Directive 2007/2/EC). The modules use high resolution image data. According to the INSPIRE directive data specification, the INSPIRE orthoimagery data specification provides a presentation that constitutes value not only in European but also in local, regional and global contexts.

As the data and service requirements, restrictions, challenges considering the modules of SDSS in SDI context have been already discussed, it is important to highlight which spatial data services are used to fulfil these requirements:

- ***Discovery service*** - for spatial datasets and spatial data service searching (Catalogue Service)
- ***View service*** –for geodata viewing (WMS)
- ***Download service*** – for geodata access (WFS for vector data, WCS for raster data)
- ***Transformation service*** – for geodata transformation (WPS)

After reviewing each module of SDSS in SDI context, it can be concluded that data requirement can be supplied by SDI components, in case if there is a gap in terms of data accessible, the stakeholders could be involved in data providing process (i.e. local authorities, bureau of meteorology, environmental agencies, tourist bureau and etc.). Due to the complexity of the models to be used as geoprocessing services, there might be some limitations with this regard. For example, coupled model-hydrological model/hydraulic model (hazard module), the evacuation time calculation model (evacuation module), the early warning model (forecasting module) are models that are required to perform spatial data analysis with many components and complex functions.

3.4. The role of public participation in flood risk management

It is important to highlight the public participation, stakeholders' involvement in flood risk management and in decision making process.

The effectiveness of flood risk management and better decision making is linked to consider a variety of participation approaches. Since the EU Floods Directive and its corresponding implementations are considered as the legal framework and bounding conditions for this research, it is significant to evaluate the EU FD planning steps (preliminary risk assessments, production of flood hazard and flood risk maps, production of flood risk management plans) in association with stakeholders and public participation.

The EU FD generates a variety of affected stakeholders, ranging from a large number of citizens or abutting landowners from industry and agriculture exposed to an immediate flood risk to various actors without direct exposure to flood hazards but with capacities to engage in or foster mitigating measures (Newig et al. 2014). There is a need for the stakeholders' involvement in a preliminary risk assessment process in order to apply a risk-based approach (Flood Action 2016). The public participation in flood risk and hazard mapping process is quite limited. Some member states have not developed participatory approaches, however, in some countries the participation in flood risk mapping extended only to professionals and experts (Newig et al. 2014). In contrast, according to the EU FD, all stakeholders must be given the opportunity to participate in the flood risk management plans development. Besides the public and the stakeholders' involvement in the EU FD planning phases, there is a requirement from the directive, that the preliminary flood risk assessments, the flood hazard maps and flood risk maps, the flood risk management plans must be accessed by the public.

3.5. Summary

In the present chapter, a conceptual design of SDSS for the mitigation of damaged caused by flash flood event in SDI environment has been set up. An overall picture of the ideal situation has been described, how the conceptual design of SDSS in SDI context could be set up. Since SDSS has a modular setup, each module of SDSS has been discussed in SDI context, also the modules have been described with respect to flood risk management phases. The EU FD planning steps have been included in these phases. The data and service requirements, challenges, restrictions for effective flood management within SDI have been discussed. Since public participation is significant in flood risk management and decision making, the role of stakeholders and decision makers has been discussed.

4. The process of flood risk management

4.1. Introduction

This chapter presents the workflows of SDSS in SDI context. In order to make flood risk management and flood risk decision making process effective, it is necessary to implement the modules of SDSS in SDI environment. For this reason, three workflows of SDSS' modules are designed and created. The workflows are described step by step. The required datasets (including their attributes) are discussed in detail. They consider the different stakeholders who are involved in the flood risk management process. The workflows allow the stakeholder to access the result of the SDSS' modules in a structured and flexible way.

4.2. The workflows of flood risk management process

Scenario 1: Creation of the flood hazard maps using hydrological/hydraulic model and SDI services

As discussed before the output of the hazard module is the flood hazard maps showing the extent of flood, water depth, flood velocity (see Fig. 4.1). For the mapping purposes (to provide a map background for orientation and to understand place relationships), orthoimagery (orthorectified image) data is requested (WCS) from the INSPIRE spatial data theme ***Orthoimagery*** (Annex 2). The next step is to display the hydrography, with the main hydrographic elements including the river network, river basin and sub-basin. The hydrography data is supplied by the INSPIRE spatial data theme ***Hydrography*** (Annex 1).

According to the INSPIRE (UML) data model, application schema –***Hydro Physical Waters*** includes feature type***- 'SurfaceWater'*** which presents the river network. It has the following attributes: geometry - geometry of the feature; levelOfDetail- resolution expressed as the inverse of an indicative scale; localType- provides 'local' name for the type of the surface water (the river); origin-origin of the surface water (natural or man-made). 'SurfaceWater' refers to feature type ***'HydroObject'***- an identity base for hydrographic objects in the real world. It has the attribute 'geographicalName', used to identify a hydrographic object in the real world. The name of water features is imported from Geographical Names (the INSPIRE, Annex 1). Another attribute of 'HydroObject' is 'hydroId' which is an identifier used to identify a hydrographic object and also defines different representations of the objects.

It is important to estimate the breach locations. For this, it is necessary to access the dyke data set and describe the growth of the breach. This information can be included in the hydrological/hydraulic model to determine flood characteristics. The dyke data set can be accessed by INSPIRE Annex3 'Utility and governmental services' which includes information on hydrological elements such as water supply, discharge points and etc. The required attributes of breach dataset are geometry, objectId which refers to the dyke data set.

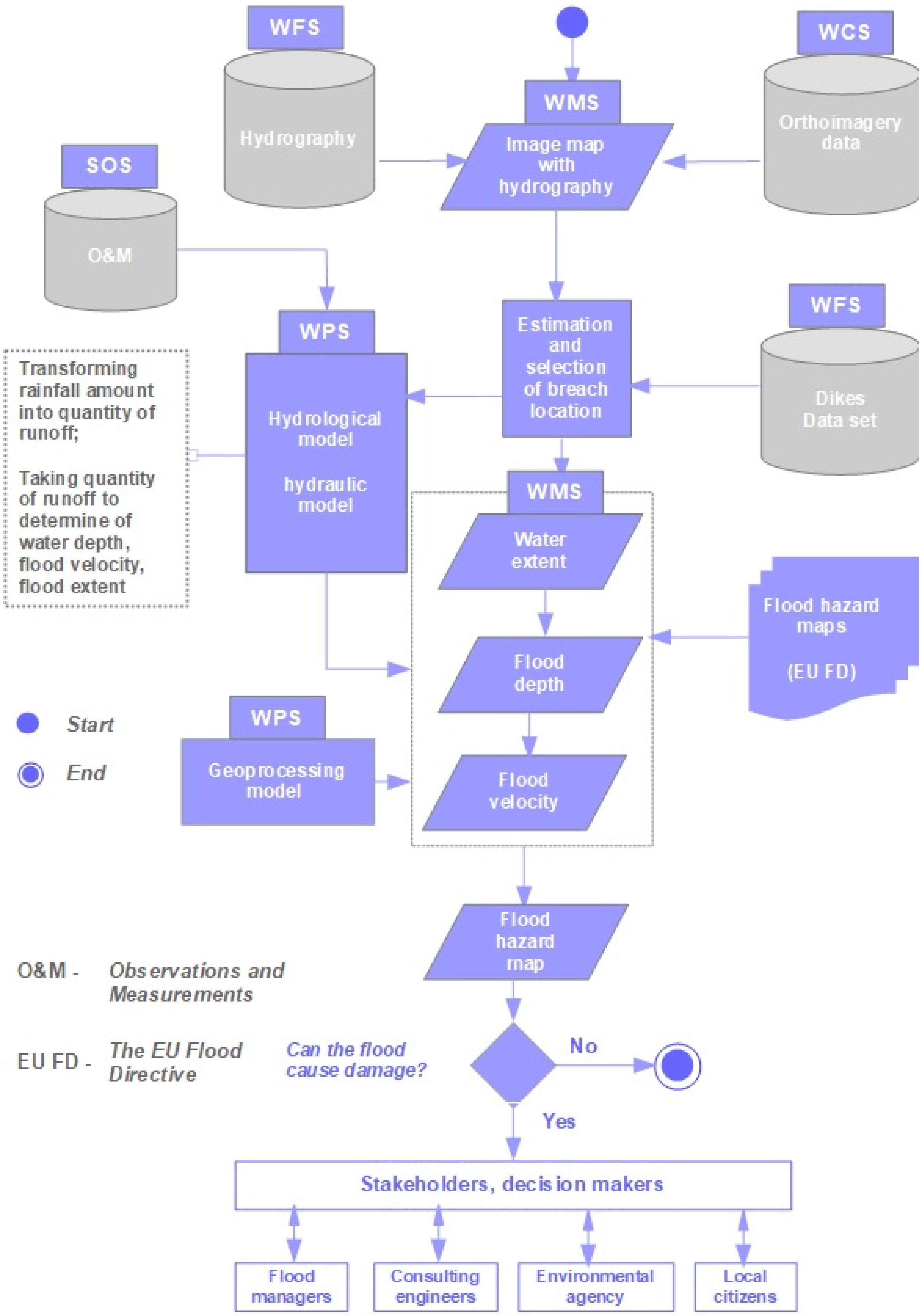


Fig. 4.1 Workflow of the hazard module

The further step is to expose the hydrological/hydraulic model as web service (WPS) and OpenMI (enables the runtime exchange of data between process simulation models and also between models and other modelling tools such as databases and analytical and visualization applications) standard for consuming them (Anthony M. Castronova et al. 2013) (see Fig. 4.2).

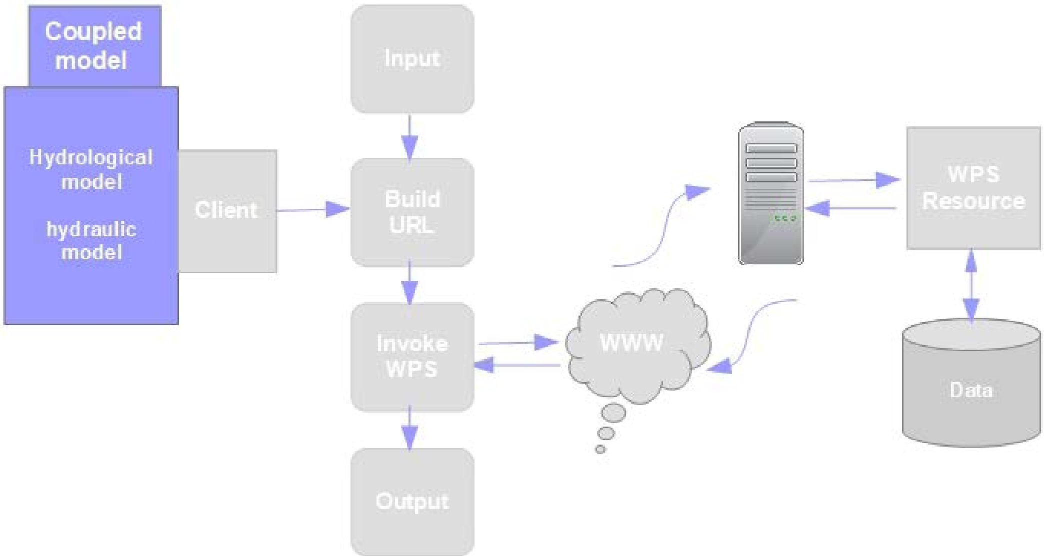


Fig.4.2 Hydrological/hydraulic model as WPS modified from (Anthony M. Castronova et al. 2013)

The approach is based on the existing work, but it is modified regarding the workflow to be implemented within the framework of this research. The process is rather complicated and may arise some difficulties during the implementation phase. In the model, the rainfall data from SOS is combined with the breach location for flood characteristics calculations. As mentioned earlier the hydrologic model transforms rainfall data into runoff, whereas the hydraulic model determines water depth by taking a quantity of runoff. After loading the input data into the model, the URL is built by the client side and WPS is invoked. By developing WPS resource a single computation is performed during its execute phase and the resource returns its output to the client, the calculation data is saved in the local database (local disk) for accessing and using it for the other calculation, data processing during the next invocation (Anthony M. Castronova et al. 2013). Due to limited time to conduct this research, the implementation of this approach would be included in the further research (see chapter 6). There is another approach regarding hydrological/hydraulic modelling, it can be done using HEC-HMS/HEC-GeoHMS and HEC-RAS/HEC-GeoRAS software respectively (see in Chapter 5).

As discussed before the output of the Hydrological/Hydraulic model is flood characteristics for each possible failure (breach) location. Using data view service (WMS) the following maps can be displayed: water depth, flood velocity, flood extent. In order to define flood risk zones, geodata processing is required (see Fig. 4.3), that can be done by geoprocessing model which is exposed as WPS. Also, it is important to point out that the flood hazard maps which are provided by the EU FD can be used as a reference and also can be integrated with the output of the hazard module.

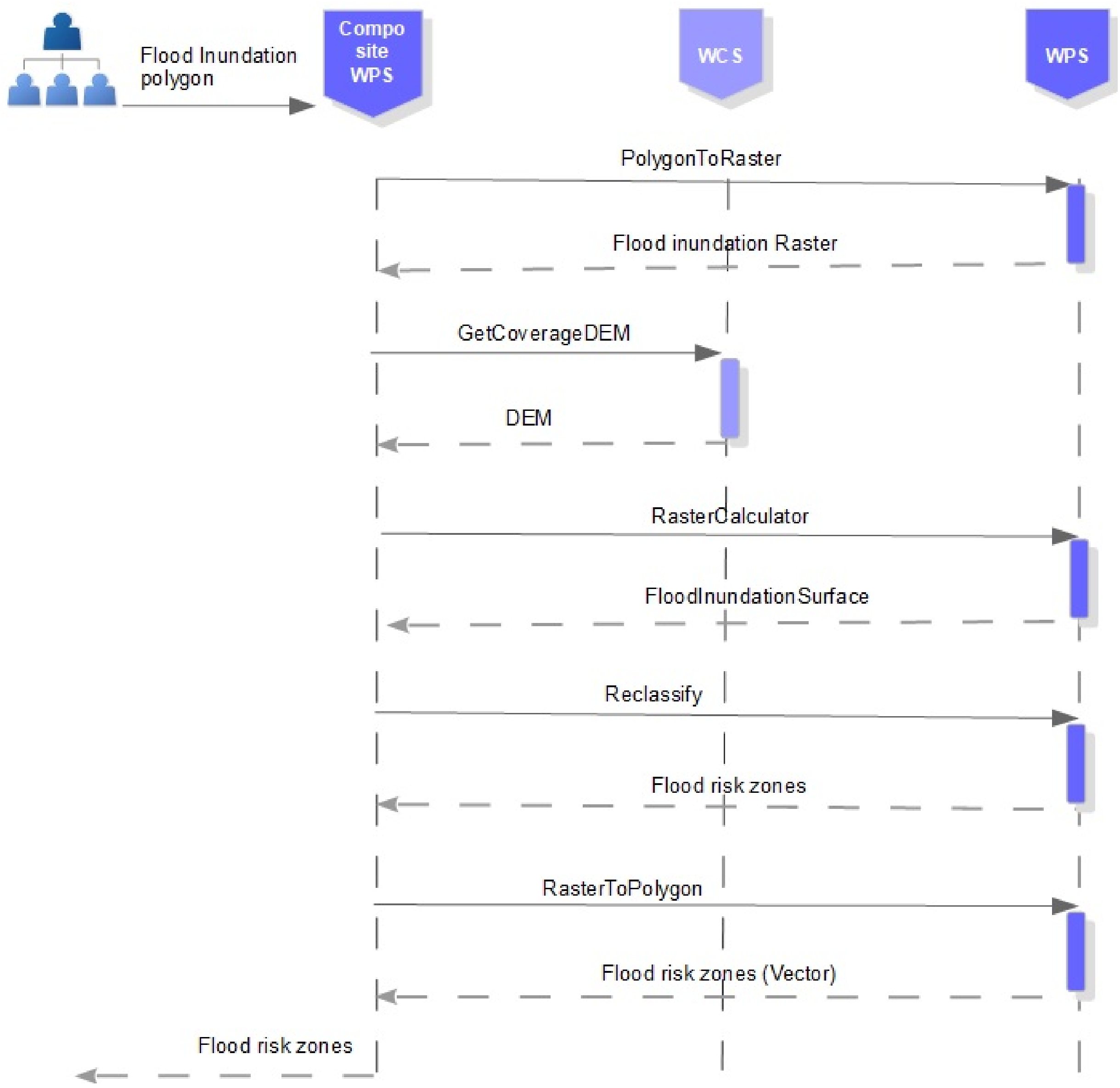


Fig. 4.3 Sequence diagram of the hazard module

Scenario 2: Creation of the exposure maps in SDI environment

The output of the exposure module is the exposure maps showing the spatial distribution and number of population at risk, the spatial distribution of property, utilities, buildings at risk, which are combined with the flood hazard maps (the output of the hazard module) (see Fig. 4.4).

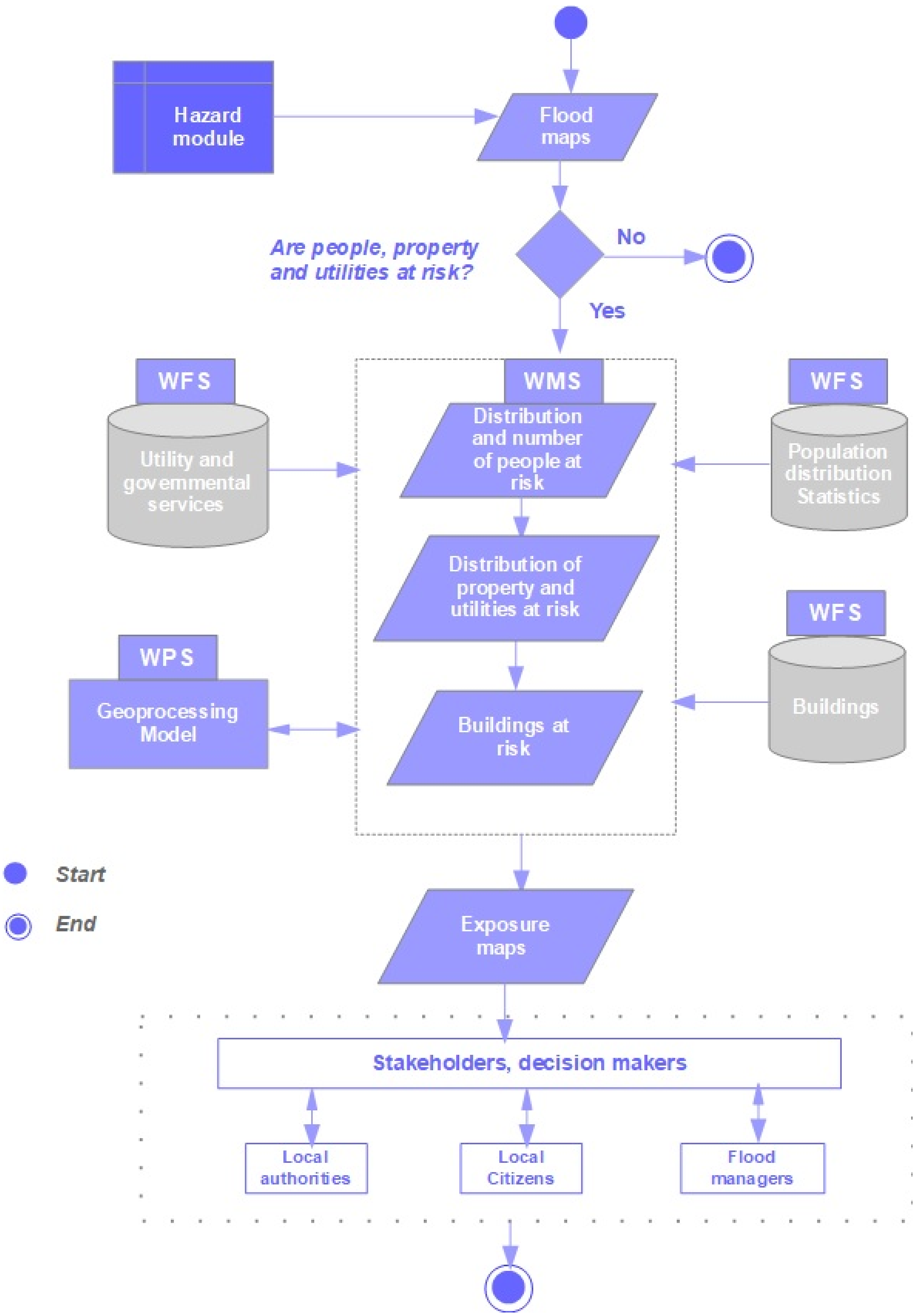


Fig. 4.4 Workflow of the exposure module

For visualization and analysing the spatial distribution and number of population INSPIRE Annex 3 ***'Population distribution and demography'*** is used. The data set has the following attributes: AgeBy5YearsValue (code values for age by 5-year classification items); Age ByYearValue (code values for age by year classification items); geGroupValue (code values for age group classification items); GenderValue (gender of a person or group of persons, female gender, male gender); StatisticalDataStatusValue (code values for statistical data status); StatisticsMeasurementMethodValue (code values for statistics measurement method);

Since the theme 'Population distribution and demography' don't have direct spatial features, its attributes describe population phenomenon related to statistical units, a reference towards a statistical unit might be done using INSPIRE identifier or another thematic identifier. INSPIRE Annex 3 ***'Statistical units'*** consists of Statistical Units Grid (from Grid package) and Statistical Units Vector (from vector package). ***Statistical grid*** (a grid composed of statistical cells) has the attributes such as INSPIRE identifier (external object identifier of the spatial object); EPSGCode (to identify the grid coordinate reference system); Resolution (the grid resolution), Width (the grid width in cell number), Height (the grid height, in cell number). ***Vector statistical unit*** comprises the following attributes: INSPIRE identifier (external object identifier of the spatial object); Thematic identifier (descriptive unique object identifier applied to spatial objects in a defined information theme, i.e. NUTS codes); Country (the code of the country the object belongs to); Geographical name (possible geographical name of the object); Validity period (the period when the statistical unit is supposed to be preferably used and not); Reference period (the period when the data is supposed to give a picture of the territorial division in statistical units).

In order to create the exposure maps showing the spatial distribution of property, utilities, buildings at risk the following data is required: INSPIRE Annex 3 'Utility and governmental services'. ***Governmental service*** (public administrations, civil protection sites, schools and hospitals) includes the attributes such as INSIPRE identifier (external object identifier of the governmental service); Service location (location where the service is offered); Service type (type of administrative and governmental service); The information on service location type (by address, by building, by activity complex, by geometry, by utility node), and on area of responsibility type (by administrative unit, by named place, by network, by polygon) can be accessed using this data set.

The utility networks profile consists of Electricity Network, Oil-Gas-Chemical Network, Sewer Network, Telecommunications Network, Thermal Network and Water Network. They have common utility network attributes such as Utility network type (the type of utility network or the utility network theme), Authority role (parties authorized to manage a utility network, such as maintainers, operators or owners).

The spatial data theme ***'Buildings'*** is provided by INSPIRE Annex 3. It consists of the following attributes: INSPIRE identifier (external object identifier of the spatial object); Condition of construction (status of construction, i.e. functional, projected, ruin); Date of construction; Data of demolition; Date of renovation (date of the last major renovation); Elevation (adapted from the definition given in the data specification of the theme Elevation); External reference (reference to external information system containing any piece of information related to the spatial object); Height above ground; Name (name of the construction). The spatial data theme also provides the information on the common semantic properties of the spatial object types Building by the attributes: Building nature (characteristic of the building related to the physical aspect and/or function of the building); Current use (activity hosted within the building); Number of dwellings; Number of building units; Number of floors above ground).

The web services are aggregated using WPS interface (see Fig. 4.5).

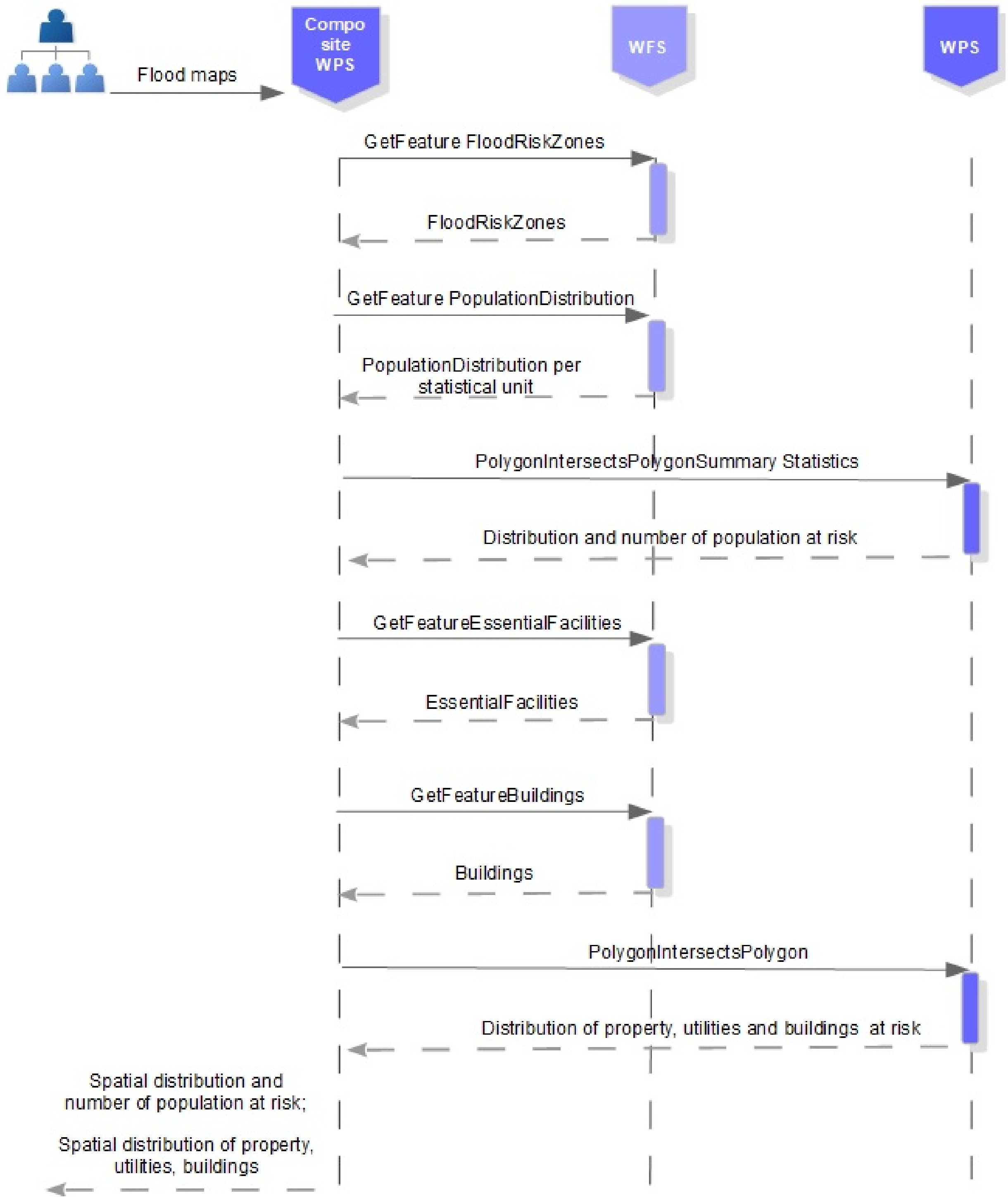


Fig. 4.5 Sequence diagram of the exposure module scenario

As discussed before WPS can handle more than a single process. It performs three mandatory operations such as GetCapabilities, DescribeProcess and Execute. In this research, the concept of ‘centralize Service Chaining’ is used. Centralized Service Chaining means that a single central service invokes all other services, one after the other and controls the entire workflow, which state-of-the-art approach and supported by common technologies (Stollberg and Zipf 2007)

Based on the flood characteristics (water depth, flood velocity, flood extent) the flood risk zones were defined in the hazard module. In order to calculate the number of people at risk, population data which is linked to statistical units to be intersected with the risk zones and the population information to be summed up. This is done by using GIS-based function such as “Intersect” and “Summary Statistics” which are available as WPS process PolygonIntersectsPolygonSummaryStatistics. Afterwards data processing, the number of population at risk (inside the flood risk zones) are determined. It is assumed that the distribution and number of population per statistical unit are provided by WFS.

In order to visualize essential facilities (hospitals, emergency centres, fire stations, police stations, schools) and buildings (residential, commercial, industrial, public) at risk, it is necessary to request the data sets which are provided by WFS-‘Utility and governmental services’ and ‘Buildings’ (INSPIRE annex3) respectively. In order to analyse and display the spatial distribution of property, utilities, buildings at risk WPS process PolygonIntersectPolygiin is used. The exposure maps are visualized by data view services (WMS).

Scenario 3: Creation of the evacuation maps in SDI environment

The output of the evacuation module is the evacuation maps that include evacuation route maps with evacuation time and available shelter locations. They based on the flood hazard maps (hazard module) and exposure maps (exposure module) and refer to the evacuation plans (prepared during preparation phase) which are activated if the evacuation takes place (see Fig. 4.6). The shelter location data set is provided by WFS with all relevant attributes such as address and building capacity. In order to determine the evacuation routes with evacuation time, the data set ***“Transport Networks”*** is provided by INSPIRE Annex1.

It includes road transport network, railway transport network, air transport network, cable transport network, water transport network. Since the scenario addresses to determine evacuation routes, this work discusses the road transport network and its attributes in detail.

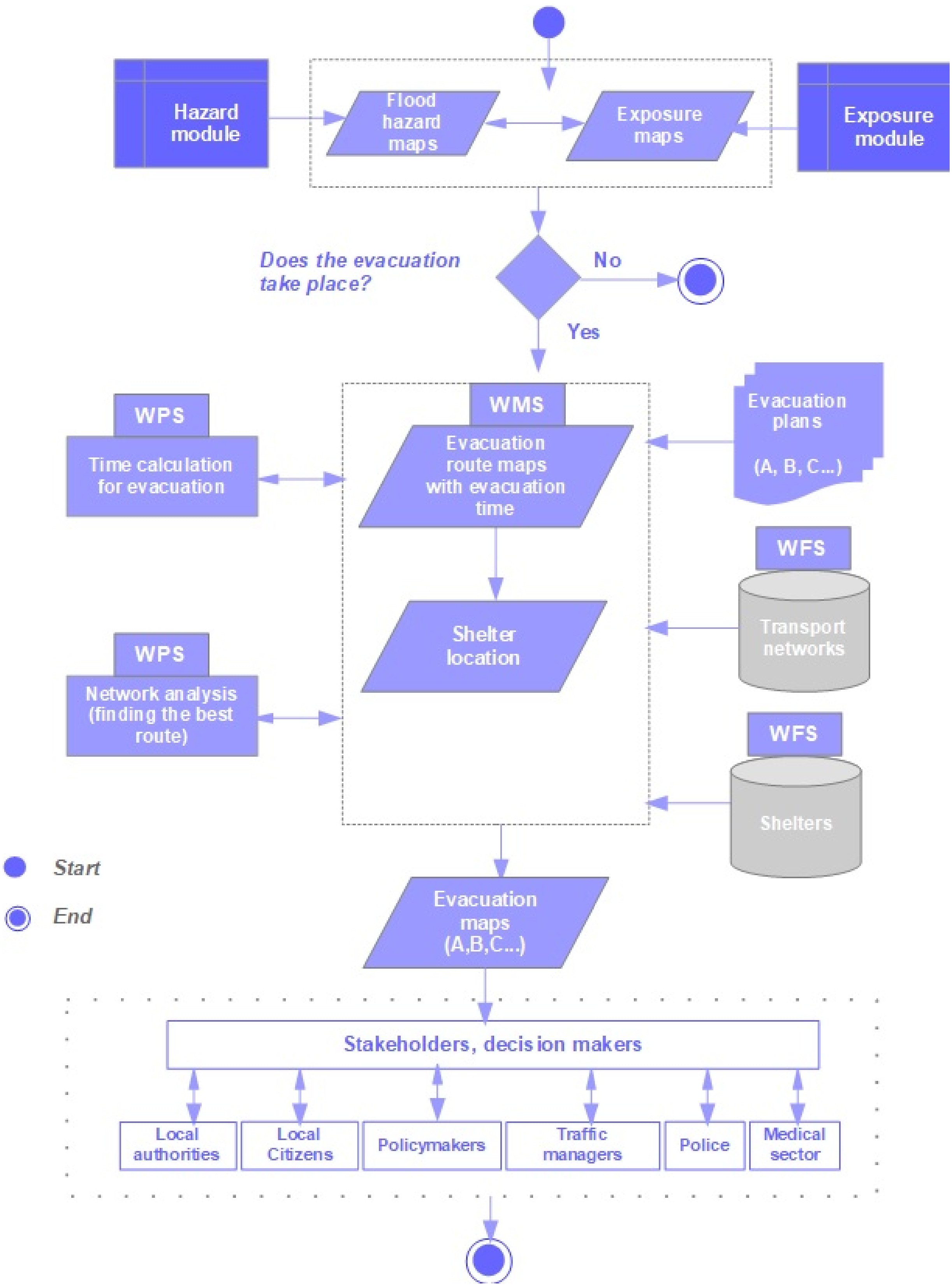


Fig. 4.6 Workflow of the evacuation module

The road transport network includes the following spatial object types and attributes: ***Functional road class*** (a classification based on the importance of the role that the road performs in the road network) with attribute – functionalclass (functional rank of the road network); ***Road surface category*** (specification of the state of the surface of the associated Road Element, indicates whether a road is paved or unpaved) with attribute – surfaceCategory (type of road surface); ***Form of way*** (a classification based on the physical properties of the Road Link) with attribute formOfWay (physical form of way); ***Road width*** (the width of the road, measured as an average value) with attribute – width (road width value); ***Road name*** (name of a road, as assigned by the responsible authority) with attribute – name (name of the road); ***Speed limit*** (limit for the speed of a vehicle on a road) with attributes: speedLimitMinMaxType (indicates if speed limit is maximum or minimum and if it is recommended), speedLimitValue (value for speed limit); ***Road service type*** (description of the type of road service area and the available facilities) with attributes: availableFacility (facility that is available for a given road service area), type (type of road service area); ***Number of lanes*** (the number of lanes of a road element) with attributes: numberOfLanes (number of lanes), direction (indicates which direction the number of lanes is valid for).

The evacuation routes are calculated by the OGC OpenLS Service by providing route service. This service has been implemented in the OK-GIS project (Open and free GIS for Disaster Management). The Route Service (RS) allows route planning on the street network and determines travel routes considering criteria such as start-destination (exit) points or shelters, time, distance, travel type. RS provides the following output (Neis et al. 2007):

- ***RouteSummary*** - general information, such as total route and total route time
- ***RouteGeometry*** - Geometry of the calculated route (line with all way points)
- ***RouteInstruction*** -" Step by step "driving- or walking instructions of the calculated route
- ***RouteMaps*** – Maps display the calculated route

The stakeholders (e.g. rescue workers) and citizens need to have the information on the areas to be avoided in order to by-pass such non accessible or restricted areas. The Emergency Route Service (ERS) has the possibility to include and use this information into the route request, in order to avoid danger zones and blocked or closed road in case of flooding (Neis et al. 2007). ERS access the restriction data (i.e. dangerous area, closed roads) by WFS. In case if there is blocked roads and non-accessible areas, WPS is used to calculate the intersection between restricted (dangerous zones) areas and street network. It determines the streets which are not accessible. Then RS calculates the routes considering blocked and restricted roads which results evacuation route maps with route instructions, evacuation time (see Fig. 4.7). The resulting route maps are used by the stakeholders and decision makers.

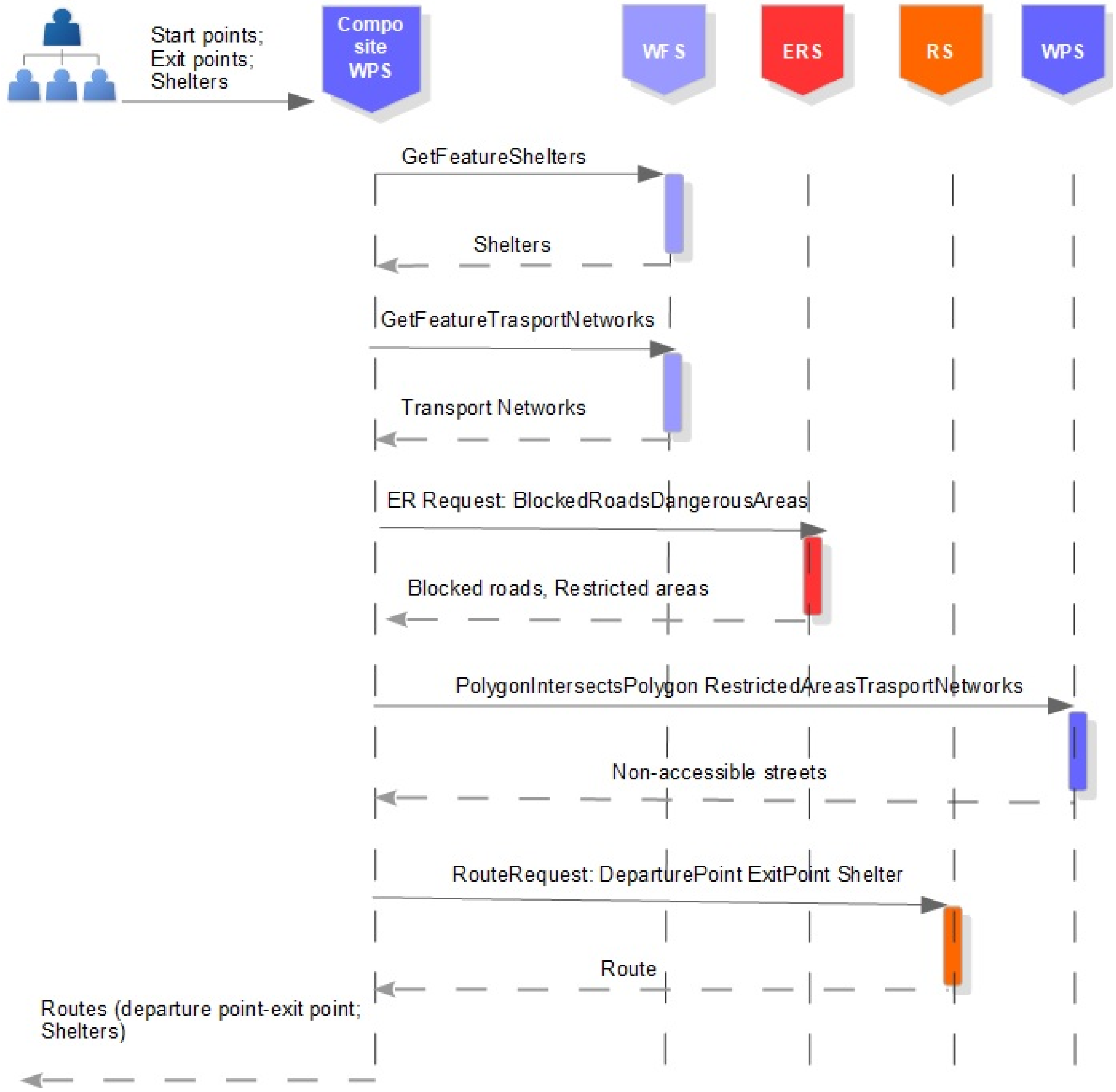


Fig. 4.7 Sequence diagram of the evacuation module scenario

4.3. Summary

In the present chapter, the following scenarios have been presented and discussed: Creation of the flood hazard maps using hydrological/hydraulic model and SDI services; Creation of the exposure maps in SDI environment; Creation of the evacuation maps in SDI environment. The geoprocessing models have been exposed as a web service (WPS). Web services were aggregated using WPS interface. For evacuation routes' calculation, the OGC OpenLS Route Service (RS) and Emergency Route Service (ERS) have been used in order to calculate the evacuation routes considering blocked and non-accessible roads. The sequence diagrams of invoking services have been created.

5. Implementation of flood risk management process within SDI

5.1. Introduction

In the present chapter, the implementation of the hazard and exposure modules will be described. Since one of the main objectives of this research is to improve the flood risk management for mitigation of damage caused by flash flooding, it will be accomplished through the implementation of flood modelling and flood mapping.

5.2. Implementation of Hazard module

In the previous chapter, the workflow for the creation of flood hazard map has been introduced and described. The next step is the implementation of the workflow that consists of flood modelling and mapping. Flood modelling includes hydrological and hydraulic modelling, whereas the flood mapping activities use the result from the flood modelling.

As a study area, the small size catchment area of the river Leghvtakhevi (Tbilisi, Georgia) has been selected. The river catchment is steep, and precipitation is characterized by intense orographic rainfall events. Due to this, the river can cause strong flash floods. The location with limited culvert capacity (or breach location) was selected. Flash floods, as a result of heavy rains have hit Tbilisi in the recent past, causing heavy damages or even catastrophes.

Table 5.1 shows the data sets that are used for the implementation. Flood modelling has been done offline, it was not included in geoprocessing service as the other models were. The main reason for that was the complexity of the modelling process, also the lack of available data. Due to limitation and unavailability of data, such as the hydrological data (river level and flow time-series data) of Leghvtakhevi river, there were some difficulties regarding hydrological modelling, no water level data is available within the catchment for calibration. There is information about historical flooding available, but this flooding occurred before significant interventions in the catchment (in 1903 and 1955); also there is not enough information available to be able to simulate those events. Though, the hydraulic model was implemented using HEC-RAS, developed by the U.S. Army Corps of Engineers and HEC-GeoRAS (can be downloaded for free from the US Army Corps of Engineers Hydrologic Engineering Center).

Data Name	Format	Details
Leghvtakhevi River catchment	GIS shapefile (Polygon)	
River network	GIS shapefile (Polyline)	Includes only rivers
Land cover	GIS shapefile (Polygon)	Source: Old 1:50,000 scale soviet topographic map
Station	GIS shapefile (Point)	Location of meteorological stations nearby the catchment: Vashlojvani station; Airport station; Kojori station.
DEM	Raster file	1 meter resolution
Roads	GIS shapefile (Polygon) GIS shapefile (Polyline)	
Buildings	GIS shapefile (Polygon)	
Points of interest	GIS shapefile (Point)	
Land use	GIS shapefile (Polygon)	

Table 5.1 Available data list and related details

The hydrologic/hydraulic modelling in GIS includes three steps: ***Pre-processing of data; model execution; Post-processing-visualization of results.*** Using HEC-GeoRAS tollbar into ArcGIS GIS data pre-processing has been done for input to HEC-RAS, whereas the RAS Mapping contains functions for post-processing of HEC-RAS results to produce flood inundation maps. The model execution has been carried out in HEC-RAS. The geometry file for HEC-RAS has been created which contains information on cross-sections, flowpath, hydraulic structures, river banks and other physical attributes of the river, moreover for the creation of a geometry file terrain(elevation) data has been used. Afterwards, GIS geometry data was exporting into HEC-RAS. Data has been checked and proceed in order to create the profiles (e.g. cross-section profile, flow profiles and etc.). The profiles have been corrected and the simulation was run. After successful simulation HEC-RAS results were exported to ArcGIS to view the inundation extent. For inundation mapping, a surface with water surface elevation was created. After subtraction, the terrain from the water surface the area with positive results (water surface is higher than the terrain) is flood area, and the area with negative results is dry. All the cells with positive values were converted to a polygon, which is the flood inundation polygon.

In order to create the hazard map, the flood risk zones (floods with high, medium, low probability) were defined. For this reason, a model (using ModelBuilder ArcGIS) has been created that strings together a sequence of geoprocessing tools for flood risk zones creation (see Fig. 5.1).

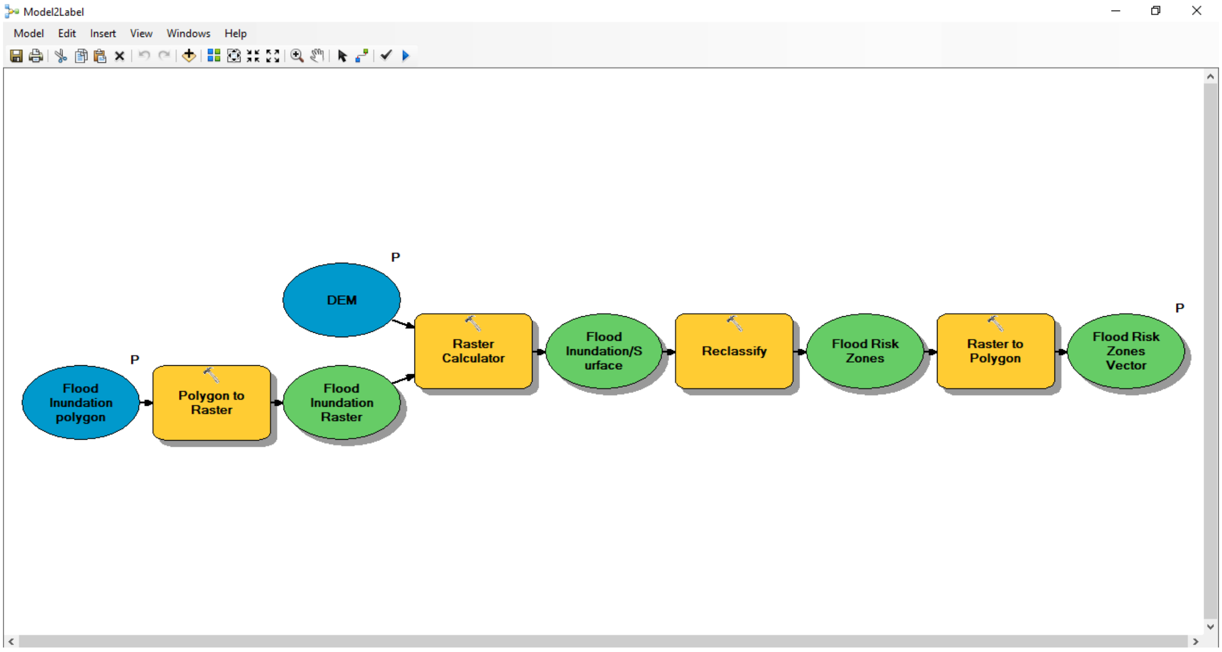
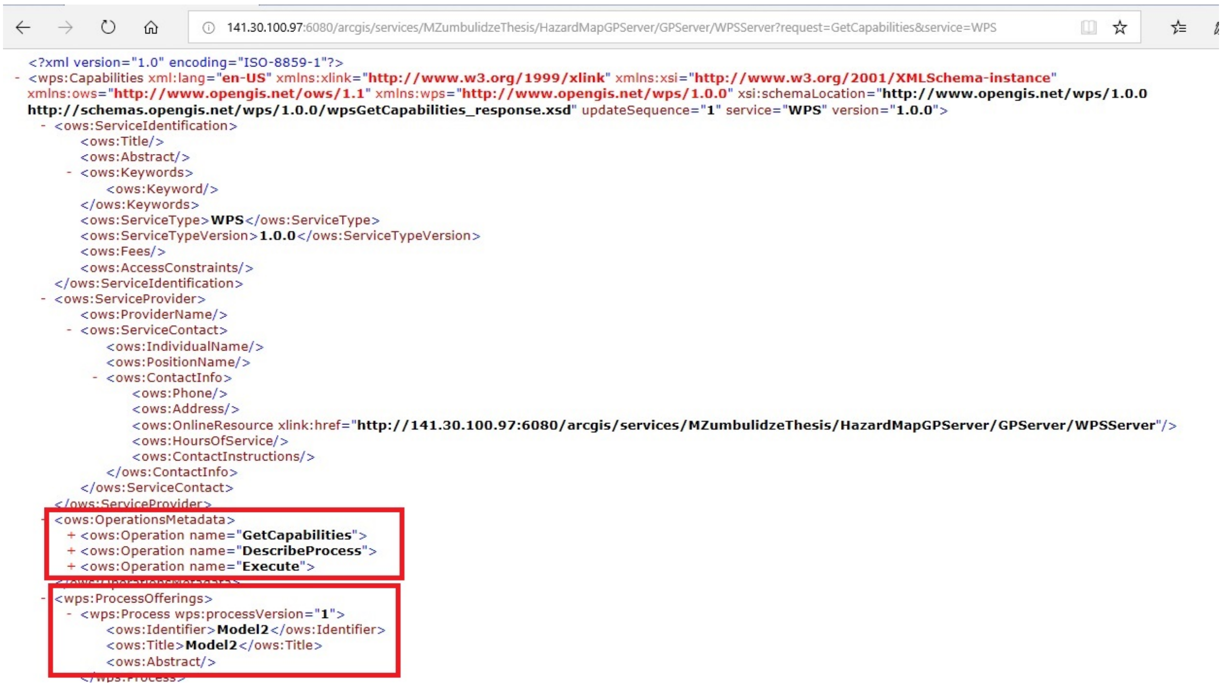


Fig. 5.1 Model for the Flood hazard map creation

GIS processing functionalities were published as a geoprocessing service to ArcGIS Server. The Geoprocessing service contains several tasks. It is easy to author geoprocessing tasks by ModelBuilder. Authoring geoprocessing tasks with ModelBuilder requires authoring the tasks within the service. For this purpose, several geoprocessing tools have been selected, the input and output parameters of the task and the location of data used by the task have been defined.

The model illustrated above defines flood risk zones. The output of the hydraulic modelling, the inundation polygon was converted to raster, using raster calculator and map algebra expression flood inundation area and elevation information were combined and then classified into flood risk zones, that was converted into a vector format. The output is a set of polygons with high, medium, low probability of flooding. The inundation polygon, DEM, the output flood risk zones variables are model parameters, which become the task arguments after the task's execution.

After the model has been run as a tool, the result was created with the information required to construct a task and geoprocessing service, afterwards its initial task was created. Fig. 5.2 and Fig. 5.3 show geoprocessing service GetCapabilities and DescribeProcess response respectively (more information on this geoprocessing service can be found in Appendix A.1.)

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- <wps:Capabilities xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
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    </ows:OperationsMetadata>
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      </wps:Process>
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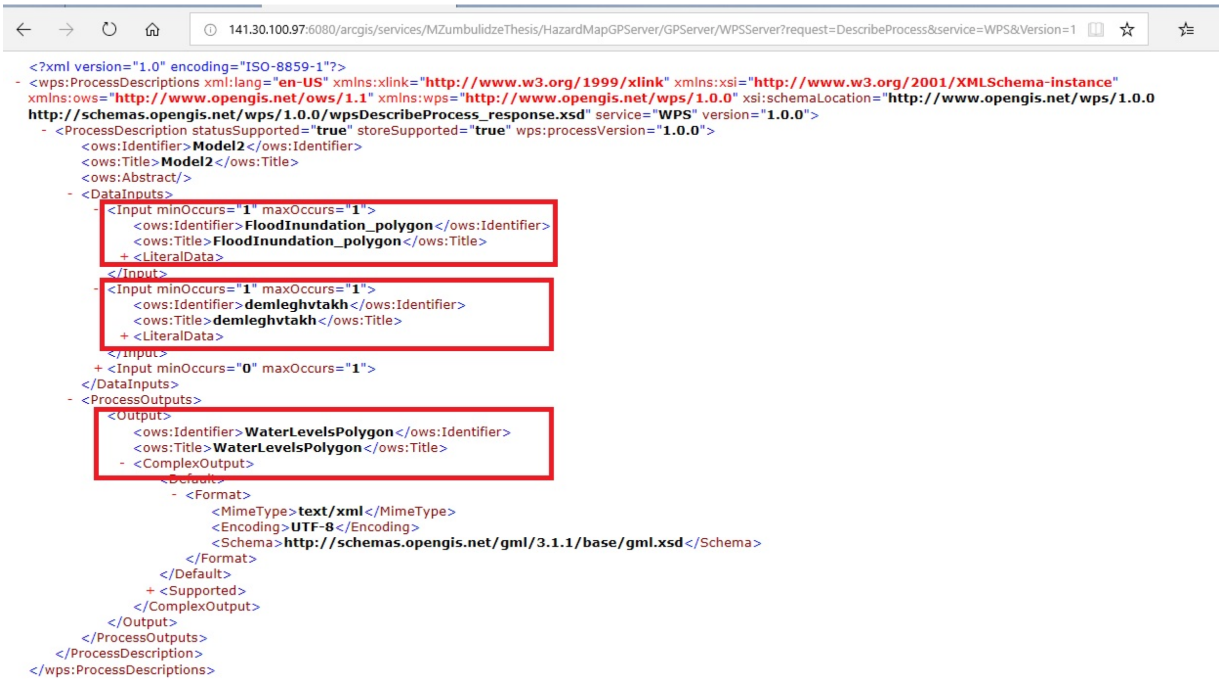
Fig. 5.2 Geoprocessing service GetCapabilities (Flood hazard map)

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  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsDescribeProcess_response.xsd" service="WPS" version="1.0.0">
  - <ProcessDescription statusSupported="true" storeSupported="true" wps:processVersion="1.0.0">
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      <ows:Title>Model2</ows:Title>
      <ows:Abstract/>
    - <DataInputs>
      - <Input minOccurs="1" maxOccurs="1">
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          <ows:Title>FloodInundation_polygon</ows:Title>
        + <LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>demleghvtakh</ows:Identifier>
          <ows:Title>demleghvtakh</ows:Title>
        + <LiteralData>
        </Input>
      + <Input minOccurs="0" maxOccurs="1">
      </DataInputs>
    - <ProcessOutputs>
      - <Output>
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          <ows:Title>WaterLevelsPolygon</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      </ProcessOutputs>
    </ProcessDescription>
</wps:ProcessDescriptions>
```


Fig. 5.3 Geoprocessing service DescribeProcess (Flood hazard map)

Based on the output of the data geoprocessing (flood risk zones), the flood hazard map was created, afterwards ArcMap map document (.mxd) was published as Web Map Service (WMS) to ArcGIS server (see Fig. 5.4) (more information on Flood hazard map WMS can be found in Appendix A.2.)

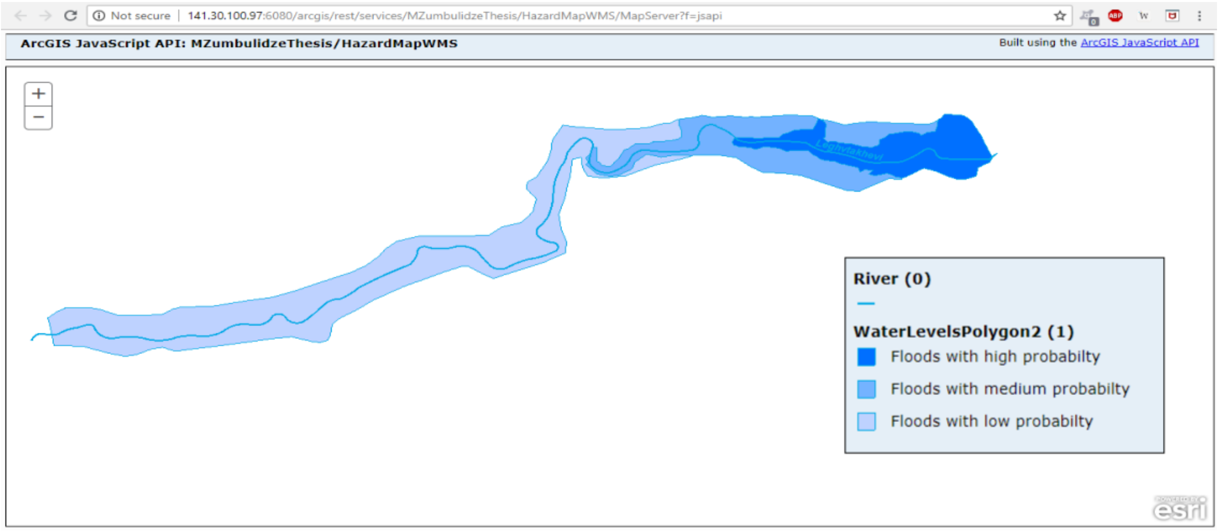

Fig. 5.4 Flood hazard map (WMS)

5.3. Implementation of Exposure module

Since the output of the exposure module is flood risk maps, the implementation of the workflow for flood risk maps (Buildings at flood risk and People at flood risk) creation has been done. As mentioned above geoprocessing tasks were authored by ModelBuilder. For the implementation of the ***building at flood risk***, several geoprocessing tools were selected (see Fig. 5.5). The flood risk zones (from the previous implementation phase), buildings and historical buildings were used as the input parameters of the task.

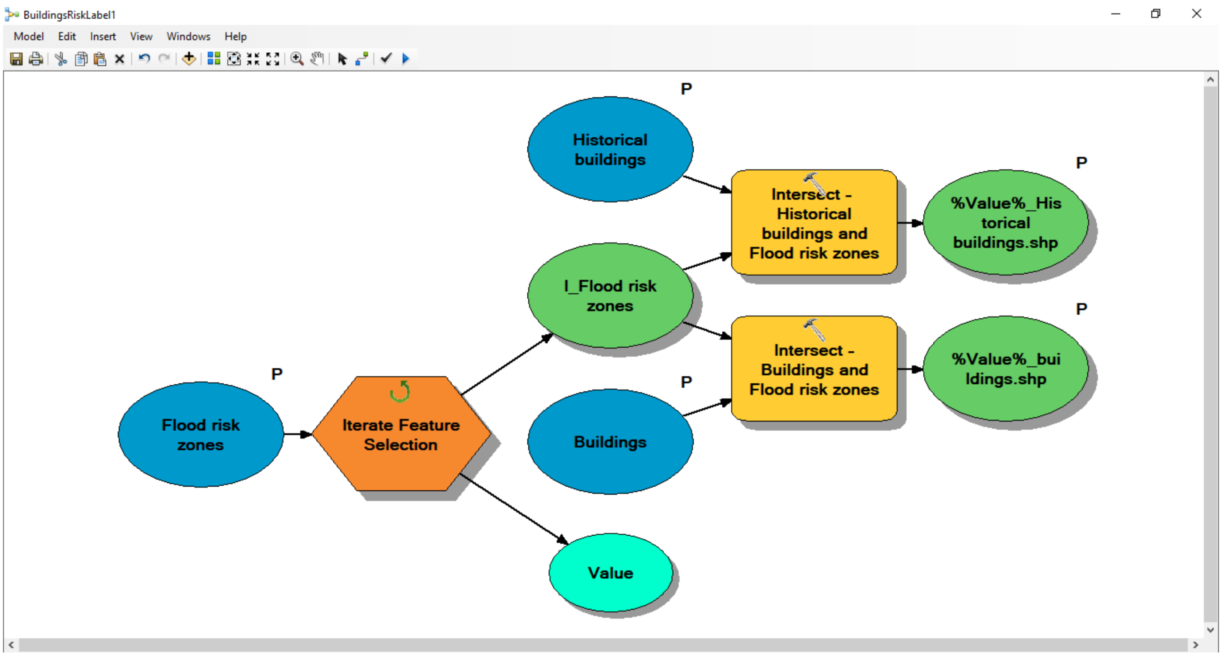

Fig. 5.5 Model for the Buildings at flood risk map creation

Iterate feature selection was applied and the value variable (contains the name of the features, e.g. floods with high probability and etc.) was used as an inline variable (e.g. %Value%) as the output name. The intermediate output of geoprocessing was intersected with buildings and historical buildings data sets in order to get buildings at risk for each flood risk zones.

As in the previous implementation phase, geoprocessing service and its initial task were created and published (more information on the service can be found in Appendix B.1.).

Fig. 5.6 displays WMS for Buildings at risk (more information on the service can be found in Appendix B.2.).

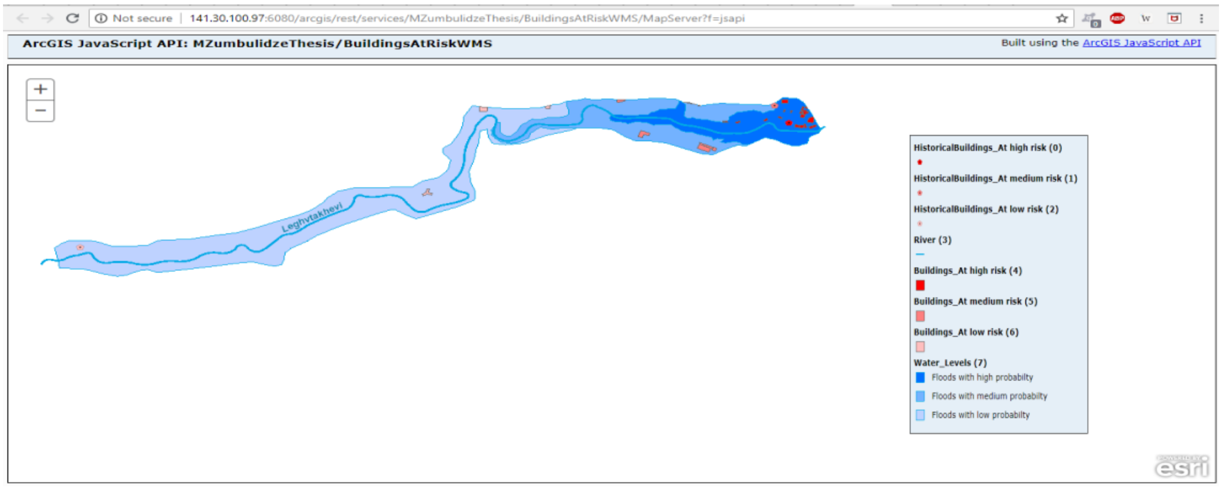

Fig. 5.6 Buildings at flood risk (WMS)

The implementation of ***Population at flood risk*** is linked to the model (see Fig. 5.7) that uses the result of the previous implementation such as buildings at high, medium and low risk as the input parameters since it contains the information on the absolute number of population per buildings. Geoprocessing tool "Summary statistic" was used to sum up the number of population. Additionally, join operation with flood risk zones was performed in order to display the number of population for each flood risk zones. After the execution of the model geoprocessing service was published (more information on the service can be found in Appendix C.1.).

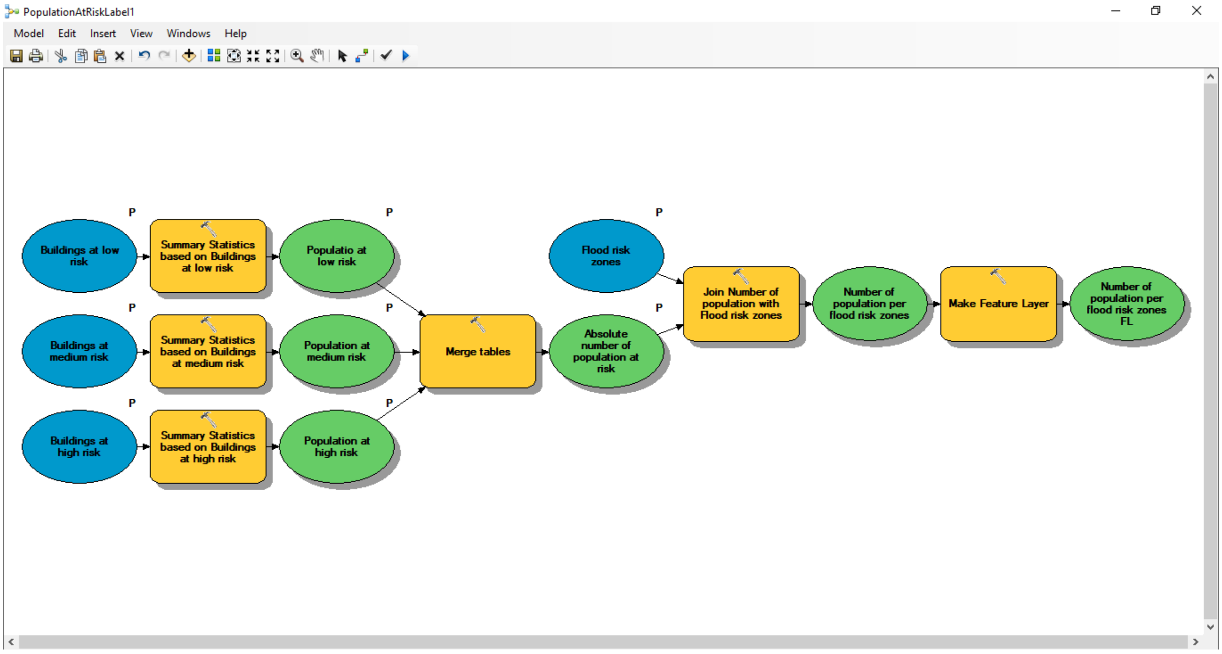

Fig. 5.7 Model for the Population at risk map creation

Similar to the previous implementations population at flood risk was published as WMS to ArcGIS server (see Fig. 5.8) (more information on the service can be found in Appendix C.2.).

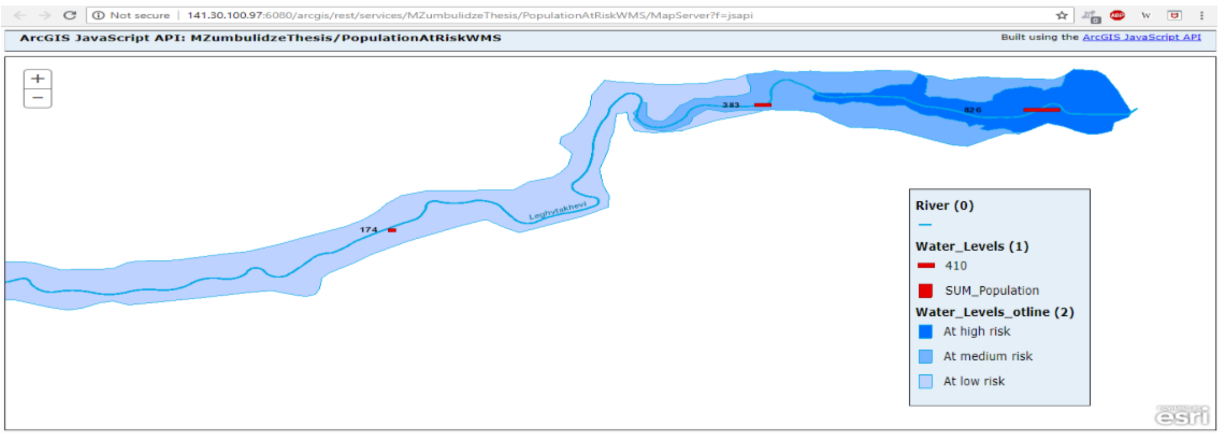

Fig. 5.8 Population at flood risk (WMS)

5.4. Update process

It is important to mention once again that there is an increased demand for up-to-date spatial data for flood risk management and decision making. Also, it is important to consider the update cycle of spatial data, it is related to the nature of data, for example, some data sets are refreshed every month, while some others have an update cycle of 3 to 5 years.

Since the implementation of this research has been done using ArcGIS environment and ArcGIS services, it is significant to point out that there is Data Interoperability extension in ArcGIS, which offers an integrated spatial ETL (extract, transform, and load) toolset to read from feature services, do a change detection against a local geodatabase and write the change set, with no downtime. It allows to send the data sets through the ChangeDetector transformer, the output shows which features are new, missing, or the same in the updated dataset.

Spatial ETL tool can be integrated with geoprocessing tools which are the part of the models (ModelBuilder) that have been used for the implementation phase. As the parameters are published within the models (e.g. a user can specify the certain parameters, select which feature classes to be used and etc.) ETL tool as a part of the workflow would be very helpful. Since the models were published as geoprocessing services, there is no need to republish them.

5.5. Summary

This chapter presented how the implementation of the Hazard module and Exposure module (from SDSS) in SDI environment could be done. For the implementation, the small size catchment area and the location with limited culvert capacity were selected, which causes flash flooding. For flood hazard mapping the hydraulic modelling was implemented including data pre-processing, model execution and visualization of results phases, that results in the flood extent and inundation area. GIS processing functionalities were published as a geoprocessing service to ArcGIS Server, several geoprocessing tools have been selected and integrated into a model, the input and output parameters of the task and the location of data used by the task have been defined. Based on data geoprocessing results the flood hazard map and flood risk maps were created and published as Web Map Service (WMS) to ArcGIS server.

6. Conclusions and recommendations

6.1. The EU FD directive, the INSPIRE directive and effective flood risk management

One of the objectives of this research is ***determination of the role of the EU Floods Directive and the EU INSPIRE Directive for effective flood risk management***. To achieve this goal, the concept of flood risk management was discussed, moreover the EU FD and the EU INSPIRE directive were reviewed. Accordingly, this goal was partially achieved by literature review.

This research focuses on flash flood, which is a highly dynamic phenomenon, it is difficult to monitor, it requires different responses (compare to the other types of flood). Considering the characteristics of flash flood, the effective flood risk management process is important to reduce damage caused by the flash flood event. Apart from the main characteristics of flood risk management such as the analysis of the flood risk, the assessment and reduction of flood risk, it is important to consider flood risk management as a decision making process which involves the stakeholders from various fields (e.g. spatial planners, flood and water managers, emergency planners and etc.). Another important point to be highlighted is the role of flood risk and flood risk management in the EU Floods Directive. The EU FD is the first EU directive which deals specifically with flood events and makes a significant contribution towards shifting flood management from protection against floods to managing the risks of floods. In order to reduce the adverse consequences (for human health, the environment, cultural heritage, economic activity) the EU FD established a framework for the assessment and management of flood risk. According to the EU FD, flood risk management consists of a preliminary flood risk assessment, providing flood hazard/flood risk maps and flood risk management plans. These steps lead to effective flood risk management and better decision making.

Geographic information (GI) plays a significant role in the effective flood risk management process. GI must be discovered, accessed, used and visualized as quickly as possible for providing reliable assistance to flood risk management and decision making process. It is supported by Spatial Data Infrastructure (SDI), one of its main components are GI services. For this reason, the EU INSPIRE directive and its corresponding implementation are considered as the legal framework for this work. It aims to have fast and integrated access to GI and GI services. The directive focuses on environmental data, that would be used for flood risk management process. Interoperability of spatial data sets and services is one of the important components of the EU INSPIRE directive which enables uncomplicated and integrated access to geodata and GI services.

For effective flood risk management and better decision making process is important to have well-structured metadata (the component of the EU INSPIRE directive) that allows the discovery of INSPIRE relevant data sets and services. In order to discover, transform, view, download and invoke spatial data network services are used, which are another component of the EU INSPIRE directive and play a significant role in the flood risk management process. They enable to consider user requirements, provide easy access to environmental geodata.

As discussed earlier various workflows for effective flood risk management have been created (see chapter 4). For the implementation of the workflows the required data sets and their corresponding attributes have been examined and discussed in detail which can be supplied by INSPIRE spatial data themes.

After reviewing the concept of flood risk management, the EU FD, the EU INSPIRE directive, it could be concluded that the role of the above mentioned legislative initiatives is crucial in effective flood risk management and better decision making process since the EU FD doesn't aim to avoid floods, its main aim is the reduction of the adverse consequences caused by flood events. Considering the EU INSPIRE directive as the framework of this research is important because it has the unified standards for SDI, it operates with standardized metadata and network services that play a significant role in the EU SDI.

6.2. SSDS components in SDI environment

In order to achieve the second objective of this research - ***Design of a service-based SDSS for hydro-meteorological extreme events in small and medium sized catchment areas,*** the components of a service-based SDSS have been determined. It was accomplished by designing a conceptual design of SDSS in SDI context, that comprises SDSS and SDI frameworks. SDSS framework was set up after reviewing and examining the existing (S)DSSs for flood risk management. The framework has a modular setup. It considers the main activities of flood risk management such as Prevention and mitigation phase; Preparation phase; Response phase; Recovery phase and consists of the following modules: Hazard module; Exposure module; Risk module; Vulnerability module; Forecasting module; Evacuation planning module; Evacuation module; Consequence module. These modules are linked to the above mentioned activities of the flood risk management process.

Since this research investigates a SDSS in SDI context, in order to make flood risk management more efficient and to support effective decision making process, SDSS's modules are linked to SDI framework that leads to the discussion about required SDI components, which required geodata could be supplied by SDI, what are the challenges and restrictions when having SDSS in SDI environment (see the next paragraph).

For making flood risk management process more effective, the workflows for the hazard module, exposure module and evacuation module have been designed and created. The required data, components, services, functionalities have been identified and included in the workflows, which makes the outputs of the above mentioned modules valuable for flood risk management process.

It is important to highlight the involvement of different stakeholders in flood risk management and decision making process. The modules of SDSS and the workflows of flood risk management have been designed in such a way that they consider all the possible stakeholders would be involved in flood risk management process. It makes this process more effective which is the main goal of this work. Also, the participation of local citizens in this process is important. It would be useful to use their perception and experience of flood risk in decision making process. There should be close communication between the local citizens, the stakeholders and decision makers.

6.3. The challenges, restrictions for SDSS in SDI environment

In chapter 3, for each module of SDSS within SDI framework data and services requirements, challenges and restrictions have been discussed. In this paragraph will be highlighted some challenges and restrictions regarding data and services interoperability, reusability and granularity of services.

In order to process geodata into geospatial information aggregated web services are used. The granularity of service is an important issue with regards to its reusability and flexibility. It is not an easy task to define criteria for service granularity optimisation. For this reason, it is important to define what type of granularity to be used, for example, functionality granularity refers to how much functionality is offered by a service and data granularity reflects the amount of data that is exchanged by a service (Haesen et al. 2008). If the granularity of service is too small, it leads to reducing the system performance. While when many functions are integrated into a service, its reusability and flexibility will be decreased.

In this research the concept of aggregated web services was applied using the WPS interface itself. The composite WPS includes web services such as WPS, WFS, Emergency Route Service (ERS), Route Service (RS). In principle, WPS interface can be used to aggregate complex geoprocessing services since the specification enables for interpretation, describes the concrete implementation of geoprocessing methods and doesn’t exclude the use of those methods as an aggregation service (Stollberg and Zipf 2007). Based on it, it could be concluded that since the current WPS concept is not fully developed, WPS interface is still open, it is possible to use the WPS interface for the aggregation and realization of several complex services (e.g. OGC Web Services). The geoprocessing services that were introduced and developed in this work are domain specific and they present geoprocessing functions, at the same time they can be reused for the other applications. In spite of this, there is still a gap in SDI environment regarding representation and implementation of complex workflows using WPS interface in accordance with OGC standards.

There are still interoperability problems in SDI environment. Spatial data integration is the most important task to be performed in SDI framework. Despite the fact that SDIs facilitate spatial integration by providing standards, guidelines for linking inconsistent data, services and data coordination policies, web services enable to access and integrate datasets from different sources, the interoperability problems still remain.

This work considers and discusses the components of SDI based on existing OGC standards and specification which enables the interoperability among SDI services. In spite of this, the interoperability of the services still is the challenge. For example, WMS has fixed components (e.g. bounding box, reference systems and etc.), which leads to the limited functions for interoperability of WMSs. Whereas WPS is generic, different geoprocessing services (e.g. services stand for buffer calculation or classification and etc.) have different WPS interfaces, which means that there is a gap in terms of interoperability. It could be concluded that the interoperability problems in SDI environment have yet to be solved.

6.4. Recommendations

In this research 3 workflows for effective flood risk management have been described, which consider only 3 modules of SDSS (Hazard module, Exposure module, Evacuation module). Since the conceptual design of SDSS in SDI context includes more modules such as Risk module, Vulnerability module, Evacuation planning module, Forecasting module, Consequence module, it would be applicable to design the workflows regarding these modules and identify the possible stakeholders to be involved in the flood management process. It will give the broader overview of the feasibility of the system with this respect.

Only two of the above mentioned workflows were implemented in this work. It had been planned to implement the workflow of evacuation model, but because of time limitation, this was unfortunately very limited. It should be mentioned that the workflow includes complex geoprocessing services which are rather complicated to be implemented, moreover the output of the workflow (evacuation maps) would play a significant role in the flood risk management process. Further research would cover the implementation of this workflow.

As discussed earlier hydrological/hydraulic modelling has been done offline, using HEC-HMS/HEC-GeoHMS and HEC-RAS/HEC-GeoRAS software respectively. It would be recommended to expose the hydrological/hydraulic model as web service (WPS) and OpenMI, this approach is based on the existing study (see chapter 4). Furthermore, it would be feasible to integrate the model in the composite WPS as OGC compliant service through the WPS interface.

The concept of the composite WPS was used in this research which invokes all the other services in a sequential manner, it is based on a Centralized Service Chaining concept. It would be recommended for the future work to inspect the concept of Cascading Chaining. According to this concept, the individual services communicate with each other and data is exchanged directly. It should be mentioned that WPS interface specifications support this concept by anticipating a Key Value Pair (KVP) encoded Execute request.

The recommendation for the future work would be the creation and development of a prototype which will be based on a conceptual design of this research. It would include SDSS framework with all modules and SDI framework respectively. Furthermore, an update function module could be integrated into the prototype to check and perform the updating process in the system. Such system looks very promising to make flood risk management and decision making process more effective.

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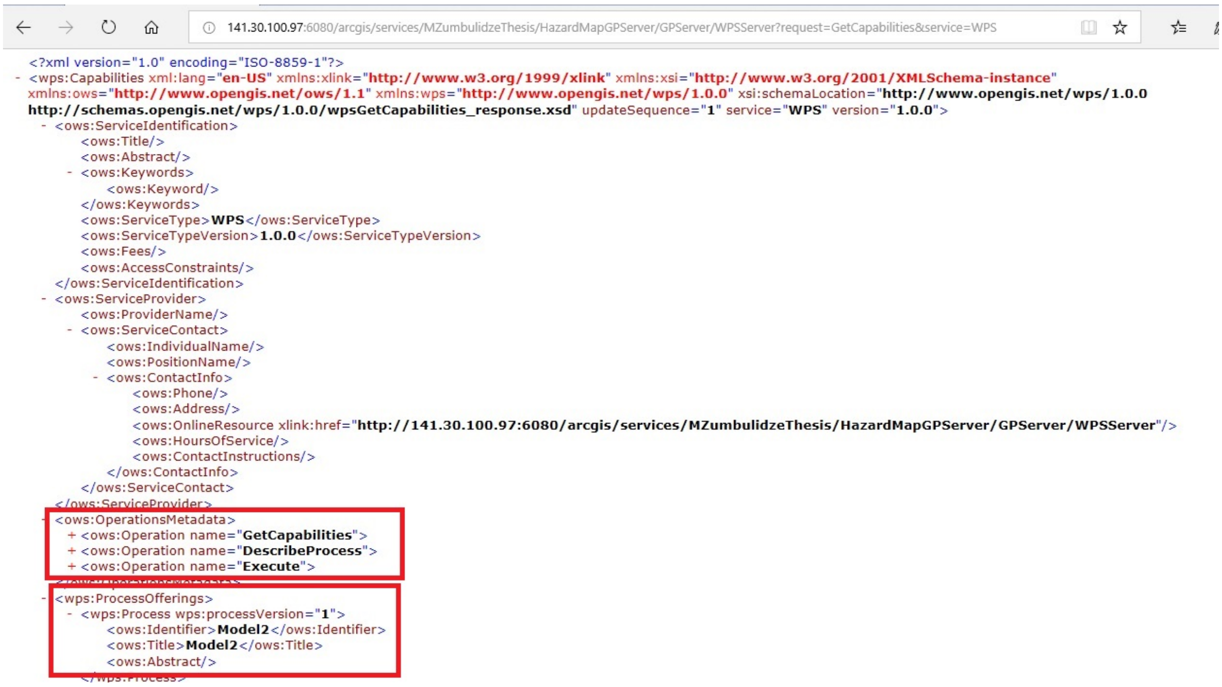
Appendix A: Workflow of Hazard map

A.1. Geoprocessing service

GetCapabilities request

URL: http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/WPSServer?request=GetCapabilities&service=WPS

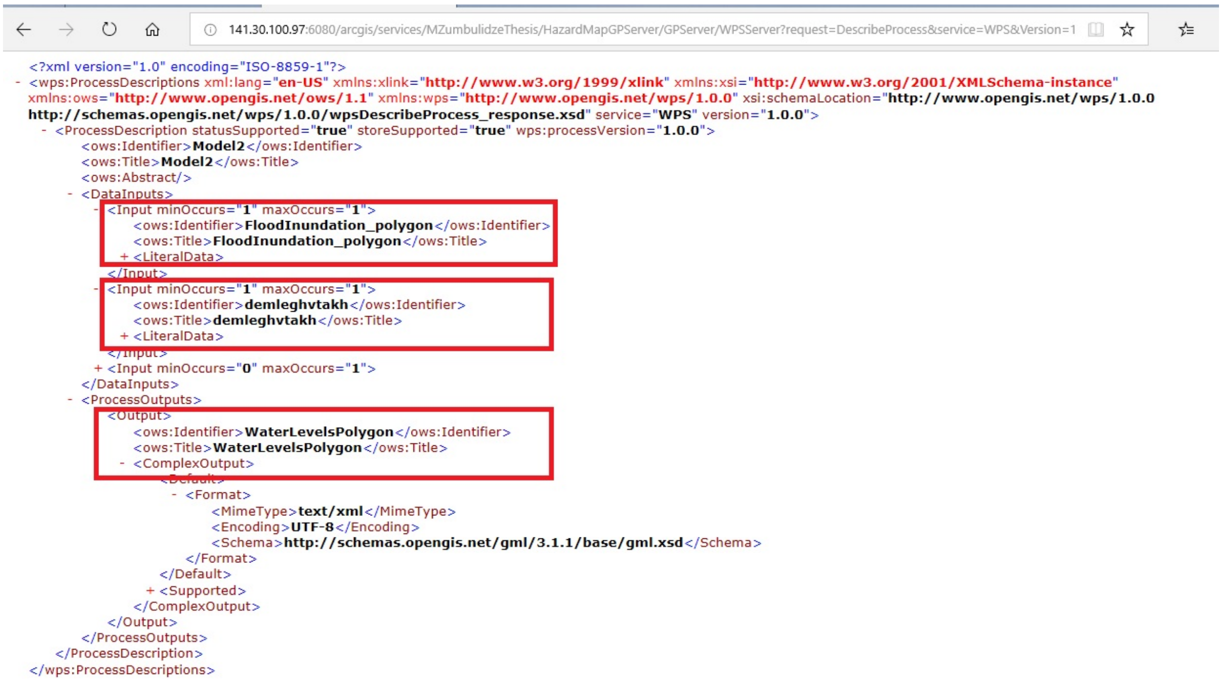


```
141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/WPSServer?request=GetCapabilities&service=WPS

<?xml version="1.0" encoding="ISO-8859-1"?>
- <wps:Capabilities xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsGetCapabilities_response.xsd" updateSequence="1" service="WPS" version="1.0.0">
  - <ows:ServiceIdentification>
      <ows:Title/>
      <ows:Abstract/>
    - <ows:Keywords>
        <ows:Keyword/>
      </ows:Keywords>
      <ows:ServiceType>WPS</ows:ServiceType>
      <ows:ServiceTypeVersion>1.0.0</ows:ServiceTypeVersion>
      <ows:Fees/>
      <ows:AccessConstraints/>
    </ows:ServiceIdentification>
  - <ows:ServiceProvider>
      <ows:ProviderName/>
    - <ows:ServiceContact>
        <ows:IndividualName/>
        <ows:PositionName/>
      - <ows:ContactInfo>
          <ows:Phone/>
          <ows:Address/>
          <ows:OnlineResource xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/WPSServer"/>
          <ows:HoursOfService/>
          <ows:ContactInstructions/>
        </ows:ContactInfo>
      </ows:ServiceContact>
    </ows:ServiceProvider>
  - <ows:OperationsMetadata>
    + <ows:Operation name="GetCapabilities">
    + <ows:Operation name="DescribeProcess">
    + <ows:Operation name="Execute">
    </ows:OperationsMetadata>
  - <wps:ProcessOfferings>
    - <wps:Process wps:processVersion="1">
        <ows:Identifier>Model2</ows:Identifier>
        <ows:Title>Model2</ows:Title>
        <ows:Abstract/>
      </wps:Process>
```


DescribeProcess request / response

URL: http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/WPSServer?request=DescribeProcess&service=WPS&Version=1.0.0&Identifier=Model2

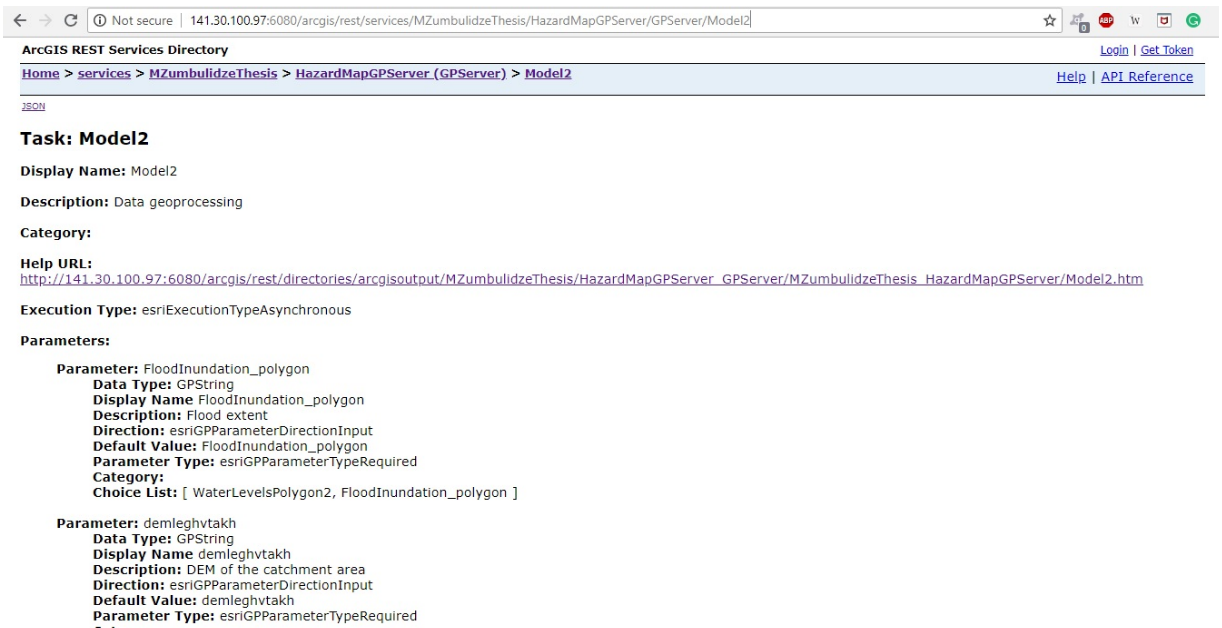


```
141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/WPSServer?request=DescribeProcess&service=WPS&Version=1

<?xml version="1.0" encoding="ISO-8859-1"?>
- <wps:ProcessDescriptions xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsDescribeProcess_response.xsd" service="WPS" version="1.0.0">
  - <ProcessDescription statusSupported="true" storeSupported="true" wps:processVersion="1.0.0">
      <ows:Identifier>Model2</ows:Identifier>
      <ows:Title>Model2</ows:Title>
      <ows:Abstract/>
    - <DataInputs>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>FloodInundation_polygon</ows:Identifier>
          <ows:Title>FloodInundation_polygon</ows:Title>
        + <LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>demleghvtakh</ows:Identifier>
          <ows:Title>demleghvtakh</ows:Title>
        + <LiteralData>
        </Input>
      + <Input minOccurs="0" maxOccurs="1">
      </DataInputs>
    - <ProcessOutputs>
      - <Output>
          <ows:Identifier>WaterLevelsPolygon</ows:Identifier>
          <ows:Title>WaterLevelsPolygon</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      </ProcessOutputs>
    </ProcessDescription>
</wps:ProcessDescriptions>
```


Task description

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/Model2


Not secure | 141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMapGPServer/GPServer/Model2

ArcGIS REST Services Directory — Login | Get Token

Home > services > MZumbulidzeThesis > HazardMapGPServer (GPServer) > Model2 — Help | API Reference

JSON

Task: Model2

Display Name: Model2

Description: Data geoprocessing

Category:

Help URL: http://141.30.100.97:6080/arcgis/rest/directories/arcgisoutput/MZumbulidzeThesis/HazardMapGPServer_GPServer/MZumbulidzeThesis_HazardMapGPServer/Model2.htm

Execution Type: esriExecutionTypeAsynchronous

Parameters:

Parameter: FloodInundation_polygon
Data Type: GPString
Display Name FloodInundation_polygon
Description: Flood extent
Direction: esriGPParameterDirectionInput
Default Value: FloodInundation_polygon
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [WaterLevelsPolygon2, FloodInundation_polygon]

Parameter: demleghvtakh
Data Type: GPString
Display Name demleghvtakh
Description: DEM of the catchment area
Direction: esriGPParameterDirectionInput
Default Value: demleghvtakh
Parameter Type: esriGPParameterTypeRequired

Parameter: WaterLevelsPolygon
Data Type: GPFeatureRecordSetLayer
Display Name WaterLevelsPolygon
Description: Flood with hiigh, medium, low probability
Direction: esriGPParameterDirectionOutput
Default Value:
Geometry Type: esriGeometryPolygon
HasZ: false
HasM: false
Spatial Reference: 32638 (32638)

Fields:
- OBJECTID *(type: esriFieldTypeOID , alias: OBJECTID)*
- Id *(type: esriFieldTypeInteger , alias: Id)*
- gridcode *(type: esriFieldTypeInteger , alias: gridcode)*
- Shape_Length *(type: esriFieldTypeDouble , alias: Shape_Length)*
- Shape_Area *(type: esriFieldTypeDouble , alias: Shape_Area)*

Features: *None.*

Parameter Type: esriGPParameterTypeRequired
Category:

Supported Operations: Submit Job

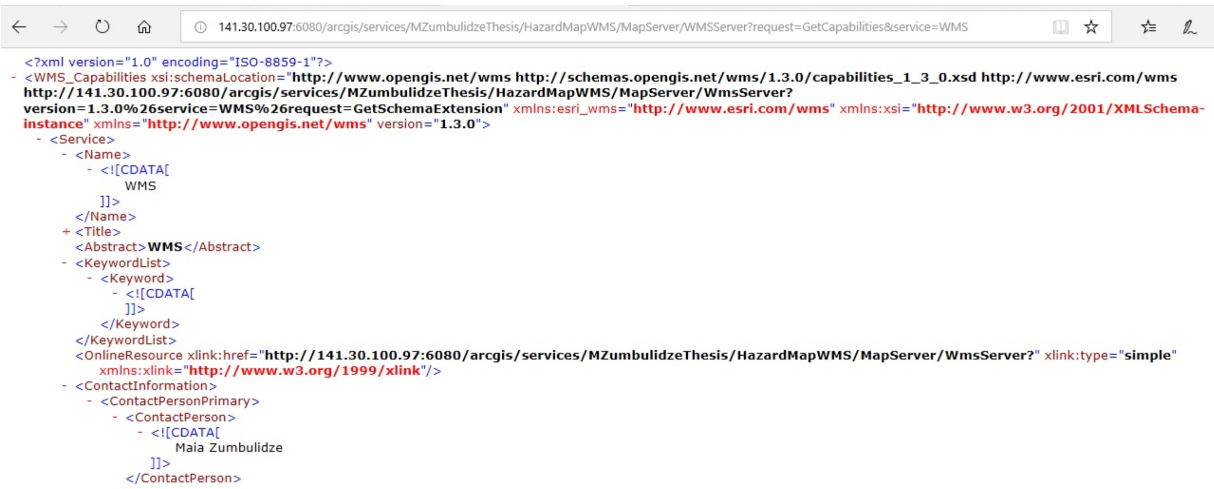
Geoprocessing service – JSON

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMapGPS-erver/GPServer/Model2?f=pjson

A.2. WMS

GetCapabilities request / response

URL: http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapWMS/MapS-erver/WMSServer?request=GetCapabilities&service=WMS



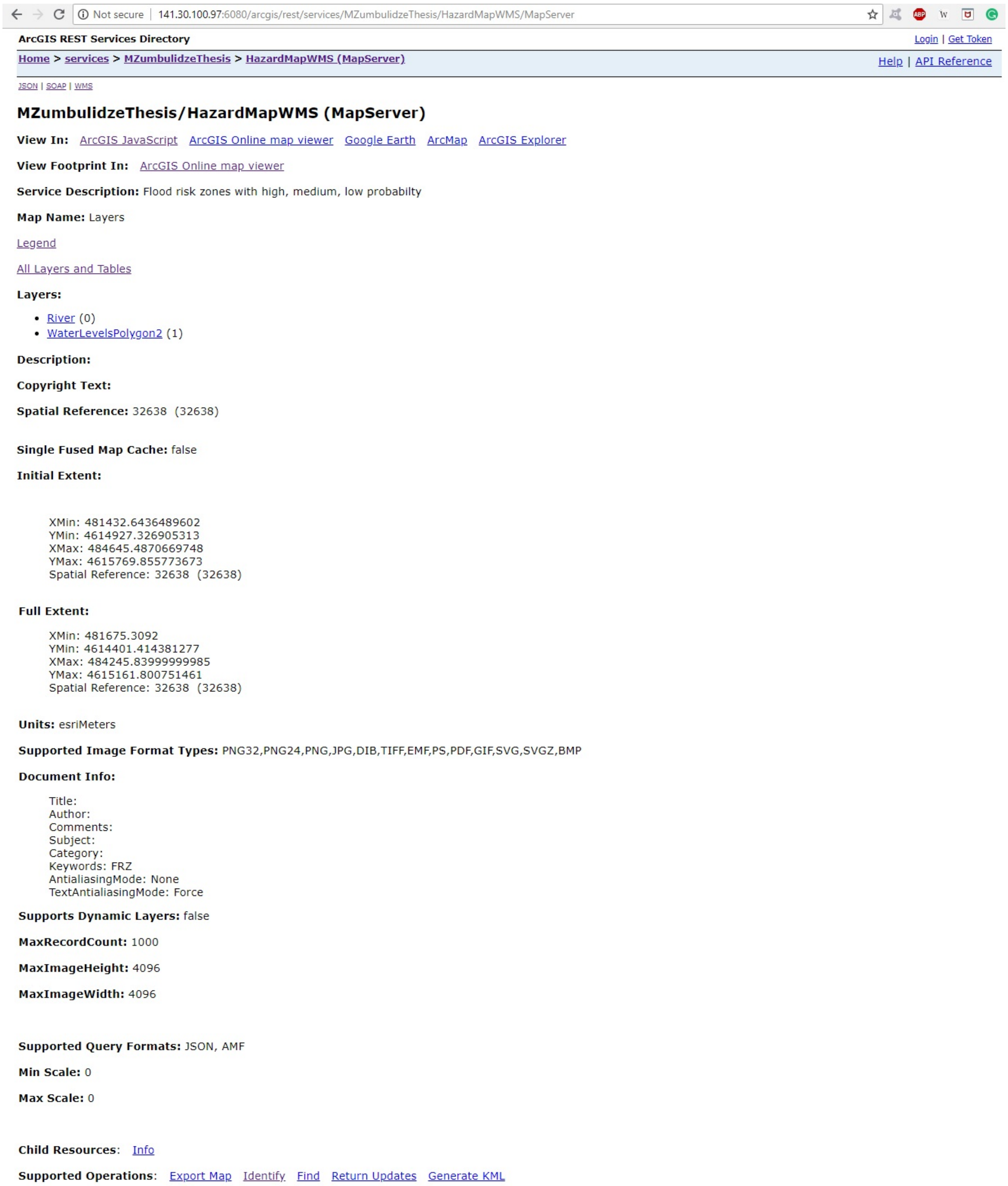

```
<?xml version="1.0" encoding="ISO-8859-1"?>
- <WMS_Capabilities xsi:schemaLocation="http://www.opengis.net/wms http://schemas.opengis.net/wms/1.3.0/capabilities_1_3_0.xsd http://www.esri.com/wms
http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapWMS/MapServer/WmsServer?
version=1.3.0%26service=WMS%26request=GetSchemaExtension" xmlns:esri_wms="http://www.esri.com/wms" xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance" xmlns="http://www.opengis.net/wms" version="1.3.0">
  - <Service>
    - <Name>
      - <![CDATA[
          WMS
        ]]>
      </Name>
    + <Title>
      <Abstract>WMS</Abstract>
    - <KeywordList>
      - <Keyword>
        - <![CDATA[
          ]]>
        </Keyword>
      </KeywordList>
      <OnlineResource xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapWMS/MapServer/WmsServer?" xlink:type="simple"
        xmlns:xlink="http://www.w3.org/1999/xlink"/>
    - <ContactInformation>
      - <ContactPersonPrimary>
        - <ContactPerson>
          - <![CDATA[
              Maia Zumbulidze
            ]]>
          </ContactPerson>
```

```
- <Layer>
  + <Title>
    <CRS>CRS:84</CRS>
    <CRS>EPSG:4326</CRS>
    <CRS>EPSG:32638</CRS>
  + <EX_GeographicBoundingBox>
    <BoundingBox maxy="41.688075" maxx="44.810715" miny="41.681171" minx="44.779807" CRS="CRS:84"/>
    <BoundingBox maxy="44.810715" maxx="41.688075" miny="44.779807" minx="41.681171" CRS="EPSG:4326"/>
    <BoundingBox maxy="4615161.800751" maxx="484245.840000" miny="4614401.414381" minx="481675.309200" CRS="EPSG:32638"/>
  - <Layer queryable="1">
      <Name>WaterLevelsPolygon2</Name>
    + <Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.688075" maxx="44.810558" miny="41.681172" minx="44.780324" CRS="CRS:84"/>
      <BoundingBox maxy="44.810558" maxx="41.688075" miny="44.780324" minx="41.681172" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615161.800751" maxx="484232.765493" miny="4614401.414381" minx="481718.375299" CRS="EPSG:32638"/>
    - <Style>
        <Name>default</Name>
        <Title>WaterLevelsPolygon2</Title>
      - <LegendURL height="48" width="190">
          <Format>image/png</Format>
          <OnlineResource xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapWMS/MapServer/WmsServer?
            request=GetLegendGraphic%26version=1.3.0%26format=image/png%26layer=WaterLevelsPolygon2" xlink:type="simple"
            xmlns:xlink="http://www.w3.org/1999/xlink"/>
        </LegendURL>
      </Style>

    </Layer>
  - <Layer queryable="1">
      <Name>River</Name>
    - <Title>
      - <![CDATA[
          River
        ]]>
      </Title>
    + <Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.687777" maxx="44.810713" miny="41.681611" minx="44.779808" CRS="CRS:84"/>
      <BoundingBox maxy="44.810713" maxx="41.687777" miny="44.779808" minx="41.681611" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615128.709900" maxx="484245.840000" miny="4614450.233400" minx="481675.309200" CRS="EPSG:32638"/>
    - <Style>
        <Name>default</Name>
        <Title>River</Title>
      - <LegendURL height="16" width="16">
          <Format>image/png</Format>
          <OnlineResource xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/HazardMapWMS/MapServer/WmsServer?
            request=GetLegendGraphic%26version=1.3.0%26format=image/png%26layer=River" xlink:type="simple"
            xmlns:xlink="http://www.w3.org/1999/xlink"/>
        </LegendURL>
      </Style>
    </Layer>
  </Layer>
</Capability>
</WMS_Capabilities>
```


Service description

URL: [http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMap-WMS/MapServer](http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMapWMS/MapServer)



Not secure | 141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMapWMS/MapServer

ArcGIS REST Services Directory Login | Get Token

Home > services > MZumbulidzeThesis > HazardMapWMS (MapServer) Help | API Reference

JSON | SOAP | WMS

MZumbulidzeThesis/HazardMapWMS (MapServer)

View In: ArcGIS JavaScript ArcGIS Online map viewer Google Earth ArcMap ArcGIS Explorer

View Footprint In: ArcGIS Online map viewer

Service Description: Flood risk zones with high, medium, low probabilty

Map Name: Layers

Legend

All Layers and Tables

Layers:

- River (0)
- WaterLevelsPolygon2 (1)

Description:

Copyright Text:

Spatial Reference: 32638 (32638)

Single Fused Map Cache: false

Initial Extent:

XMin: 481432.6436489602
YMin: 4614927.326905313
XMax: 484645.4870669748
YMax: 4615769.855773673
Spatial Reference: 32638 (32638)

Full Extent:

XMin: 481675.3092
YMin: 4614401.414381277
XMax: 484245.83999999985
YMax: 4615161.800751461
Spatial Reference: 32638 (32638)

Units: esriMeters

Supported Image Format Types: PNG32,PNG24,PNG,JPG,DIB,TIFF,EMF,PS,PDF,GIF,SVG,SVGZ,BMP

Document Info:

Title:
Author:
Comments:
Subject:
Category:
Keywords: FRZ
AntialiasingMode: None
TextAntialiasingMode: Force

Supports Dynamic Layers: false

MaxRecordCount: 1000

MaxImageHeight: 4096

MaxImageWidth: 4096

Supported Query Formats: JSON, AMF

Min Scale: 0

Max Scale: 0

Child Resources: Info

Supported Operations: Export Map Identify Find Return Updates Generate KML

WMS – JSON

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/HazardMap-WMS/MapServer?f=pjson

Appendix B: Workflow of Buildings at flood risk

B.1. Geoprocessing service

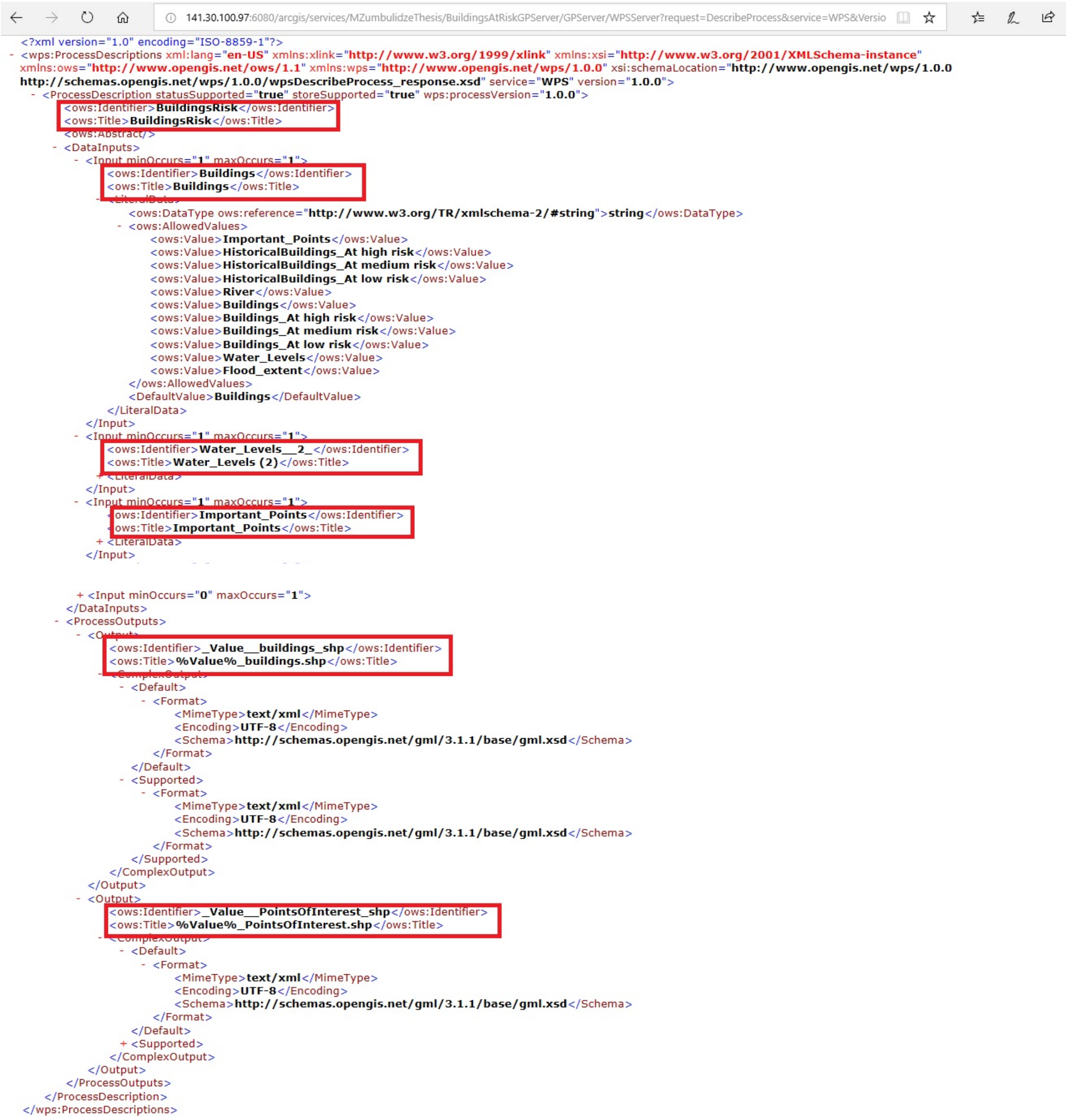
GetCapabilities request / response

URL: http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/WPSServer?request=GetCapabilities&service=WPS


```
141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/WPSServer?request=GetCapabilities&service=WPS
<?xml version="1.0" encoding="ISO-8859-1"?>
- <wps:Capabilities xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsGetCapabilities_response.xsd" updateSequence="1" service="WPS" version="1.0.0">
  - <ows:ServiceIdentification>
      <ows:Title/>
      <ows:Abstract/>
    - <ows:Keywords>
        <ows:Keyword/>
      </ows:Keywords>
      <ows:ServiceType>WPS</ows:ServiceType>
      <ows:ServiceTypeVersion>1.0.0</ows:ServiceTypeVersion>
      <ows:Fees/>
      <ows:AccessConstraints/>
    </ows:ServiceIdentification>
  + <ows:ServiceProvider>
  - <ows:OperationsMetadata>
    + <ows:Operation name="GetCapabilities">
    + <ows:Operation name="DescribeProcess">
    - <ows:Operation name="Execute">
      - <ows:DCP>
        - <ows:HTTP>
            <ows:Get xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/WPSServer?"/>
            <ows:Post xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/WPSServer"/>
          </ows:HTTP>
        </ows:DCP>
      </ows:Operation>
    </ows:OperationsMetadata>
  - <wps:ProcessOfferings>
    - <wps:Process wps:processVersion="1">
        <ows:Identifier>BuildingsRisk</ows:Identifier>
        <ows:Title>BuildingsRisk</ows:Title>
        <ows:Abstract/>
      </wps:Process>
    </wps:ProcessOfferings>
  - <wps:Languages>
    + <wps:Default>
    + <wps:Supported>
    </wps:Languages>
</wps:Capabilities>
```


DescribeProcess request / response

URL: http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/WPSServer?request=DescribeProcess&service=WPS&Version=1.0.0&Identifier=BuildingsRisk



```
141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/WPSServer?request=DescribeProcess&service=WPS&Versio

<?xml version="1.0" encoding="ISO-8859-1"?>
- <wps:ProcessDescriptions xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsDescribeProcess_response.xsd" service="WPS" version="1.0.0">
  - <ProcessDescription statusSupported="true" storeSupported="true" wps:processVersion="1.0.0">
      <ows:Identifier>BuildingsRisk</ows:Identifier>
      <ows:Title>BuildingsRisk</ows:Title>
      <ows:Abstract/>
    - <DataInputs>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Buildings</ows:Identifier>
          <ows:Title>Buildings</ows:Title>
        - <LiteralData>
            <ows:DataType ows:reference="http://www.w3.org/TR/xmlschema-2/#string">string</ows:DataType>
          - <ows:AllowedValues>
              <ows:Value>Important_Points</ows:Value>
              <ows:Value>HistoricalBuildings_At high risk</ows:Value>
              <ows:Value>HistoricalBuildings_At medium risk</ows:Value>
              <ows:Value>HistoricalBuildings_At low risk</ows:Value>
              <ows:Value>River</ows:Value>
              <ows:Value>Buildings</ows:Value>
              <ows:Value>Buildings_At high risk</ows:Value>
              <ows:Value>Buildings_At medium risk</ows:Value>
              <ows:Value>Buildings_At low risk</ows:Value>
              <ows:Value>Water_Levels</ows:Value>
              <ows:Value>Flood_extent</ows:Value>
            </ows:AllowedValues>
            <DefaultValue>Buildings</DefaultValue>
          </LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Water_Levels__2_</ows:Identifier>
          <ows:Title>Water_Levels (2)</ows:Title>
        + <LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Important_Points</ows:Identifier>
          <ows:Title>Important_Points</ows:Title>
        + <LiteralData>
        </Input>

      + <Input minOccurs="0" maxOccurs="1">
      </DataInputs>
    - <ProcessOutputs>
      - <Output>
          <ows:Identifier>_Value__buildings_shp</ows:Identifier>
          <ows:Title>%Value%_buildings.shp</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          - <Supported>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Supported>
          </ComplexOutput>
        </Output>
      - <Output>
          <ows:Identifier>_Value__PointsOfInterest_shp</ows:Identifier>
          <ows:Title>%Value%_PointsOfInterest.shp</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      </ProcessOutputs>
    </ProcessDescription>
  </wps:ProcessDescriptions>
```


Task description

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/BuildingsRisk

Not secure | 141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/BuildingsRisk

ArcGIS REST Services Directory — Login | Get Token

Home > services > MZumbulidzeThesis > BuildingsAtRiskGPServer (GPServer) > BuildingsRisk — Help | API Reference

JSON

Task: BuildingsRisk

Display Name: BuildingsRisk

Description: Buildings at flood risk

Category:

Help URL: http://141.30.100.97:6080/arcgis/rest/directories/arcgisoutput/MZumbulidzeThesis/BuildingsAtRiskGPServer_GPServer/MZumbulidzeThesis_BuildingsAtRiskGPServer/BuildingsRisk.ht

Execution Type: esriExecutionTypeAsynchronous

Parameters:

Parameter: Buildings
Data Type: GPString
Display Name Buildings
Description: Buildings located in the catchment area
Direction: esriGPParameterDirectionInput
Default Value: Buildings
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Important_Points, HistoricalBuildings_At high risk, HistoricalBuildings_At medium risk, HistoricalBuildings_At low risk, River, Buildings, Buildings_At high risk, Buildings_At medium risk, Buildings_At low risk, Water_Levels, Flood_extent]

Parameter: _Value__buildings_shp
Data Type: GPFeatureRecordSetLayer
Display Name %Value%_buildings.shp
Description: Buildings at different flood risk probabilty
Direction: esriGPParameterDirectionOutput
Default Value:
Geometry Type: esriGeometryPolygon
HasZ: false
HasM: false
Spatial Reference: 32638 (32638)

Fields:

- FID *(type: esriFieldTypeOID , alias: FID)*
- FID_Water_ *(type: esriFieldTypeInteger , alias: FID_Water_)*
- OBJECTID *(type: esriFieldTypeInteger , alias: OBJECTID)*
- Id *(type: esriFieldTypeInteger , alias: Id)*
- Shape_Leng *(type: esriFieldTypeDouble , alias: Shape_Leng)*
- WaterLev_C *(type: esriFieldTypeSmallInteger , alias: WaterLev_C)*
- WaterLevel *(type: esriFieldTypeString , alias: WaterLevel , length: 50)*
- Risk *(type: esriFieldTypeString , alias: Risk , length: 50)*
- FID_Buildi *(type: esriFieldTypeInteger , alias: FID_Buildi)*

Parameter: _Value__PointsOfInterest_shp
Data Type: GPFeatureRecordSetLayer
Display Name %Value%_PointsOfInterest.shp
Description: Historical buildings at different flood risk probabilty
Direction: esriGPParameterDirectionOutput
Default Value:
Geometry Type: esriGeometryPolygon
HasZ: false
HasM: false
Spatial Reference: 32638 (32638)

Fields:

- FID *(type: esriFieldTypeOID , alias: FID)*
- FID_Water_ *(type: esriFieldTypeInteger , alias: FID_Water_)*
- OBJECTID *(type: esriFieldTypeInteger , alias: OBJECTID)*
- Id *(type: esriFieldTypeInteger , alias: Id)*
- Shape_Leng *(type: esriFieldTypeDouble , alias: Shape_Leng)*
- WaterLev_C *(type: esriFieldTypeSmallInteger , alias: WaterLev_C)*
- WaterLevel *(type: esriFieldTypeString , alias: WaterLevel , length: 50)*
- Risk *(type: esriFieldTypeString , alias: Risk , length: 50)*

Parameter: Water_Levels__2_
Data Type: GPString
Display Name Water_Levels (2)
Description: Flood risk zones
Direction: esriGPParameterDirectionInput
Default Value: Water_Levels
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Important_Points, HistoricalBuildings_At high risk, HistoricalBuildings_At medium risk, HistoricalBuildings_At low risk, River, Buildings, Buildings_At high risk, Buildings_At medium risk, Buildings_At low risk, Water_Levels, Flood_extent]

Parameter: Important_Points
Data Type: GPString
Display Name Important_Points
Description: Historical buildings in the catchment area
Direction: esriGPParameterDirectionInput
Default Value: Important_Points
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Important_Points, HistoricalBuildings_At high risk, HistoricalBuildings_At medium risk, HistoricalBuildings_At low risk, River, Buildings, Buildings_At high risk, Buildings_At medium risk, Buildings_At low risk, Water_Levels, Flood_extent]

Supported Operations: Submit Job

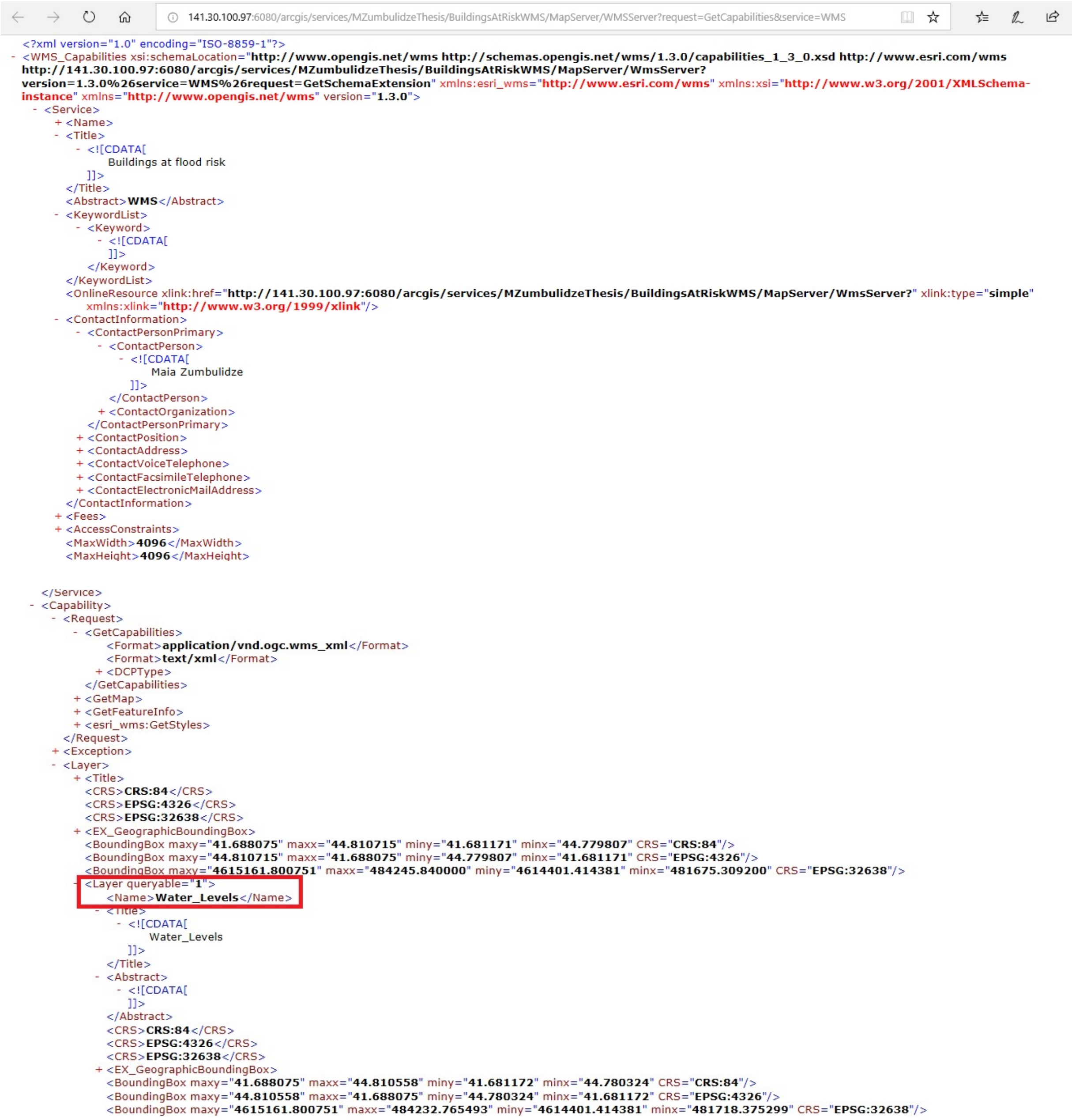
Geoprocessing service – JSON

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/BuildingsAtRiskGPServer/GPServer/BuildingsRisk?f=pjson

B.2. WMS – Buildings at flood risk

GetCapabilities request / response

URL:http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer/WMSServer?request=GetCapabilities&service=WMS



```
141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer/WMSServer?request=GetCapabilities&service=WMS
<?xml version="1.0" encoding="ISO-8859-1"?>
- <WMS_Capabilities xsi:schemaLocation="http://www.opengis.net/wms http://schemas.opengis.net/wms/1.3.0/capabilities_1_3_0.xsd http://www.esri.com/wms
  http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer/WmsServer?
  version=1.3.0%26service=WMS%26request=GetSchemaExtension" xmlns:esri_wms="http://www.esri.com/wms" xmlns:xsi="http://www.w3.org/2001/XMLSchema-
  instance" xmlns="http://www.opengis.net/wms" version="1.3.0">
  - <Service>
    + <Name>
    - <Title>
      - <![CDATA[
          Buildings at flood risk
        ]]>
      </Title>
      <Abstract>WMS</Abstract>
    - <KeywordList>
      - <Keyword>
        - <![CDATA[
          ]]>
        </Keyword>
      </KeywordList>
      <OnlineResource xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer/WmsServer?" xlink:type="simple"
        xmlns:xlink="http://www.w3.org/1999/xlink"/>
    - <ContactInformation>
      - <ContactPersonPrimary>
        - <ContactPerson>
          - <![CDATA[
              Maia Zumbulidze
            ]]>
          </ContactPerson>
        + <ContactOrganization>
        </ContactPersonPrimary>
      + <ContactPosition>
      + <ContactAddress>
      + <ContactVoiceTelephone>
      + <ContactFacsimileTelephone>
      + <ContactElectronicMailAddress>
      </ContactInformation>
    + <Fees>
    + <AccessConstraints>
      <MaxWidth>4096</MaxWidth>
      <MaxHeight>4096</MaxHeight>

    </Service>
  - <Capability>
    - <Request>
      - <GetCapabilities>
          <Format>application/vnd.ogc.wms_xml</Format>
          <Format>text/xml</Format>
        + <DCPType>
        </GetCapabilities>
      + <GetMap>
      + <GetFeatureInfo>
      + <esri_wms:GetStyles>
      </Request>
    + <Exception>
    - <Layer>
      + <Title>
        <CRS>CRS:84</CRS>
        <CRS>EPSG:4326</CRS>
        <CRS>EPSG:32638</CRS>
      + <EX_GeographicBoundingBox>
        <BoundingBox maxy="41.688075" maxx="44.810715" miny="41.681171" minx="44.779807" CRS="CRS:84"/>
        <BoundingBox maxy="44.810715" maxx="41.688075" miny="44.779807" minx="41.681171" CRS="EPSG:4326"/>
        <BoundingBox maxy="4615161.800751" maxx="484245.840000" miny="4614401.414381" minx="481675.309200" CRS="EPSG:32638"/>
      - <Layer queryable="1">
          <Name>Water_Levels</Name>
        - <Title>
          - <![CDATA[
              Water_Levels
            ]]>
          </Title>
        - <Abstract>
          - <![CDATA[
            ]]>
          </Abstract>
          <CRS>CRS:84</CRS>
          <CRS>EPSG:4326</CRS>
          <CRS>EPSG:32638</CRS>
        + <EX_GeographicBoundingBox>
          <BoundingBox maxy="41.688075" maxx="44.810558" miny="41.681172" minx="44.780324" CRS="CRS:84"/>
          <BoundingBox maxy="44.810558" maxx="41.688075" miny="44.780324" minx="41.681172" CRS="EPSG:4326"/>
          <BoundingBox maxy="4615161.800751" maxx="484232.765493" miny="4614401.414381" minx="481718.375299" CRS="EPSG:32638"/>
```

```
    </Layer>
  - <Layer queryable="1">
      <Name>Buildings_At low risk</Name>
    + <Title>
    - <Abstract>
      - <![CDATA[
        ]]>
      </Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.687761" maxx="44.799891" miny="41.684285" minx="44.794822" CRS="CRS:84"/>
      <BoundingBox maxy="44.799891" maxx="41.687761" miny="44.794822" minx="41.684285" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615128.927399" maxx="483345.769587" miny="4614744.052400" minx="482924.852700" CRS="EPSG:32638"/>
    + <Style>
    </Layer>
  - <Layer queryable="1">
      <Name>Buildings_At medium risk</Name>
    + <Title>
    + <Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.687992" maxx="44.806862" miny="41.685967" minx="44.802482" CRS="CRS:84"/>
      <BoundingBox maxy="44.806862" maxx="41.687992" miny="44.802482" minx="41.685967" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615153.340046" maxx="483926.333142" miny="4614929.304600" minx="483562.326500" CRS="EPSG:32638"/>
    + <Style>
    </Layer>
  - <Layer queryable="1">
      <Name>Buildings_At high risk</Name>
    + <Title>
    + <Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.687990" maxx="44.810379" miny="41.686865" minx="44.805100" CRS="CRS:84"/>
      <BoundingBox maxy="44.810379" maxx="41.687990" miny="44.805100" minx="41.686865" CRS="EPSG:4326"/>


    </Layer>
  - <Layer queryable="1">
      <Name>River</Name>
    + <Title>
    - <Abstract>
      - <![CDATA[
        ]]>
      </Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.687777" maxx="44.810713" miny="41.681611" minx="44.779808" CRS="CRS:84"/>
      <BoundingBox maxy="44.810713" maxx="41.687777" miny="44.779808" minx="41.681611" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615128.709900" maxx="484245.840000" miny="4614450.233400" minx="481675.309200" CRS="EPSG:32638"/>
    + <Style>
    </Layer>
  - <Layer queryable="1">
      <Name>HistoricalBuildings_At low risk</Name>
    + <Title>
    - <Abstract>
      - <![CDATA[
        ]]>
      </Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.682293" maxx="44.781377" miny="41.682293" minx="44.781377" CRS="CRS:84"/>
      <BoundingBox maxy="44.781377" maxx="41.682293" miny="44.781377" minx="41.682293" CRS="EPSG:4326"/>
      <BoundingBox maxy="4614525.694335" maxx="481804.348415" miny="4614525.694335" minx="481804.348415" CRS="EPSG:32638"/>
    + <Style>
    </Layer>
  - <Layer queryable="1">
      <Name>HistoricalBuildings_At medium risk</Name>
    + <Title>
    + <Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>


    </Layer>
  - <Layer queryable="1">
      <Name>HistoricalBuildings_At high risk</Name>
    + <Title>
    + <Abstract>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.687109" maxx="44.809293" miny="41.687109" minx="44.809293" CRS="CRS:84"/>
      <BoundingBox maxy="44.809293" maxx="41.687109" miny="44.809293" minx="41.687109" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615054.829156" maxx="484128.959086" miny="4615054.829156" minx="484128.959086" CRS="EPSG:32638"/>
    + <Style>
    </Layer>
  </Layer>
 </Capability>
</WMS_Capabilities>
```

Service description

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer

Not secure | 141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer

ArcGIS REST Services Directory Login | Get Token

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JSON | SOAP | WMS

MZumbulidzeThesis/BuildingsAtRiskWMS (MapServer)

View In: ArcGIS JavaScript ArcGIS Online map viewer Google Earth ArcMap ArcGIS Explorer

View Footprint In: ArcGIS Online map viewer

Service Description: Buildings at flood risk considering flood zones with high, medium, low probability

Map Name: Layers

Legend

All Layers and Tables

Layers:

- HistoricalBuildings_At high risk (0)
- HistoricalBuildings_At medium risk (1)
- HistoricalBuildings_At low risk (2)
- River (3)
- Buildings_At high risk (4)
- Buildings_At medium risk (5)
- Buildings_At low risk (6)
- Water_Levels (7)

Description:

Copyright Text:

Spatial Reference: 32638 (32638)

Single Fused Map Cache: false

Initial Extent:

XMin: 482077.92612592725
YMin: 4614664.85575251
XMax: 484058.47538868804
YMax: 4615184.230559179
Spatial Reference: 32638 (32638)

Full Extent:

XMin: 481675.3092
YMin: 4614401.414381277
XMax: 484245.83999999985
YMax: 4615161.800751461
Spatial Reference: 32638 (32638)

Units: esriMeters

Supported Image Format Types: PNG32,PNG24,PNG,JPG,DIB,TIFF,EMF,PS,PDF,GIF,SVG,SVGZ,BMP

Document Info:

Title:
Author:
Comments: Risk map showing buildings at risk when flash flood occurs considering different water levels, floods with high probabilitz, floods with medium probabilitz, floods with low probability.
Subject: Risk map showing buildings at risk when flash flood occurs
Category:
Keywords: Buildings at flood risk
AntialiasingMode: None
TextAntialiasingMode: Force

Supports Dynamic Layers: false

Supported Query Formats: JSON, AMF

Min Scale: 0

Max Scale: 0

Child Resources: Info

Supported Operations: Export Map Identify Find Return Updates Generate KML

WMS-JSON

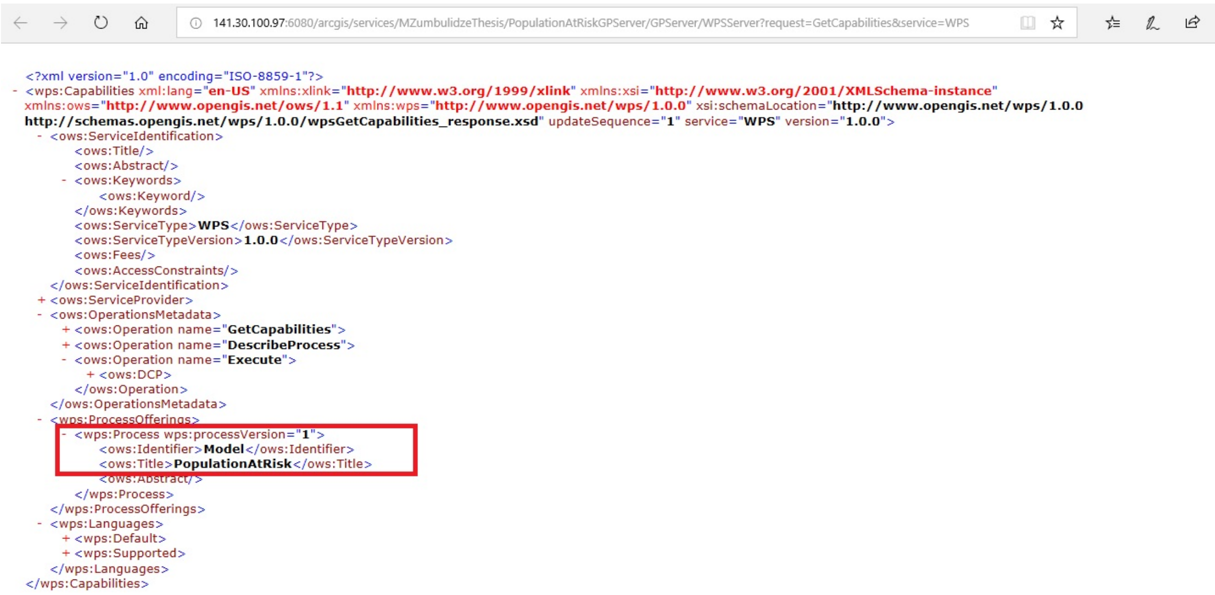
URL: [http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/Building-sAtRiskWMS/MapServer?f=pjson](http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/BuildingsAtRiskWMS/MapServer?f=pjson)

Appendix C: Workflow of Population at flood risk

C.1. Geoprocessing service

GetCapabilities request / response

URL: [http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskGPS-erver/GPServer/WPSServer?request=GetCapabilities&service=WPS](http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskGPServer/GPServer/WPSServer?request=GetCapabilities&service=WPS)



141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskGPServer/GPServer/WPSServer?request=GetCapabilities&service=WPS


```
<?xml version="1.0" encoding="ISO-8859-1"?>
- <wps:Capabilities xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsGetCapabilities_response.xsd" updateSequence="1" service="WPS" version="1.0.0">
  - <ows:ServiceIdentification>
      <ows:Title/>
      <ows:Abstract/>
    - <ows:Keywords>
        <ows:Keyword/>
      </ows:Keywords>
      <ows:ServiceType>WPS</ows:ServiceType>
      <ows:ServiceTypeVersion>1.0.0</ows:ServiceTypeVersion>
      <ows:Fees/>
      <ows:AccessConstraints/>
    </ows:ServiceIdentification>
  + <ows:ServiceProvider>
  - <ows:OperationsMetadata>
    + <ows:Operation name="GetCapabilities">
    + <ows:Operation name="DescribeProcess">
    - <ows:Operation name="Execute">
      + <ows:DCP>
      </ows:Operation>
    </ows:OperationsMetadata>
  - <wps:ProcessOfferings>
    - <wps:Process wps:processVersion="1">
        <ows:Identifier>Model</ows:Identifier>
        <ows:Title>PopulationAtRisk</ows:Title>
        <ows:Abstract/>
      </wps:Process>
    </wps:ProcessOfferings>
  - <wps:Languages>
    + <wps:Default>
    + <wps:Supported>
    </wps:Languages>
</wps:Capabilities>
```


DescribeProcess request

URL: [http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskGPS-erver/GPServer/WPSServer?request=DescribeProcess&service=WPS&Version=1.0.0&Iden-tifier=Model](http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskGPServer/GPServer/WPSServer?request=DescribeProcess&service=WPS&Version=1.0.0&Identifier=Model)

```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
- <wps:ProcessDescriptions xml:lang="en-US" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:ows="http://www.opengis.net/ows/1.1" xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0
  http://schemas.opengis.net/wps/1.0.0/wpsDescribeProcess_response.xsd" service="WPS" version="1.0.0">
  - <ProcessDescription statusSupported="true" storeSupported="true" wps:processVersion="1.0.0">
      <ows:Identifier>Model</ows:Identifier>
      <ows:Title>PopulationAtRisk</ows:Title>
      <ows:Abstract/>
    - <DataInputs>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Buildings_At_low_risk</ows:Identifier>
          <ows:Title>Buildings_At low risk</ows:Title>
        + <LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Buildings_At_medium_risk</ows:Identifier>
          <ows:Title>Buildings_At medium risk</ows:Title>
        + <LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Buildings_At_high_risk</ows:Identifier>
          <ows:Title>Buildings_At high risk</ows:Title>
        + <LiteralData>
        </Input>
      - <Input minOccurs="1" maxOccurs="1">
          <ows:Identifier>Water_Levels</ows:Identifier>
          <ows:Title>Water_Levels</ows:Title>
        + <LiteralData>
        </Input>
      + <Input minOccurs="0" maxOccurs="1">
      </DataInputs>
    - <ProcessOutputs>
      - <Output>
          <ows:Identifier>Population_at_low_risk</ows:Identifier>
          <ows:Title>Population_at_low_risk</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>


              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      - <Output>
          <ows:Identifier>Population_at_medium_risk</ows:Identifier>
          <ows:Title>Population_at_medium_risk</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      - <Output>
          <ows:Identifier>Population_at_high_risk</ows:Identifier>
          <ows:Title>Population_at_high_risk</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>
                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      - <Output>
          <ows:Identifier>Population_merge</ows:Identifier>
          <ows:Title>Population_merge</ows:Title>
        - <ComplexOutput>
          - <Default>
            - <Format>
                <MimeType>text/xml</MimeType>


                <Encoding>UTF-8</Encoding>
                <Schema>http://schemas.opengis.net/gml/3.1.1/base/gml.xsd</Schema>
              </Format>
            </Default>
          + <Supported>
          </ComplexOutput>
        </Output>
      </ProcessOutputs>
    </ProcessDescription>
  </wps:ProcessDescriptions>
```


Task description

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/PopulationAtRiskGPServer/GPServer/PopulationAtRisk

Not secure | 141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/PopulationAtRiskGPServer/GPServer/PopulationAtRisk

ArcGIS REST Services Directory Login | Get Token

Home > services > MZumbulidzeThesis > PopulationAtRiskGPServer (GPServer) > PopulationAtRisk Help | API Reference

JSON

Task: PopulationAtRisk

Display Name: PopulationAtRisk

Description: Flood risk and population

Category:

Help URL: /rest/directories/arcgisoutput/MZumbulidzeThesis/PopulationAtRiskGPServer_GPServer/MZumbulidzeThesis_PopulationAtRiskGPServer/Model.htm

Execution Type: esriExecutionTypeAsynchronous

Parameters:

Parameter: Buildings_At_low_risk
Data Type: GPString
Display Name Buildings_At low risk
Description: buildings and population at low flood risk
Direction: esriGPParameterDirectionInput
Default Value: Buildings_At low risk
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Water_Levels_Layer, Water_Levels, Buildings_At medium risk, Buildings_At low risk, Buildings_At high risk]

Parameter: Buildings_At_medium_risk
Data Type: GPString
Display Name Buildings_At medium risk
Description: buildings and population at medium flood risk
Direction: esriGPParameterDirectionInput
Default Value: Buildings_At medium risk
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Water_Levels_Layer, Water_Levels, Buildings_At medium risk, Buildings_At low risk, Buildings_At high risk]

Parameter: Buildings_At_high_risk
Data Type: GPString
Display Name Buildings_At high risk
Description: buildings and population at high flood risk
Direction: esriGPParameterDirectionInput
Default Value: Buildings_At high risk
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Water_Levels_Layer, Water_Levels, Buildings_At medium risk, Buildings_At low risk, Buildings_At high risk]

Parameter: Water_Levels
Data Type: GPString
Display Name Water_Levels
Description: Flood risk zones
Direction: esriGPParameterDirectionInput
Default Value: Water_Levels
Parameter Type: esriGPParameterTypeRequired
Category:
Choice List: [Water_Levels_Layer, Water_Levels, Buildings_At medium risk, Buildings_At low risk, Buildings_At high risk]

Parameter: Population_at_low_risk
Data Type: GPRecordSet
Display Name Population_at_low_risk
Description: Number of population at low flood risk
Direction: esriGPParameterDirectionOutput
Default Value:
Fields:

- OBJECTID *(type: esriFieldTypeOID , alias: OBJECTID)*
- WaterLev_C *(type: esriFieldTypeSmallInteger , alias: WaterLev_C)*
- FREQUENCY *(type: esriFieldTypeInteger , alias: FREQUENCY)*
- SUM_Population *(type: esriFieldTypeDouble , alias: SUM_Population)*

Features: *None.*

Parameter Type: esriGPParameterTypeRequired
Category:

Parameter: Population_at_medium_risk
Data Type: GPRecordSet
Display Name Population_at_medium_risk
Description: Number of population at medium flood risk
Direction: esriGPParameterDirectionOutput
Default Value:
Fields:

- OBJECTID *(type: esriFieldTypeOID , alias: OBJECTID)*
- WaterLev_C *(type: esriFieldTypeSmallInteger , alias: WaterLev_C)*
- FREQUENCY *(type: esriFieldTypeInteger , alias: FREQUENCY)*
- SUM_Population *(type: esriFieldTypeDouble , alias: SUM_Population)*

Features: *None.*

Parameter Type: esriGPParameterTypeRequired
Category:

Parameter: Population_at_high_risk
Data Type: GPRecordSet
Display Name Population_at_high_risk
Description: Number of population at high flood risk
Direction: esriGPParameterDirectionOutput
Default Value:
Fields:

- OBJECTID *(type: esriFieldTypeOID , alias: OBJECTID)*
- WaterLev_C *(type: esriFieldTypeSmallInteger , alias: WaterLev_C)*
- FREQUENCY *(type: esriFieldTypeInteger , alias: FREQUENCY)*
- SUM_Population *(type: esriFieldTypeDouble , alias: SUM_Population)*

Features: *None.*

Parameter: Population_merge
Data Type: GPRecordSet
Display Name Population_merge
Description: Number of population at flood risk zones
Direction: esriGPParameterDirectionOutput
Default Value:
Fields:
- OBJECTID *(type: esriFieldTypeOID , alias: OBJECTID)*
- WaterLev_C *(type: esriFieldTypeSmallInteger , alias: WaterLev_C)*
- FREQUENCY *(type: esriFieldTypeInteger , alias: FREQUENCY)*
- SUM_Population *(type: esriFieldTypeDouble , alias: SUM_Population)*

Features: *None.*

Parameter Type: esriGPParameterTypeRequired
Category:

Supported Operations: Submit Job

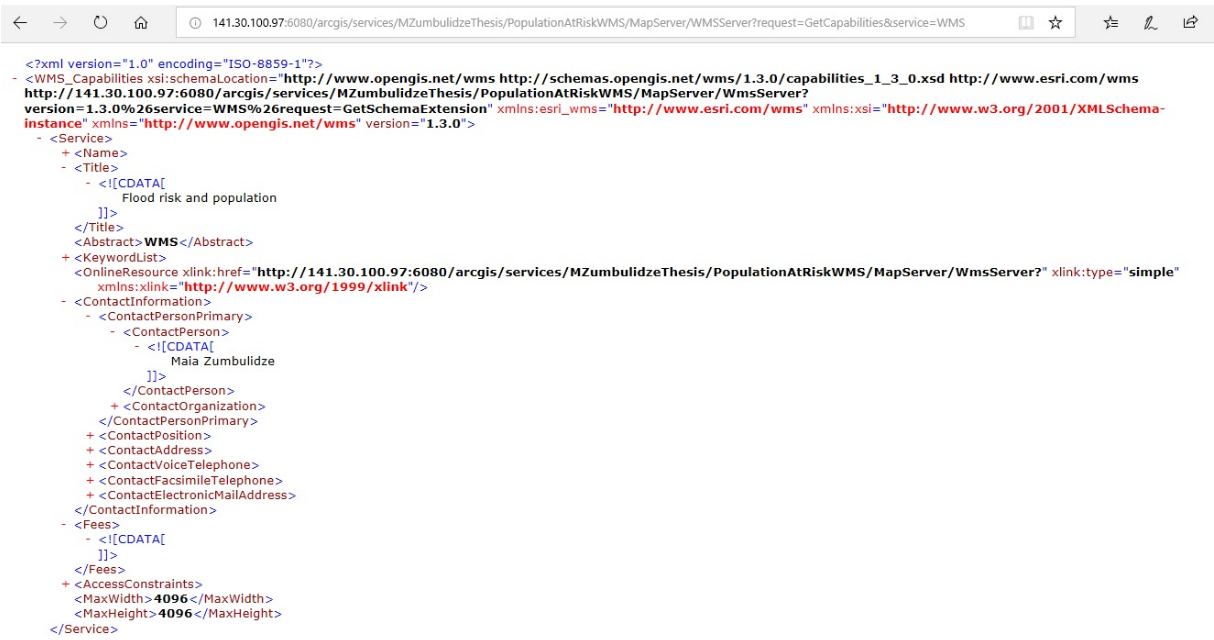
Geoprocessing service-JSON

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/PopulationA-tRiskGPServer/GPServer/PopulationAtRisk?f=pjson

C.2. WMS – Population at flood risk

GetCapabilities request / response

URL: http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationA-tRiskWMS/MapServer/WMSServer?request=GetCapabilities&service=WMS


141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskWMS/MapServer/WMSServer?request=GetCapabilities&service=WMS


```
<?xml version="1.0" encoding="ISO-8859-1"?>
- <WMS_Capabilities xsi:schemaLocation="http://www.opengis.net/wms http://schemas.opengis.net/wms/1.3.0/capabilities_1_3_0.xsd http://www.esri.com/wms
  http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskWMS/MapServer/WmsServer?
  version=1.3.0%26service=WMS%26request=GetSchemaExtension" xmlns:esri_wms="http://www.esri.com/wms" xmlns:xsi="http://www.w3.org/2001/XMLSchema-
  instance" xmlns="http://www.opengis.net/wms" version="1.3.0">
  - <Service>
    + <Name>
    - <Title>
      - <![CDATA[
          Flood risk and population
        ]]>
      </Title>
      <Abstract>WMS</Abstract>
    + <KeywordList>
      <OnlineResource xlink:href="http://141.30.100.97:6080/arcgis/services/MZumbulidzeThesis/PopulationAtRiskWMS/MapServer/WmsServer?" xlink:type="simple"
        xmlns:xlink="http://www.w3.org/1999/xlink"/>
    - <ContactInformation>
      - <ContactPersonPrimary>
        - <ContactPerson>
          - <![CDATA[
              Maia Zumbulidze
            ]]>
          </ContactPerson>
        + <ContactOrganization>
        </ContactPersonPrimary>
      + <ContactPosition>
      + <ContactAddress>
      + <ContactVoiceTelephone>
      + <ContactFacsimileTelephone>
      + <ContactElectronicMailAddress>
      </ContactInformation>
    - <Fees>
      - <![CDATA[
        ]]>
      </Fees>
    + <AccessConstraints>
      <MaxWidth>4096</MaxWidth>
      <MaxHeight>4096</MaxHeight>
    </Service>
```

```
- <Capability>
  - <Request>
    + <GetCapabilities>
    + <GetMap>
    + <GetFeatureInfo>
    + <esri_wms:GetStyles>
    </Request>
  + <Exception>
  - <Layer>
    + <Title>
      <CRS>CRS:84</CRS>
      <CRS>EPSG:4326</CRS>
      <CRS>EPSG:32638</CRS>
    + <EX_GeographicBoundingBox>
      <BoundingBox maxy="41.688075" maxx="44.810715" miny="41.681171" minx="44.779807" CRS="CRS:84"/>
      <BoundingBox maxy="44.810715" maxx="41.688075" miny="44.779807" minx="41.681171" CRS="EPSG:4326"/>
      <BoundingBox maxy="4615161.800751" maxx="484245.840000" miny="4614401.414381" minx="481675.309200" CRS="EPSG:32638"/>
      <Layer queryable="1">
        <Name>Water_Levels_otline</Name>
      + <Title>
      + <Abstract>
        <CRS>CRS:84</CRS>
        <CRS>EPSG:4326</CRS>
        <CRS>EPSG:32638</CRS>
      + <EX_GeographicBoundingBox>
        <BoundingBox maxy="41.688075" maxx="44.810558" miny="41.681172" minx="44.780324" CRS="CRS:84"/>
        <BoundingBox maxy="44.810558" maxx="41.688075" miny="44.780324" minx="41.681172" CRS="EPSG:4326"/>
        <BoundingBox maxy="4615161.800751" maxx="484232.765493" miny="4614401.414381" minx="481718.375299" CRS="EPSG:32638"/>
      + <Style>
      </Layer>
      <Layer queryable="1">
        <Name>Water_Levels</Name>
      + <Title>
      + <Abstract>
        <CRS>CRS:84</CRS>
        <CRS>EPSG:4326</CRS>
        <CRS>EPSG:32638</CRS>
      + <EX_GeographicBoundingBox>
        <BoundingBox maxy="41.688075" maxx="44.810558" miny="41.681172" minx="44.780324" CRS="CRS:84"/>
        <BoundingBox maxy="44.810558" maxx="41.688075" miny="44.780324" minx="41.681172" CRS="EPSG:4326"/>

      </Layer>
      <Layer queryable="1">
        <Name>River</Name>
      + <Title>
      + <Abstract>
        <CRS>CRS:84</CRS>
        <CRS>EPSG:4326</CRS>
        <CRS>EPSG:32638</CRS>
      + <EX_GeographicBoundingBox>
        <BoundingBox maxy="41.687777" maxx="44.810713" miny="41.681611" minx="44.779808" CRS="CRS:84"/>
        <BoundingBox maxy="44.810713" maxx="41.687777" miny="44.779808" minx="41.681611" CRS="EPSG:4326"/>
        <BoundingBox maxy="4615128.709900" maxx="484245.840000" miny="4614450.233400" minx="481675.309200" CRS="EPSG:32638"/>
      + <Style>
      </Layer>
    </Layer>
  </Capability>
</WMS_Capabilities>
```


Service description

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/PopulationAtRiskWMS/MapServer

Not secure | 141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/PopulationAtRiskWMS/MapServer

ArcGIS REST Services Directory Login | Get Token

Home > services > MZumbulidzeThesis > PopulationAtRiskWMS (MapServer) Help | API Reference

JSON | SOAP | WMS

MZumbulidzeThesis/PopulationAtRiskWMS (MapServer)

View In: ArcGIS JavaScript ArcGIS Online map viewer Google Earth ArcMap ArcGIS Explorer

View Footprint In: ArcGIS Online map viewer

Service Description: Population at flood risk considering flood risk zones

Map Name: Layers

Legend

All Layers and Tables

Layers:

- River (0)
- Water_Levels (1)
- Water_Levels_otline (2)

Tables:

- Population_at_high_risk (3)
- Population_at_medium_risk (4)
- Population_at_low_risk (5)
- Merge_Tables (6)

Description:

Copyright Text:

Spatial Reference: 32638 (32638)

Single Fused Map Cache: false

Initial Extent:

XMin: 481754.72148108087
YMin: 4614615.422062733
XMax: 484380.216896386
YMax: 4615432.446859804
Spatial Reference: 32638 (32638)

Full Extent:

XMin: 481675.3092
YMin: 4614401.414381277
XMax: 484245.83999999985
YMax: 4615161.800751461
Spatial Reference: 32638 (32638)

Units: esriMeters

Supported Image Format Types: PNG32,PNG24,PNG,JPG,DIB,TIFF,EMF,PS,PDF,GIF,SVG,SVGZ,BMP

Document Info:

Title:
Author:
Comments: Risk map showing buildings at risk when flash flood occurs considering different water levels, floods with high probabilitz, floods with medium probabilitz, floods with low probability.
Subject: Risk map showing buildings at risk when flash flood occurs
Category:
Keywords: Population at flood risk
AntialiasingMode: None
TextAntialiasingMode: Force

Supports Dynamic Layers: false

MaxRecordCount: 1000

MaxImageHeight: 4096

MaxImageWidth: 4096

Supported Query Formats: JSON, AMF

Min Scale: 0

Max Scale: 0

Child Resources: Info

Supported Operations: Export Map Identify Find Return Updates

WMS – JSON

URL: http://141.30.100.97:6080/arcgis/rest/services/MZumbulidzeThesis/PopulationA-tRiskWMS/MapServer?f=pjson