Flood risk assessment and mitigation measure for Rioni River

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by

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Abstract

Flooding events cause economical, social and environmental damage and lives loss. This fact increases the negative potential of alluvial floods all over the world. Understanding of flood hazard is the first step for Flood risk management. River Rioni is a frequently flooded populated region with developing infrastructure. Flood risk management strategies have not been developed for this region for many years and there is no spatial planning approach for regional development.

This research aims to the flood hazard assessment for Rioni River. An incorporated hydrological modeling approach for hazard assessment for Rioni River has been adopted in this research. The steps involved during research can be broadly divided into following parts historical flood events database have been collected and magnitude frequency relationship have been defined by analyzing the hydrological data with statistical evaluation of the events. The second step involved modeling of events with chosen return periods using SOBEK1D2D hydrodynamic model. DTM was generated by combining the natural and manmade terrain. The flood simulation for selected return periods were generated for 10, 25, 50, and 100 y. The model was calibrated based on varying Manning's friction coefficient within the channel to gain the best results using observed data for 1987 y flood even and flood hazard map have been generated for the region. Next the mitigation measure strategy has been developed for investigated region and hazard maps for different mitigation measure strategies were prepared.

Acknowledgements

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Table of contents

List of figures

List of tables

ACRONYMS

1D	1 dimensional
2D	2 dimensional
ADP	Acoustic Doppler Profiler)
Arc GIS	Geographic information system software produced by ESRI.
ASCII	American standard code for information interchange.
GIS	Geographic information system
CENN	Caucasus Environmental NGO Network
CIDA	Canadian International Development Agency
Delft FLS	Delft flooding system
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DSS	decision support systems
EM-DAT	Emergency Disasters Database
FEMA	Federal Emergency Management Agency
FEWS	Delft Forecasting Early Warning System
FFA	Flood frequency analysis
GHG	Greenhouse Gas
HMS	Hydrological Modelling System
HFDRR	Hyogo Framework for Disaster Risk Reduction
IDW	Inverse Distance Weighted
IMWM	Project in Georgia (Coastal protection study of City Poti)
ISDR	International Strategy for Disaster Reduction
MATRA	Dutch for social transformation (Maatschappelijke Transformatie)
MOE	Ministry of Environment Protection and Natural Resources Of Georgia
NEA	National Environmental Agency
PGIS	Participatory GIS
RMSE	Root Mean Squared Error
SOBEK	Flood modelling software
UNDP	United National Development Program
USGS	United State Geological Survey
TSKALKANALPROJECT	Georgian government organization, “Water system project”

1. Introduction

1.1. Floods and flood problems

Flooding events cause economical, social and environmental damage and lives loss. Based on the Hyogo Framework for Disaster Risk Reduction's (HFDRR, 2010) flood statistical data from 1980 to 2008 have been registered almost 3000 flood events which caused nearly 200,000 deaths, while the economic loss during this period was 397 billion US$ (annual economic loss 13.5 billion US$). Global climate change is likely to increase temperature, change precipitation patterns and raise the frequency of extreme flood events (IPCC, 2001).

River floodplain as the attractive area for settlements is the most densely populated zones in the world with a large accumulation of property. This fact increases the negative potential of alluvial floods all over the world. Flood risk management as the way for control and mitigate the flooding processes and its consequences is widely used by different stakeholders and decision makers. In order to promote a sustainable development and decrease the flood effect it is a prerequisite to use spatial planning in flood risk management (Greiving, 2006)

Flood hazard as part of the flood risk management can be defined as probability that flood prone area will be inundated for a given period of time with a specific return period (Alkema, 2007). Flood modeling is a relatively new approach which is widely used for flood hazard, and risk assessment. Flood hazard and risk based spatial planning must be applied for flood prone areas (Pender, 2007). Flood control measures aimed at lowering the vulnerability of people and their property include list of means, i.e. river engineering works, such as dams, flood walls, embankments, or river training works, retention polders (Klijn, 2009). Traditionally, flood risk management focuses on preventing floods by river training and embankments, it has some disadvantages such as embankment break caused by erosion or overtopping the embankment and nowadays alternative resilient management strategies are applied in different countries (Bruijn, 2005) For example, the Netherlands as a country with long history of flood risk management using the structural mitigation measure strategy represented by protective dikes for centuries, at present employs alternative mitigation measure strategies in different regions like depoldering for Oude Maasje, flood bypass for Green river, etc. Ideally, the trade-off between different flood mitigation measures has to be applied depending on the regional characteristics, flood type and frequency, land use of floodplain as well as the vulnerability of the region. The decision support systems (DSS) are supposed as the helpful tool for the flood risk management. Now DSS is not meant only for experts, it is a new trend to represent the final output of experts' research in way to meet their (decision makers) skills and requests (Klijn, 2009). For many countries DSS is a new and unfeasible opportunity due to the lack of data and techniques as well as experts.

Kolcheti lowland is cut by River Rioni. This is a frequently flooded populated region with developing infrastructure. Flood risk management strategies have not been developed for this region for many years and there is no spatial planning approach necessary for planning and developing the region up today, which takes into account the regional flood hazard problems. Besides, there is no trade of between different mitigation measures.

This project aims at flood modeling of the Lower Rioni River in West Georgia using flood modeling techniques in order to understand flood hazard and represent useful tool for decision-makers in view of spatial planning and future risk assessment for the region.

1.2. Objectives and research questions

The main objectives of the research are as follows:

I. **Estimate flood hazard for Rioni River**

II. **Determine the effect of different mitigation measure.**

Sub-objectives of this research can be determined as:

1. ***Hazard assessment for the region using hydrodynamic modelling:***
   1) *Determine magnitude-frequency relationship for investigated region*
   2) *Determine model data: bathymetry, terrain height and roughness*
   3) *Determine boundary conditions of the model*
   4) *Model calibration using a past flood event*
   5) *Running the model for different return periods using the current layout*
2. ***Flood hazard for different mitigation measures***
   1) *Computation of flood hazard for different mitigation measures*
   2) *Comparison of mitigation measures based on flood hazard.*

1.3. literaturre review

1.3.1. Past studies

Rioni River management has a long history of development and number of researches and investigation has been done for the area of our interest, but as a matter of dissemination and losing of data records and/or paper works during last decades presently was possible to found a very limited number of reports and literature which could be applied for further review and study of the investigated region.

In 2009 the Ministry of Environment Protection and Natural Resources of Georgia (MOE) and United Nations Development Program (UNDP) country office published a co-operative report on carried out projects overview on greenhouse gas (GHG) and climate change in Georgia. In the presented report the GHG and climate change problems have been analyzed and discussed for different regions of Georgia. Regarding to the investigated area must be mentioned performed work on vulnerability assessment of the climate change and adaptation measures for Black Sea coastal zone;

According to above mentioned report **"**Georgian Black sea coastal zone is considered as the most vulnerable to the climate change ecosystem in Georgia having at the same time serious anthropogenic press particularly in the deltas of rivers Rioni and Chorokhi". The vulnerability of Rioni River delta has been evaluated as 17 marks. Compeered to other segments less vulnerable are the lower reaches of Rioi River, whose total index is estimated with 9 marks (UNDP and MOE report, 2009). As a result of current global warming, four major hazards were revealed for the Black Sea: 1. An increasing rate of eustasy (sea level rise relative to land). 2. Growing intensity and frequency of storm surges (storms), Change in their seasonal appearance; 3. Increasing intensity of sedimentation processes in the deltas of glacier-fed rivers (endangering only the Rioni Delta and its mid-flow). 4. The growing probability of days with heavy precipitation increases the probability and intensity of floods at the Rioni River, as the backwater curve of river discharge into the sea is rising. These conclusions once more highlight the importance of estimation flood hazard, quantification of expected discharge and hazard assessment for Rioni River delta.

Erosion of riverbanks and river bank formation pose a large threat of flooding for South Caucasian rivers like River Rioni. Such rivers as the Rioni, Alazani, Araks and Mtkvari, flow in channels packed with alluvium and rising 1–1.5 m above the floodplain, with occasional disastrous floods". The researchers suggest creating a united centre in South Caucasus for monitoring and managing different risks, and set priorities for development and managing of geodynamic hazards in South Caucasus (Bondirev and Tseretely, 2009).However this is a broad overview and discussion of the problems and is not concentrated at any location spatially.

The brief overview of the Rioni River history, hydrology and geomorphologic activities has been found In Mikhailova et al (1998). Z.Janelidze, in his address to the International symposium on "floods and modern methods of control measures" had a look at tendency of increasing of heavy floods of the Rioni River in Kolkheti lowland. Based on historical resources, archeological researches and present situation analysis he concludes that the reason of flood hazard increasing is deforestation of the region (Janelidze. 2009). Even though the fact that above mentioned research has been done for the area of our interests it is not powerful source in terms of information, since it does not represent statistical analysis of the data; no methodologies have been described in article.

IMWM (Project, Coastal protection study of Poti) Project took place in 1998 and is linked to coastal erosion study for the area of port city Poti. The good overview of the Rioni River history, hydrological regime and influence of the hydropower dams on the discharge of the river are done in the project. In the research the affect of Rioni River on the discharge rate and sedimentation transport to the coastal zone have been studied. Above mentioned project and represented MSc research are in close relation due to the overlapping of the investigated zones as well as because of river system should be considered as one system.

In the 2009 the flash flood forecasting project held in Georgia and aimed to investigate the selective region and develop introduction of flood and flash flood forecasting model for the Mountain area (case study Rioni River). On the basis of a topographic analysis of the Rioni watershed, a simulation model for the Hydrological Modeling System (HMS) hydrological model has been set up, calibrated and integrated to Delft-Flood early warning system (FEWS). A real-time numerical weather prediction system has been product. The precipitation and temperature forecasts have been configured (Regiani, 2009). This innovation would be the important in order to control and manage Rioni River delta.

1.3.2. Participatory GIS (PGIS)

Represented research carried out in a data poor environment from the point of view of historical data regarding to inundation processes. Concerning to flood hazard and risk assessment local community knowledge have been found as an important, indeed primary source for information (Whitehouse, 2001) which can be collected through field work and used for hazard estimation as well as for complete gap on flood frequency, flood characteristic, triggering factors and its consequences, local knowledge is also usefull for calibration and verification of risk and disaster scenarios (Bassolé, 2001) throughe the information about water propagation, duration, maximum water level can be obtained using local knowledge and participatory GIS. PGIS can be defined as effective tool for collection, storage, manipulation and integration of local knowledge of communities at risk for spatial planning, analysis and modeling of flood hazard and risk (Guarin, 2008). As McCall (2008) mentioned, it is surprising that we have not many more examples of participatory use of GIS and participatory mapping regarding to hazard and risk assessments. Indeed very few literatures are available for the local knowledge collected for flood hazard and risk assessment. As good examples of using local knowledge in flood hazard and risk assessment should be introduced Phd research of Guarin (2008). In the research the detailed description of PGIS methodologies and implementation are represented for hazard mapping, risk assessment as well as for calibration.

1.3.3. Flood Frequency Analysis

The first step for flood risk management is the estimation of the flood hazard for the region, this process can be done based on the study of triggering factors causing flood and/or investigation of spatial extent of historical events for given region, flood frequency and magnitude relationship estimation (Geohazards, 2009). To determine and quantify the flood frequency and flow variation within a given area the probabilistic approach tool is widely used (Robson, 1999). Gumbel extreme value distribution aims to build the relationship between the probability of the occurrence of a certain event, its return period and its magnitude (El-Naqa and Zeid, 1993). The allocation of best fitted probability functions can be studied using statistical reproduction for employment in peak flow analysis. Different approaches of flood frequency statistical analysis for extreme events are given by Robson (1999). The first approach is based on estimation of peak flow and the event flow and the second technique was based on simulation techniques using parameter modeling in data poor regions (Calver, 2009). Pearsons statistics can be defined as significant tool for analysis of goodness of fit of the data and various observations for the same combination of explicative variables (Smyth, 2003).

1.3.4. Flood modeling

Following the magnitude frequency analyses the next step was the selection of an appropriate model for simulation of the flood process. After the potential flood hazard is identified for the given region, the most important is to understand and identify the characteristics of hazard. For this issue the newly developed modeling approach can be used. Output parameters from modeling should give users the correct characterizations of the flood processes and not only the flood extend (like in traditional methodology for flood hazard mapping), but also for flood depth, water flow velocity, warning time, duration (Alkema, 2007).

Flood modeling for hazard and risk assessment became the popular tool on different stages of flood management (Plate, 2002) it is necessary to choose the proper approach to simulate flood processes among available tools and softwares.

Nowadays 1D and 2D modeling approaches are wide used for modeling of river flow. The Saint-Venant equitation is widely used for 1D flow modeling. This (1D) approach was used to develop softwares like MIKE 11 (MIKE-11, 2009) and HEC-RAS (HEC-RASS, 2010). This approach is suitable to estimate possible flooding processes using river discharge within river channel. Specifically for modeling of river morphology MIKE 21C- 2D modeling has been developed (Sklenar, 2007). For flow modeling in complex terrain the best approach is 2D modeling and requires of representation of terrain topography in terms of DEM (Alkema, 2007). While the 2D flood modeling can be defined as best solution for simulation of inundation processes, combined 1D and 2D modeling is widely used in order to decrease the computation time and get realistic overflow water propagation parameters. Such approach is used by SOBEK. 1D-2D SOBEK model has been developed by WL/Delft Hydraulics in The Netherlands (Delft-Hydraulics, 2009).

1.3.5. Flood hazard assessment and mapping

According to Stephan Baas (2008) hazard can be defined as "potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". Hazards have different origins: natural (geological, hydro-meteorological) or can be provoked by humane (environmental degradation and technological hazards). Each hazard is characterized by its location, frequency and probability of occurrence in a specific region within a specific time and magnitude. The investigation of hazard assessment is associated to study of physical aspects and phenomenon of the given hazard through collection and analysis of historical records, this process is defined as hazard assessment (Geohazards, 2009). Aspects of exposure and vulnerability are not considered in the hazard term, since it focuses on the event or physical condition (Bureau of Reclamation 2004).

According to CSIRO (2000) flood hazard is a function of: flood magnitude, water depth and velocities, rate of water rise, duration, evacuation problems, and size of population at risk, land use, flood awareness and warning time. Flood hazard categories reflect the flood behavior across the floodplain and can be represented by four degrees of hazard: low, medium, high and extreme. Above mentioned hazard categories are subdivided as qualitative flood hazard categories and is very useful for local communities and decision makers. Also quantitative manner of representation of flood hazard are very impotent for mitigation planning purpose as well as for risk assessment because they allow quantitative determination of the frequency and magnitude of flood.

As a result of hazard assessment any special aspect of given hazard can be mapped, this provide information on its (hazard) distribution (Bell, 1999). The proper flood hazard maps provide users with information addressing to spatial and temporal probabilities of the floods (FEMA, 2010). Flood hazard mapping is defined as one of the main steps in flood risk management (Plate, 2002) and can be considered to be the important tool for different issues: local planning, risk assessment as they provide the information about past or possible hazards to local communities and decision makers. A flood hazard maps illustrate the intensity of flood situation and probability of occurrence. The most important indicator for flood hazard assessment are flood depth and water flow velocity as they represent the most dangerous aspects for population and/or property (Merz, 2007).

2. Study area

The investigated region is situated in the western part of Georgia, in the Rioni River delta (Figure 2.1). Four municipalities share the Rioni River delta within the area of our interest: Khobi, Senaki, Lanchkhuti and Poti regions with port city Poti. This is the populated region with developed infrastructures. The south part of Rioni River floodplain towards the Black Sea is covered in Kolkheti marshes and Lake Paliastomi. They represent the most extensive wetland areas within the Black Sea region. Wetlands in Central Kolkheti have been designated as wetlands of international importance by the Ramsar Convention and represent a national park of the Georgia. The area of park is 28 940 ha (Jaoshvili, 2004). The total surface of our study area amounts to 350 km^2.

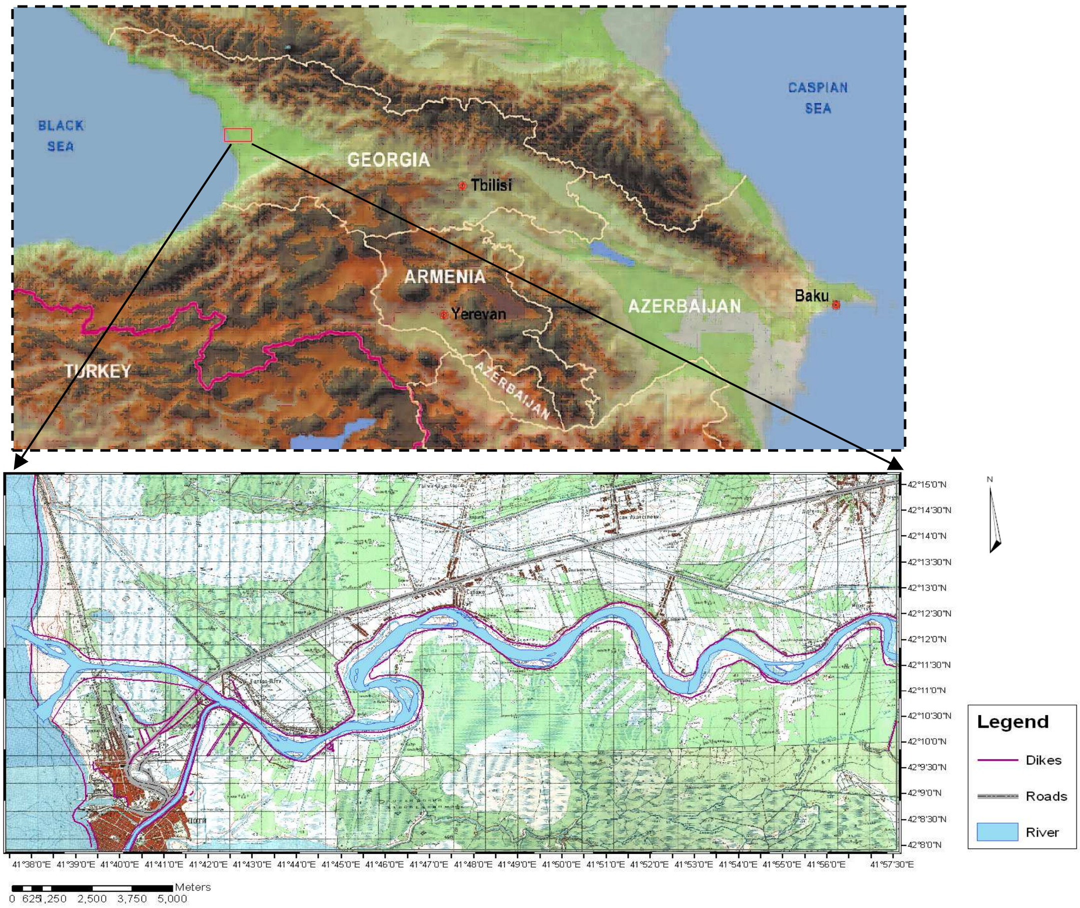


Figure 2.1 Study area

2.1. History of the region

During the centuries, Kolkheti lowland has been covered in marsh. At the beginning of the last century, the plan of draining the swamp area had been developed. The project was initiated in 1920 and finished in 1938. As a result of this proceeding, agricultural activity increased more than 3 times (from 3000-ha to 11000-ha) along with rapid growing of the population density (Metsniereba, 1974). Another effect of this activity included the increasing discharge on the Rioni River (up to 4850 m^3/s according to Janelidze.2009), augmented hazardous events and vulnerability of society. Because of location of Port city Poti and changing of river system during the 1920-1938 the city was affected by numerical flood events, to decrease the hazard of the city Rioni River was shifted (additional channel was cut) to the north through the Nabada area in 1939.The new branch at the present is called North Channel and Its long is about 7 km. The river branch flowing through Poti City is called South Channel (or City Channel) and is about 7.5 km long. Furthermore, in 1959 the sluice works in the Rioni River were completed. These sluice works are meant for distributing water (and sediment) through both Rioni branches in a controlled way (IMWM, 2000). Figure 2.2 shows the past and present location of river's branches.

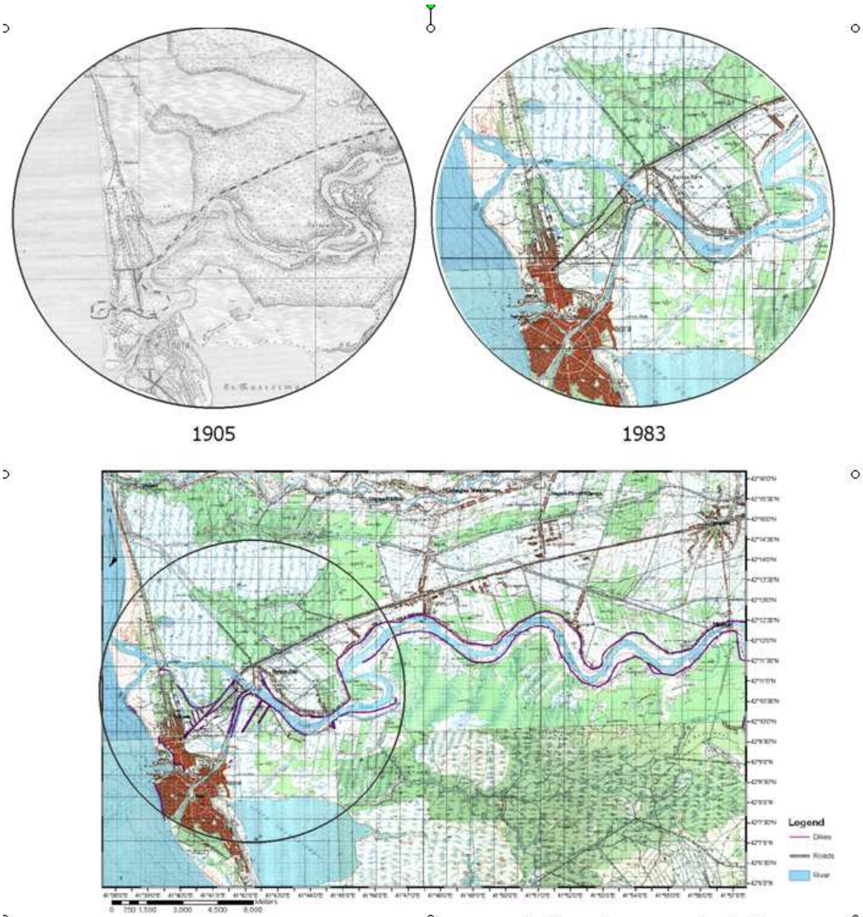


Figure 2.2 Past (left) and present (right) location of Rioni River

Riverbed protective embankments were under construction during the period from 1920 to 1938 for the regulation of water flow along the Rioni River (Metsniereba, 1974). The protective dams pass along polders for 60 kilometres representing the erection of 2-6m height made from clays, loams and silty sands. They were constructed on the both side of Rioni River for discharge peaks lower than 3500m^3/s (Janelidze. 2009).

During the years the activities for protecting agricultural lands from floods and other natural reductions were implemented, but the situation deteriorated during the 90s of the last century, when repair and management of the water channels were halted because of difficult economic situation in the country after the collapse of the Soviet Union. At the present time due to incorrect exploitation, neglect of repair activity the embankment has been severely deformed and intensively eroded during even average floods (Janelidze. 2009). The embankment is not protected from cattle trails and dense vegetation that leads to dike damage and increases flood risks caused by dike break. Figure 2.3 represents the current situation of the dikes and schematization of the possible damage for the constructions.

Figure 2.3 Dikes' condition for Rioni River.

On 26-27 October of 2003 flood discharge on the Rioni River increased up to 2100 m^3/s as a result, the left embankment of the river had been destroyed and water flow to village Sagvichio, Chaladidi, Sakhorcio, Shavi Grele (NEA, unpublished data). Till now, this part of embankment has not been rebuilt and if the discharge rate is more than 2100 m^3/s the inundation occurs in the south part of the investigated region. In figure 2.4 the dikes location in the study area and the destroyed part of dike are represented.

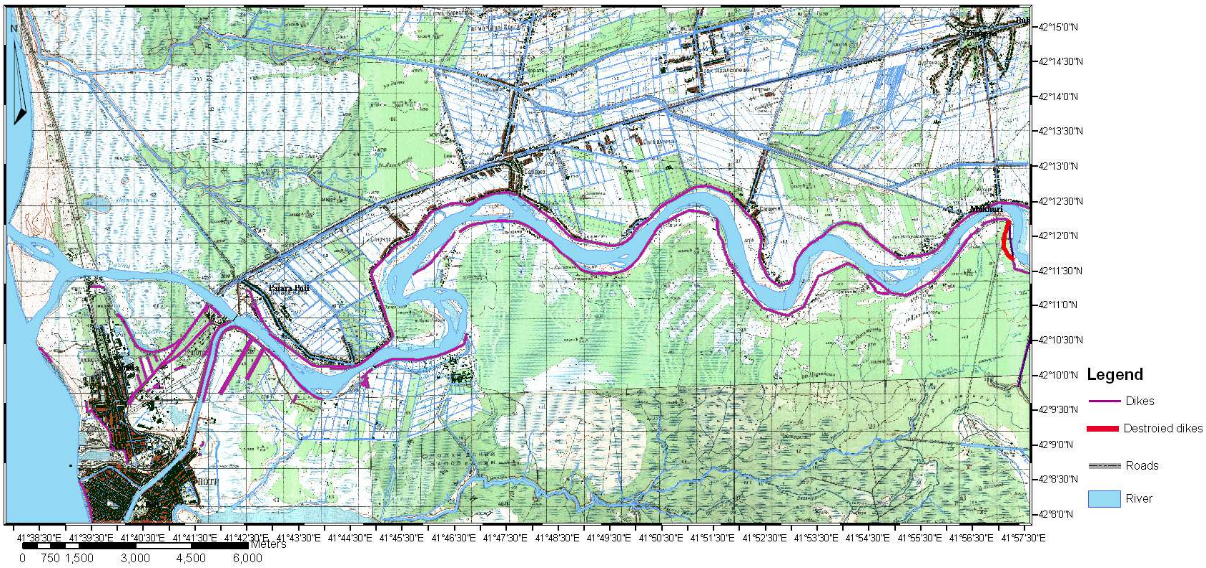


Figure 2.4 Present locations of the dikes and destroyed segment for Rioni River.

2.2. Topography

The Rioni River is the principal river of western Georgia. It originates from the Caucasus Mountains, in the region of Racha and flows west to the Black Sea. The length of the river is 327 km, the area of the entire catchment amounts to 13 500 km2. Fifty-one percent of the Rioni drainage area is situated in a mountain region. Upstream from Kutaisi, the river flows along a wild, narrow rift while downstream from Kutaisi it flows into extensive swampy lowland that abruptly changes the character of the river's flow to a meandering channel, forming numerous sand islands.

The Kolkheti lowland is an intermountain depression with near flat geomorphology and is covered by marine and fluvial sediments (Maruashvili, 1971). It is tilted to the west where the altitude is less than 10m above sea level and to the east the heights gradually increases up to 150 meters.

2.3. Climate

The climate is determined by the Black Sea to the West and the amphitheatre of three big mountain ranges (the Great Caucasus, the Likhi and the Meskheti), in addition to the surrounding Kolkheti lowland (wetland) in the centre. Because of its geographic situation the Kolkheti lowland region represents unique climate grouping. It combines a high annual temperature of 14,1^{o} C with extremes ranging from -15^{o} C to +45^{o} C. The annual amount of precipitation varies between 2,531 mm in the south and 1,458 mm in the north of Kolkheti lowland. 29% of the precipitation falls in summer. Consequently, annual air humidity is high with values between 70% and 83% (Poti station).

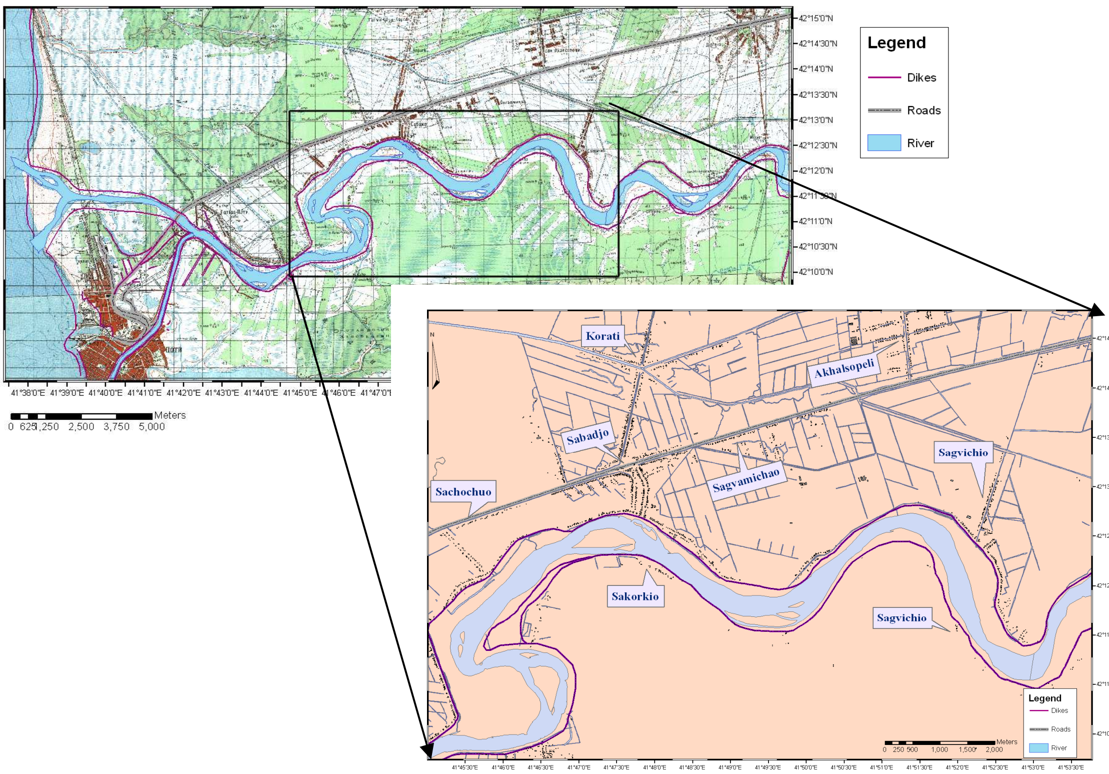


Figure 2.5 Settlements affected by 1987 flood

2.4. Flood characteristics

Rioni River is the largest river of the Georgian Black Sea basin. An average annual water discharge of the river is 430 m^3/s with extremes ranging from 2480 to 3640 in the Rioni River delta (Table 2.1). Rapid warming, intensive snow melt and/or high precipitations are the cause factors of raising the discharge in the Rioni River. Disastrous floods mainly caused by rapid warming and intensive snow-

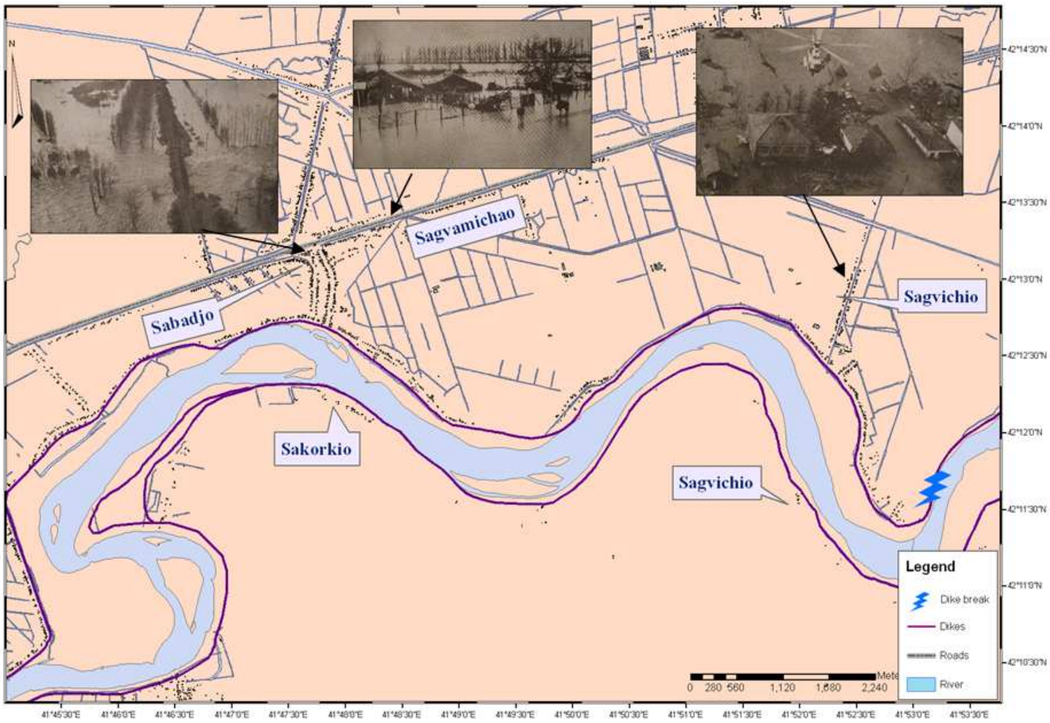


Figure 2.6 Maps and photos of 1987 flood event;

melt or by dike break, result in extensive damage. For example, the population in Imereti was reduced by 30–35% as a consequence of floods on the River Rioni in 1811–1812. In 1982 inundated area made up 130 km and had cost US$12 million (Bondyrev and Tsereteli, 2009).

in January 1987 after the continuous heavy rainfall during 10 days and hurricane on the Black sea, the water level in the river increased (discharge measure exceeded the 3640 m^3/s level) and finally during the night of 31 January to 1 February dike had broken down. Three villages were destroyed (Sagvichio, Chaladidi and Patara Poti), six villages suffered from water and sediments. Two people died. Overall number of destroyed buildings was 300, duration of the flood event was 3-4 days and for two days water level was more than 2 m (6 m above sea level). Rioni flood of 1987 had cost US$300 million (Bondyrev and Tsereteli, 2009). Figure 2.5 and figure. 2.6 represent the area affected by 1987 flood event.

Maximum discharge measured on Rioni River estuary were 5484 m^3/s in 1922 (Hydrometizdat, 1989 in Janelidze, 2009;); 3640 m^3/sec on 31 January-1 February of 1987; 3430m^3/s on 1 - 2 April 1982 (unpublished database of National Environmental Agency (NEA)) Table 2-1 represents the top 10 observed discharge for Rioni River and Figure 2.7 shows the maximum annual discharge for 1939-1990, this dataset does not include above mentioned discharge value 5484 m^3/s for 1922, this will be discussed afterwards (see section 6.2).

Table 2-1: Top 10 flood's discharge from 1939 to 1990

	Year	Discharge m^3/s
	1922*	5484
1	1987	3640
2	1982	3430
3	1981	3160
4	1990	3150
5	1988	3020
6	1963	3000
7	1989	2920
8	1956	2850
9	1980	2650
10	1962	2520

(*) 1922 flood is represented in table, but is not numbered as flood due to the doubtful information. This question will be discussed in section 6.2.

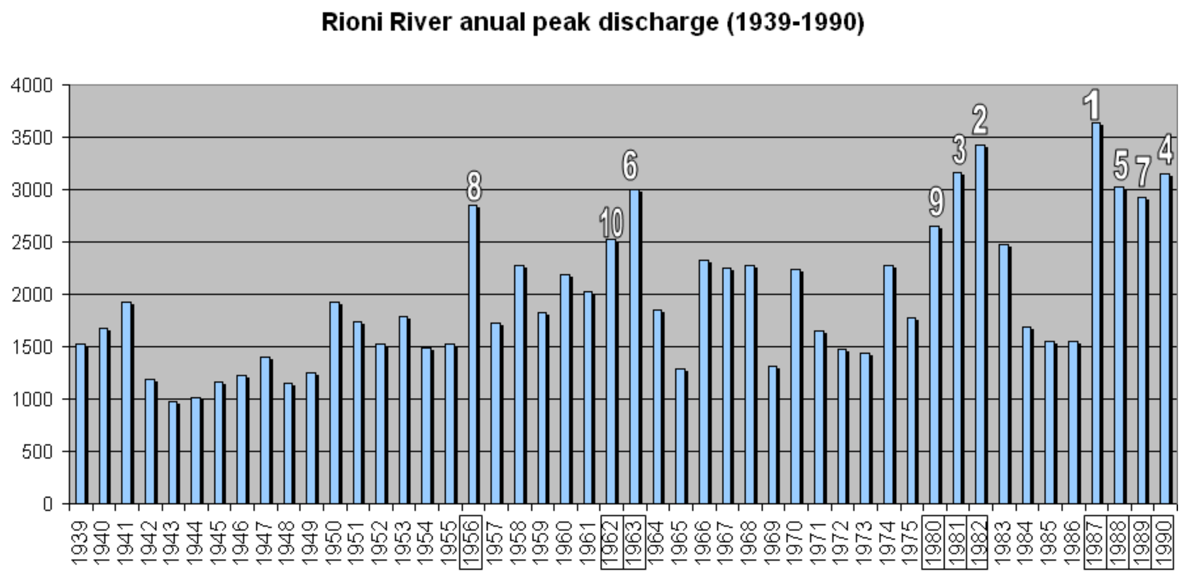


*Figure 2.7 M*aximum annual discharges for 1939 – 1990 (top 10 floods are marked and numbered by discharge value)

2.5. Economic activities

Economic activity in the region is developed in the port of Poti (city due to the relocation of the main river channel to the north is not affected by flood any more) and is represented on the flood prone right bank of the Rioni River. During the years the economy of the area was linked to the tea-growing, citrus plantation, horticultures cultivation as well as to the widely developed cattle-breeding. In the region, there are chemical industry objects, developed food and light industry. A number of building material factories are located in the flood prone area. Transportation activity plays an important role in the region's economy. Area is crossed by intercity road and railway system, which connect west part (Poti port, Batumi, Supsa) and east part of the country and plays an important role in goods transportation. The floodplain on the southern side is designed as a national park, it has less economic activities and low population density; 35 families live in this part of investigated region.

2.6. Land use

In The Rioni River lowland the human activities are represented in the port of Poti and on the north side of Rioni River. The south part is covered by Lake Paliastomi, extensive wetland and forest areas. Land use and land cover in the north part (right bank of Rioni River) of the region is multifarious. Agricultural, cattle and livestock activities are mainly undertaken in this area. Land is occupied by gardens, tea-trees, wheat fields, pasture. Dense water channel system for managing the water flow in the area is present here. Main purpose of channel system is to manage the water flow through the swampy area.

3. Data and Methods

3.1. Data

To reach goals listed in the introduction part of this research the different type of dataset must be used: topographic data, hydrological information, profiles of the riverbed, historical information on the past flood events, spatial information on infrastructure, population.

Must be mentioned a number of problems and difficulties which exist during the data collection in Georgia. First of all existing problems come from close and not transparent structure in different organization: the public services, Nongovernmental organizations (NGO) or private companies have self-contained politics regarding data, its dissemination and/or interchange of the databases. There is not united database system in Georgian government and/or scientific organizations. At the present time a large number of databases were destroyed during post Soviet Union period and also huge database created in that period are not updated till now in to a digital format.

Available data at CENN and NEA at the starting point:

1. Scanned and georeferenced topographic maps of the study area in 1: 50 000 scale.
2. Hydrological discharge database for 1980 - 1990 for River Rioni hydrological station near village Chaladidi.
3. Two Rioni Riverbed profiles measured in 1987 and 2008.
4. Aerial photos of the whole region (panchromatic raster images with 20 cm cell size)
5. Cadastral data of the area. Includes data on infrastructure, land-use, buildings, parcel types and river-channel network, roads and railways.

Throughout the elaboration of this MSc thesis the number of information has been gathering during field work from different sources (Municipaly of the Khobi, Tskalkanal Project, private data etc) and added to the dataset:

1. Topographic maps of the study area in 1:5 000 scale.
2. Topographic maps of the study area in 1:25 000 scale.
3. Reports on the area’s economic activities, flooding problems.
4. Hydrological discharge database for 1939-1976 for River Rioni hydrological station village Chaladidi.

Additionally NEA, CENN and ministry of environment extract Rioni riverbed profiles using river surveyor ADP (Acoustic Doppler Profiler). The job have been done under framework of “Institutional building for natural disaster risk reduction (DRR) in Georgia" project supported by MATRA (Maatschappelijke Transformatie)

Finally, the following dataset were using during research: fieldwork observation, elevation data, cadastral data, land cover and land use maps, observed water level for Rioni River, cross sections for Rioni River, roads and infrastructure of study area. (Table 3.1)

Table 3-1: Database used for research

N	Data	Type	Date	Organization
1	Topo-maps 1 : 50 000	Scanned, Geo-referenced maps	1983	CENN
2	Topo-maps 1 : 25 000	Printed maps	1956	Private sources
3	Topo-maps 1 : 5 000	Printed maps	1969	Private sources
4	Discharge (daily) 1980 - 1990	Digital	1980-1990	CENN, NEA
5	Discharge (Annual peak)	Hard copy	1939-1976	Tskalkanalproject
7	Riverbed profiles	Digital	2010	CENN, MOE, NEA
8	Aerial photos	Digital (20cm cell size)	1999-2001	CENN
9	Cadastral data	Digital	1999-2001	CENN
10	Reports	Hard copy		Private sources

3.1.1. Elevation data

A significant input for hydrodynamic modeling is the correct representation of terrain on which the model will work on. To product DEM the following dataset were using:

1. 1 : 25 000 scale printed topographic maps for investigated region. (Pulkovo 1942 that was transformed to WGS 1984).
2. 1 : 5 000 scale printed topographic maps for central part of investigated region. (Projection unknown and was geo-referenced into WGS 1984).

3. Cadastral data for the region, represented as set of measured points for different features: parcel boundaries, roads (projection: Transverse Mercator; the accuracy and methodology of measurements are unknown).

3.1.2. Areal images and cadastral data

Aerial images of the region were represented as a set of panchromatic raster images with 20 cm cell size and cover all area of interest. The aerial images were surveyed during 1999-2001 for cadastral issues and were geo-referenced in WGS 1984.

Available cadastral data covers all area of research and is represented as spatial database in Transverse Mercator projection system. Database gathered during 1999-2001 fieldwork under framework of “Cadastre and Land Register Project” financed by KFS (Kreditanstalt für Wiederaufbau). Dataset contains point, poly line, polygon shape files and represent in addition to the elevation points:

1. Hydrological network of the area (rivers, channels).
2. Buildings (industrial, private, residential).
3. Land parcels (private, public).
4. Land cover and land use (forest, wetlands, fields, pastures).
5. Infrastructure of the area (main roads, railway, country roads and tracks).

3.1.3. Hydrological data

The hydrological data have been collected from the national environmental agency and “Tskalkanal project”. Database is represented as discharge measurement information for River Rioni (upstream village Chaladidi). After arrangement of data we have following discharge information.

I. 1980 – 1990 discharge daily measurements. Appendix 1 a.
II. 1939 – 1976 maximum annual water discharge. Appendix 1 b.

3.1.4. Riverbed profiles and dike break location

Riverbed’s profile information has been measured for Rioni River and its branches. NEA, CENN and Ministry of environment have done fieldwork during April and June of 2010. The gathered information covers all area of interest and is represented by 27 profiles for different river segments. Profiles are measured not only for riverbeds but also for dikes, exzamples of profiles and its location can be found in appendix 2. Profiles were measured using river surveyor ADP (Acoustic Doppler Profiler). Using same equipment the destroyed dike segment has been measured and was used for DTM generation, (see section 3.2.6 and section 5.2)

3.2. Methods

In the previous section the outline of the available and collected (during the period of research) datasets have been represented. Through these datasets cover different aspects of required information to assess flood hazard the gap regarding to the knowledge on the nature and frequency of floods, historical inundation events, destroyed embankments and heights is presented. Analysis of existing and previous flood problems its interpretation takes an important role in flood research, so on it was required to fill up the gap in the existing data and collect the required information during the field work stage.

The fieldwork was focused on collection of data related to the past inundation events (water propagation, water depth) and estimation of destroyed dikes location for 1987 flood using local knowledge and participatory GIS approach. Preliminary reworked questionnaire was introduced to the local community and the number of population has been inquired. Also maps, reports, information on flooding problems in forms of interview were derived through different organizations like local and regional municipalities. Using GPS the height of the embankments (main roads and railways) have been defined as well as tunnels and bridges parameters. Gathered information was used for understanding and analysis of flood problems in the region, digital terrain model creation, calibration and validation of SOBEK model.

3.2.1. Field work

During described study two field works were carried out. One of them took place in November of 2009 (23/11/09 – 26/11/09) and the second one was completed in March of 2010 (19/03/10-.22/03/10).

I. The following steps were undertaken for the first field work (23/11/09 – 26/11/09):

Meeting with representatives of local government in Khobi during these meetings available data about the region were collected in forms of reports, maps and interviews from local and regional authorities; also topographic maps of the region have been collected and information about population (amount of total polulation, edults, householders). Following settlements exist within the study area: Sagvichio, Chaladidi (Sagvamichio, Sabajo and Sachochuo districts), Patara Poti, Akhalsopeli, Korati, Gagma-shua-khevi, Sakorkio (Figure 2.5 and 2.6).

Three most vulnerable settlements toward the flood and/or 1987 dike break event have been chosen (figure 3.1):

1. Sagvichio
2. Chaladidi (Sagvamichio, Sabajo and Sacochuo districts)

3. Patara Poti.

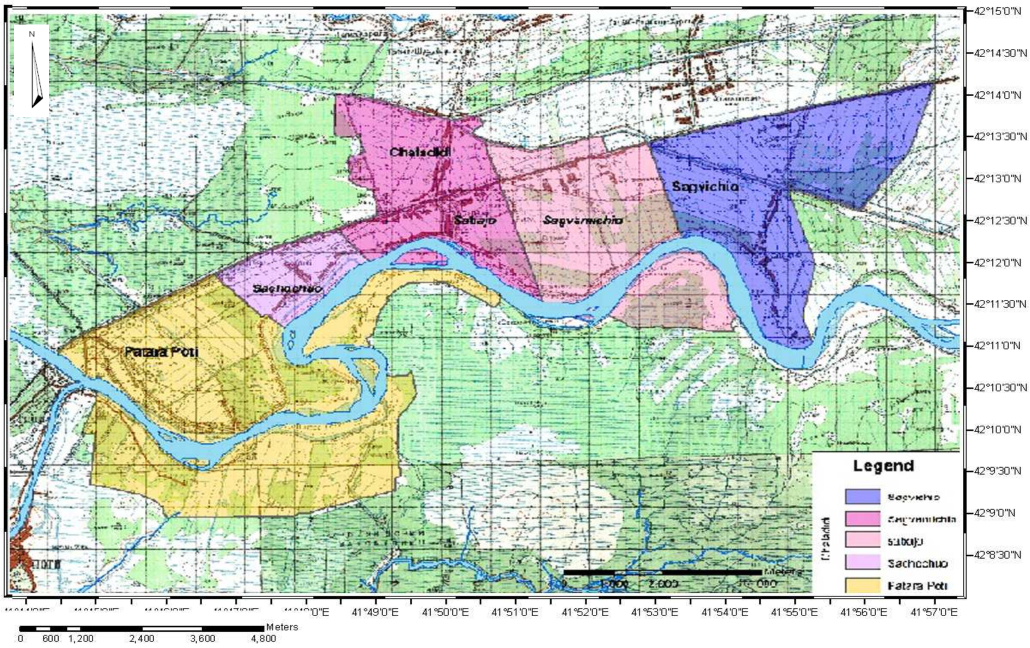


Figure 3.1 Study area and settlements

During field work information on 1987 flood event have been collected; the population was interviewed about the current situation and on the flood problems as well as about the water depth, water propagation during 1987 and 2003 floods. The location and the water depth for 1987 event have been estimated using participatory Gis techniques and were mapped. The questionnaire is represented in the appendix 3 and resultant maps are shown in section 5.1.

- Below are given those actions that have been applied during the second field work (19/03/10-.22/03/10).

First of all, field work was carried out along the main roads and railway. All significant changes in height were established by measuring the relevant height of the roads and railway towards natural terrain using ruler or comparison objects. The precise locations of these points were determined by GPS and were mapped as well. The locations of tunnels and bridges were also established using the same approach. Besides, the population was inquired in order to obtain additional information about the water level during 1987 flood. Finally, information about relevant height of the handmade objects towards natural terrain was collected and pictures were taken. Locations of the main road, railway, bridges and surface tunnels were mapped; their characteristics (height, width) were measured as well (see section 5.1)

3.2.2. Digital terrain model (DTM)

The variation in surface elevation for a given area plays an important role in water flow and propagation. Digital terrain model (DTM) as a basic element for flood modeling requires a high precision. The accuracy of DEM should be represented as height accuracy.

The DTM for flood simulation has been constructed based on multi-source approach. Existing dataset (printed maps in a different scale and coverage) has been integrated and reworked: scanned, geo-referenced, digitized and integrated into one dataset. Different scale and precise datasets (1:50 000 and 1:25 000 maps) cover same area in the central part of investigated region and generate contraction due to the differences in contourlines location. In order to increase overlapping and variety of the data the following procedures carried out for creation of digital terrain model:

I. Printed maps in 1: 25 000 scales have been scanned and geo-referenced (Projection: Transverse Mercator, Central Meridian: 39, Spheroid: WGS 1984).
II. Contour lines (height intervals of 50 cm) and measured height points (totally 433 points) have been digitized from topographic maps (1: 25 000 scale).
III. The maps of 1: 5 000 scale have been also scanned and digitized using the same coordinate system (Projection: Transverse Mercator, Central Meridian: 39, Spheroid: WGS 1984).
IV. The dataset of contour lines (height interval of 25 cm) and points (totally 2 457 points) have been created for central part of investigated region.

Two dataset based on the digitized elevation data were created: 1:25 000 and 1:5000 point maps. Kriging interpolation method was used for calculation of DEM, as the Kriging method have been defined as appropriate method and full-filled the requirements for hydrological flood modeling purpose (Rahman and Alkema, 2006). Four different DTM have been calculated based on 1:50 000 and 1:25 000 topo maps: two DTMs in 50 and 25 m resolution for whole area and two DTMs in 50 and 25 m resolution for central part (see section 5. figure xx represents the digitised contourlines for different scale maps and different areas of coverage). All four maps have been transformed into point maps (using ArcGis “raster to point” option) and were merged with cadastral measured points (elevation) based on spatial location function (nearest point). Additionally point maps generated from 25 and 50 m resolution DTM for central part (1:5000) have been merged with point maps generated from 25 and 50 m for whole area (1:25000). Based on generated point maps with altitude attributes for DTMs and cadastral data the error test has been done using standard RMSE (root main square error) formula (Equation 3.1)

Based on RMSE results the decisions about data usability have been done. Here must be explained the motivation of using cadastral data for RMSE calculation and analysis of error propagation:

1. Cadastral data is the latest dataset in our database
2. The measurements have been done using differential GPS modern techniques.

$$RMSE = \sqrt{\frac{\sum_{n=1}^{n} (Z_i - Z_m)^2}{n}}$$

Equation 3.1Rroot main square error (RMSE)

Where: Zi – Height interpolated (DTM value); Zm – Height measured (cadastral value), N – number of points

Therefore, cadastral data are assumed to be the most precise and accurate data among available height dataset and the accuracy along with the quality of DTM was calculated based on this data. Further analysis of cadastral datasets including their comparison with topo maps, areal photos, visual interpolation and detected high RMS (RMS>4), revealed a large number of mistakes and uncertainty in cadastral dataset. So, this invoked the thorough examination of cadastral data which resulted in rejecting all handmade (bridges, tunnels heights, roads embankments) objects, since the topo data include only natural terrain altitude and compeer these two dataset was out of logic. Also all points with altitude more then 16 meters have been deleted, as the examination of different scales and period’s topo maps illuminate the altitude variation between -0.7 up to 15 meters for specified region. Based on the reworked cadastral data, the final RMSE test has been done (results are represented in section 5. see table 5.2 and 5.3). After all above mentioned steps, using combined contourmaps and point maps data the Kriging interpolation method has been used for creation of DTM (Ordinary Kriging method, spherical semivariogram, minimum number of used pointes was defined as 5). Calculation was done by using Arc GIS.

Elaboration, analysis of RMSE error test results, also visual interpretation clarify that cadastral data contains number of uncertainty, unclear altitude representations becomes data hard to use. To avoid unnecessary errors and variation in altitude during DTM calculation have been decided to only contourlines and point maps derived from topographic maps in 1:25000 and 1:5000 scale. The resultants DTM as well as digitized topomaps are represented in section 5.2

3.2.3. Main road and railway

Within areas which involves not only natural terrain but another features also; like roads, buildings, river banks and dykes and which influence the flow dynamics and flood propagation these features have to be accounted for model setups (Jenson, 1988).

The given area as an inhabited region with developing infrastructure has got a number of handmade features: roads, railways, tunnels and buildings. The height of some of these elements varies between 1 up to 25 m above natural terrain. The location and position of these elements affect on water propagation in case of flood. So this information should be represented in the DTM.

The location of roads and railway network was taken from cadastral data as poly line feature and was transformed into polygon shape file using buffering option.

Different types of roads such as main roads, village roads have different width. Precise road width was determined out from areal images and transformation of polyline road shape file into polygon file was done based on these data. By overlapping the buffered roads and railway with cadastral survey height measurements, the height points for roads were produced. During field work the comparative height of the major roads with respect to the natural relief had been estimated by field measurement (section 3.2.1). Absolute height of those points was calculated by adding comparative height of the handmade features (roads and railways) to the interpolated DTM's altitude at the same location. Finally, using field work points (with calculated absolute height for all field observation) and cadastral altitude measurements, the road raster map was generated using the inverse distance weight (IDW) interpolation method and masked by roads shape file; due to the final DTM resolution the minimum width of the road was defined as 50m. The result of this is a road DTM, which still needs to be combined with the DEM calculated from topographic data.

3.2.4. Bridges and tunnels

The infrastructure of the region contains a number of tunnels and bridges. The location and parameters of those elements (height, width) influence on water propagation as opening for water flow through elevated roads embankment, which should play a water barrier function during the flooding process. The information about the location, width and height of these elements was obtained from the campaigns engaged in the field work which took place in March of 2010 and mapped using GPS and Arc GIS. Additionally, cadastral data and aerial photos were also used for verification and creation of bridges and tunnels location map for main road and railways as embankment features. This information was used during the creation of main roads and railway raster map. The altitude of bridges and tunnels location was defined as natural altitude for raster map, minimum width was defined as 50m due to the DTM resolution.

3.2.5. Embankment modeling

Artificial levees along the Rioni River reach riverbed both on the right and left sides. Dikes have protective purpose in case of high water discharge and their altitude varies for different segments between 2-6m above natural terrain. The dikes' failure is the one of the most hazardous reason of inundation in the region. For instance, dike collapses took place in 1987 and 2003. Position and height of the dikes play an important role in flood modeling process. The location of the levees was specified and then digitized using 1: 5000 and 1: 25 000 topographic maps. Since measured points of riverbed profiles cross the dikes on both sides of the river, these data was used to estimate the height of the dike (Figure 3.2). Therefore using buffering option in Arc GIS the polygon map of dikes with height attribute has been created and finally rasterized into 50m cell size grid and masked by dikes shape file.

3.2.6. Generation of digital terrain models for flood simulation

To estimate hazard and evaluate proper flood hazard maps for reality it is necessary to take into account following factors:

1. Current dike height
2. Location of destroyed dike and its shape

For flood hazard assessment destroyed dikes accurate height and location became available from NEA's field work results (section 3.1.4).

Finally three types of DTM have been generated based on above described methodologies:

1. DTM with initial dike height.
2. DTM with current dike height (destroyed dike)
3. DTM with dike height 1 m more then initial one

ESTIMATION OF DIKE'S HEIGHT USING CROS SECTION DATA

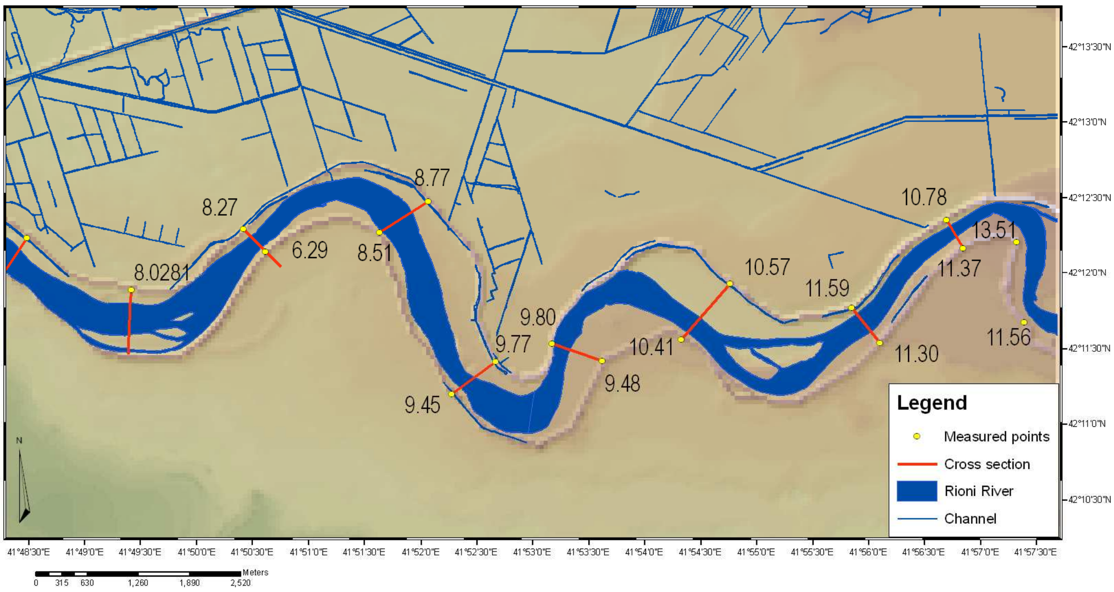


Figure 3.2 Estimation of the dike's height using cross section measurements

For reconstruction of 1987 flood event, validation and calibration of the SOBEK simulations, the digital terrain model N1 was used. Flood hazard assessment was based on digital terrain model N2, and finally mitigation measure was performed using N1 and N 3 digital terrain models were used.

3.2.7. Surface roughness coefficients

Roughness coefficients represent the resistance to flood flows in channels and flood plains. In densely vegetated flood plains, the major roughness is caused by trees, vines and bushes (Arcement etal.). The values were derived from Mannings coefficient (Chow, 1959) depending on land use map and applied for flood modelling.

A surface roughness coefficient map has been developed based on cadastral information. Available polygonal land use layer has been acquired from cadastral dataset. The polygonal shape file contains relevant information for roughness coefficient map, but does not represent the complete information to generate proper roughness coefficient map e.g. totally 20669 polygons are represented in shape file and 1275 polygons are without description (no value or missing). Furthermore, even after completion of the attribute table, data needs to be interpolated and approved in order to generate proper roughness coefficient map. The initial attributive table of cadastral data is represented below in table 3.2:

Table 3-2: Parcel type classes in cadastral data

ID	Parcel type	ID	Parcel type	ID	Parcel type	ID	Parcel type
0	Not Applied	17	Forest	35	Reserve	52	Island
1	Residential	18	Reservation	36	Reserve	53	Stones
2	Industry	19	Water Place	37	Reserve	54	Deep
3	Service-Trade	20	Communication	38	Reserve	55	Meadow
4	Health	21	Boundary Zone	39	Reserve	56	Rock
5	Education	23	Bridge	40	Reserve	57	Reservoir
6	Culture	24	Surveyed by other projects	41	Bridge-Road	58	Private
7	Sport	25	Road/Street	42	Bridge-Railway	59	Lease
8	Police-Military	26	Railway	43	Bushes	60	Reserve
9	Municipal	27	Cemetery	44	Windbreaker line	61	State Use
10	Empty-Not Used	28	Non-residential Building	45	Lake	62	State Ownership
11	Religion	29	Sculpture	46	Channel	63	Mixed Ownership
12	Mixed	30	Garage	47	Bog	64	Reserve
13	Park/Rest	31	Square	48	Descent	99	Other
14	Crops	32	Reserve	49	Pull		
15	Arable	33	Sea coast	50	River		
16	Pasture	34	Reserve	51	Valley		

Visual interpretation approach was applied for verification of polygonal land use data. Missing and/or undefined polygons has been compiled based on the visual interpretation of areal images and local knowledge of region. The parcels of polygons were grouped by land cover types. For instance, parcel types: 19 (Water place), 45 (Lake), 46 (Channel), 47 (bog), 49 (Pull), 50 (River), 57 (Reservoir) were grouped as they represent one roughness class "water".

Finally, the map was reclassified into 6 classes. Classification was based on Mannings's coefficients of roughness for flood plains. Table 3.3 (Chow,1959).

Table 3-3: Land cover classes and surface roughness coefficients (Chow, 1959).

Land cover classes	Surface roughness coefficients
Bare land (sand)	0.03
Build up area (buildings, roads, residential areas)	0.10
Farmland (pasture, low crops, arable)	0.05
Water (water bodies, lakes, channels)	0.03
Wetland (marshes, bog)	0.04
Woodland (trees, bushes, shrubs)	0.07

3.2.8. Hydrological analyses for boundary conditions

Statistical methods should be applied to calculate flood probability. This can be established using discharge information for river segment. To estimate flood hazard it is necessary to evaluate and analyse the distribution of the available data and calculate probability of the occurrence of expected flood events (Calver, 2009). Gumbel extreme value distribution plot, as one of the widely used statistical methods was applied for this purpose (Robson, 1999).

The daily discharge information (1.01.1980-31.12.1990) was processed and maximum annual value table was generated. Furthermore, annual discharge data of 1980-1990 and 1939-1976 were combined into one dataset. Magnitude frequency relationship was estimated on the basis of the discharge obtained from hydrological station upstream from village Chaladidi (station Mukhuri). Table 3.4 represents the maximum discharge for 48 years (1939 – 1975 and 1980 – 1990). Gumbel extreme value distribution plot was applied to get the probability values of the occurrence of extreme floods. Next step was to determine the discharge for different recurrence periods using Gumbel plot results. To determine upstream boundary condition for flood simulation, the expected discharge for different return periods for 10, 25, 50 100 and 200 years was calculated. In food researches the hydrographs shapes plays an essential role as basis for understanding the hydrologic behaviour of the basin (Jain, 2006). For construction of flood simulation for different return periods the hydrograph shape must be defined and applied for different return periods. To reach this goal the shape of the hydrograph taken from the 1987 flood have been used, as it represent well documented real flood event (daily discharge for this period was available). Based on this data (13 days measurements) the hydrographs for 10, 25, 50, 100 and 200 y have been generated by keeping the correlation toward the 1987 flood. The results for this analysis can be found in section 5.4 the discussion is represented in section 6.2.

Table 3-4: Annual maximum discharges for Rioni River station Mukhuri (1939 – 1975 and 1980 – 1990) colours identify the different time series and gap between two databases

N	Year	Discharge m^3/s
1	1939	1520
2	1940	1670
3	1941	1920
4	1942	1190
5	1943	979
6	1944	1010
7	1945	1160
8	1946	1220
9	1947	1400
10	1948	1150
11	1949	1250
12	1950	1930
13	1951	1740
14	1952	1520
15	1953	1790
16	1954	1490
17	1955	1530
18	1956	2850
19	1957	1720
20	1958	2280
21	1959	1820
22	1960	2190
23	1961	2030
24	1962	2520
25	1963	3000
26	1964	1850
27	1965	1290
28	1966	2330
29	1967	2250
30	1968	2280
31	1969	1310
32	1970	2240
33	1971	1650
34	1972	1480
35	1973	1440
36	1974	2280
37	1975	1780
38	1980	2650
39	1981	3160
40	1982	3430
41	1983	2480
42	1984	1690
43	1985	1550
44	1986	1552
45	1987	3640
46	1988	3020
47	1989	2920
48	1990	3150

4. Flood modeling

4.1. SOBEK

SOBEK (Delft-Hydraulics, 2009) is a software package for the integral simulation of natural processes. Software has been developed by Wl Delft Hydraulics for flood processes modeling and management. SOBEK uses two main approaches in fluvial hydraulic modelling: 1 dimension (1D) and 2 dimension (2D) modeling based on the different input data. To build up proper model for inundation simulation using Delft-FLS four types of information are required:

1. Hydrological data: discharge (Q) or water depth (h) time series at the inflow boundary of the model and a Q (h) relation at the outflow boundary of the model.
2. Elements of the dike breach and scour hole to determine the discharge to the floodplain or polder.
3. DEM of the channel, embanked floodplain and polders, including the height and location of dikes, roads, ditches, and sluices.
4. Land surface cover in terms of hydraulic roughness, as well as hydraulic roughness of the main channel. The model produces raster maps of water height and level, flow velocity and direction, and calculates from these an inundation depth map at each time step. (Hesselink and Stelling, 2003)

1D modelling in SOBEK environment is based on the Saint-Venant Equations. The model calculates the water depth and flow velocity in the particular location based on the cross-sections measured perpendicular to the flow direction (river or canal). The parts between cross-sections are interpolated during calculation. These methods foresee the main flow direction, but any movement perpendicular to the main flow is ignored. This approach is useful when the calculation time is limited or DEM for river bed is not available (Alkema, 2007).

When the river overtops the embankment the 1D modelling cannot explicate the water propagation in complex surroundings, it is assumed that flow now is not parallel to the channel anymore and 2D hydraulic modelling must be applied for complex terrain. 2D modelling in SOBEK is based on the two dimensional solution of the Saint Venant Equations.

Combination of 1D and 2D flow modelling in SOBEK was designed to simulate dam breaks and flood processes. It is based upon the complete De Saint Venant Equations and simulates steep fronts, wetting and drying processes, sub critical and supercritical flow.

4.2. Model setup

To get outputs for hazard assessment of the region, the model for flood simulation was built in SOBEK environment. First stage was reconstruction of historical flood event of 1987, for this issue following factors was taken into account:

1. Triggering factors of the event, its parameters.
2. The duration and magnitude of the event
3. Hydrological data available at the time of the flood event

The combined channel flow and overland flow (1D 2D) module of the SOBEK was used for calculation. The model was schematized to get outputs for flood hazard assessment and mitigation measure.

The initial values for the 1987 flood event were used in the settings e.g., simulation runs for a period between 0:00 AM on 26 January 1987 and 0:00 AM on 06 February 1987, duration 14 days, initial water level was defined for boundary conditions. The interval for output maps was estimated as 60 minutes. The network editor module (in SOBEK) was used to schematize the model. The different requirements are in need to schematize the 1D and 2 D flow process. For the 1D channel flow module 27 cross sections were used and friction was determined as 0.02 (Manning coefficients, see section 5.6.1), upper stream boundary was determined as real flood hydrograph for 1987 period (26.01.1987-26.02.1987) and downstream boundary as sea level – 0.5, calculation points, boundary nodes and connection nodes were added as well. The inputs for 2D overland flow module were 50m cell size DTM and the friction map with Manning's friction coefficients. The example of model schematization has been illustrated by the figure (Figure 4.1). A number of history stations were also inscribed in the model to compare the 2D flow results at a specific location (field measurement locations of the water depth). The first ran models results clarify that the area which was defined as investigated region at initial stage is not sufficient for discharge value occurred in the region and over flooding affect has been observed in the models as the edges of the DTM play the "wall" role in this case. To avoid the effect of "twirling water flood" additional boundaries have been added into the schematisation and boundary conditions have been defined as 0.5 above see level.

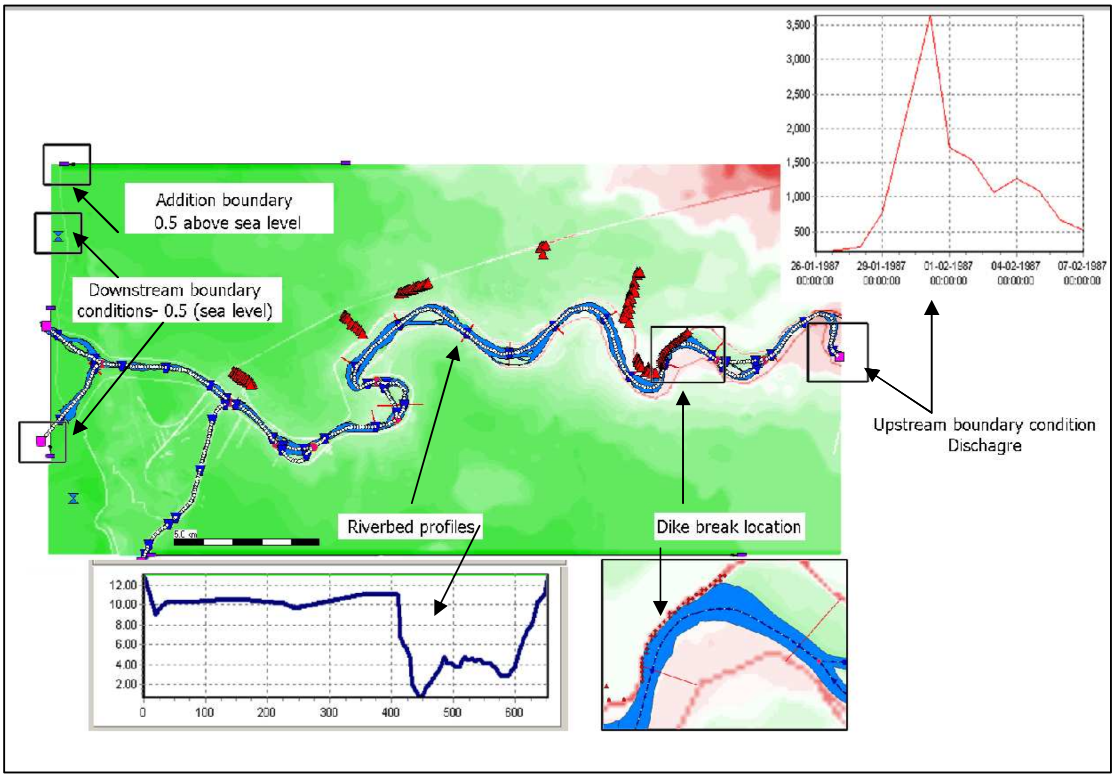


Figure 4.1 SOBEK model schematization used for calibration 1987 event

1- Section shows the Rioni River Upstream boundary in terms of discharge (daily measurements)

2-Second represents the downstream boundary (boundary level was defined as sea level)

3 -Section shows the dike breaking scenario, defined for each pixel of descried dike

4 -Section: riverbed profiles for Rioni River

5 - History stations for record the water level change history.

4.3. Model calibration and verification analysis

There are mainly two ways to test the flood inundation models to verify and validate the output results. The first one refers to the testing the numerical scheme of the models and must be done by comparisons with analytic solutions, theoretical analyses of consistency, stability and convergence and second one use laboratory experiments approach where the model simulation results are compared with the results of an inundation experiment (Hesselink, 2003). The major disadvantage in this research, on the subject of calibration and verification of the inundation models refers to data poor environment. It is therefore important to test the real flood consistency of simulated models and to assess the uncertainties in the results.

Hydrological dataset have been already used for schematization (section 4.2) and couldn’t be applied for testing flood model. Unfortunately there was not possibility to find any available documented data on 1987 flood event like maps and/or water depth or other flood parameters. lack of information regarding to water propagation, destroyed dikes segment, water depth or damage caused by 1987 flood make difficult to examine SOBEK models output. To fit full the gap in the knowledge the field work campaigns carried out and the information on water propagation and water depth during 1987 flood event have been collected based on PGIS (participatory GIS) approach, the goals and methodologies of the field work as well as the questionnaire are discussed in section 3.1, results can be founded in section 5.1. Therefore only one possibility exists to compare and verify the models: the quality of the SOBEK outputs have been tested based on field work data.

Surface friction controls the amount of water flowing through the area (Alkema, 2007). Changing in Manning roughness coefficients for channel and/or floodplain area, are accepted and widely used by researchers and experts (Aronica, 1998). Hydraulic models of flood include channel and floodplain roughness coefficients; both can be spatially varied and may be adjusted as part of a calibration process (Hall, 2005).

The calibration of the model was executed based on optimization of friction values. Manning's friction coefficients were specified based on different land use types to generate friction surface parameters within channel. At the first stage for simulation of 1D and 2D flow standard roughness values for riverbed and for water area **-** 0.03 (Manning's coefficients) was defined. The results show the abnormal high water depth in the river channel and floodplain area in comparison with field work data. Totally 3 models with different friction coefficients (Manning's friction value: 0.05; 0.01 and 0.02) have been ran in order to define best Manning value for SOBEK schematisation. Decrease of the roughness coefficient to 0.02 for channel gave the results better fitted to the field work measured observation.

Table 4-1: Manning's coefficient for SOBEK model calibration

Land cover classes	**Surface roughness coefficients**
Bare land (sand)	0.03
Build up area (buildings, roads, residential areas)	0.10
Farmland (pasture, low crops, arable)	0.05
Water (water bodies, lakes, channels)	**0.01 - 0.03 (varying)**
Wetland (marshes, bog)	0.04
Woodland (trees, bushes, shrubs)	0.07

The table 4.1 demonstrates the surface roughness values used for the model. Changes were made in the channel roughness parameters while the values for the overland flow module were, as indicated in the table. The results for model calibration have been discussed later in the next section 5.6.1

4.4. Flood hazard assessment.

Hazard assessment was performed by calculating the annual probability of occurrence of flood for 25, 50, and 100 y return periods. Using above described schematization and friction parameters (section 4.2 Figure 4.1 and section 4.3) four simulations have been run in SOBEK environment. The methodologies used to define upstream boundary conditions are described in section 3.4 and resultant hydrographs can be found in section 5.4. Hazard mapping was completed using the parameter maps in terms of depth and velocity generated by SOBEK. The output maps (*.asc) were imported into the ArcGIS, identified and mapped in a 0-1 scale of damage and their annual probability of occurrence. This meet the definition of the hazard: "existing event has a probability of occurrence within a specified period and within a given area and has a given intensity" (Geohazards, 2009) The resultant flood hazard map for different return periods can be seen in section 5.5.6 Final raster map with attribute in terms of occurrence probability and minimum water depth have been generated.

4.5. Mitigation measures:

In order to estimate the favourable and/or unfavourable aspects of the existing circumstances (destroyed dike) regarding to the alternative mitigation measure strategies it is essential to elaborate changed simulation for different probability of flood occurrence and dike conditions.

Using transformed parameters for the dikes like increased levee height two types of mitigation measure scenarios were performed following hypothetical models:

Scenario 1. Dikes are reconstructed to the original height and location (SOBEK model was designed for 25, 50, 100 y return periods).

Scenario 2. Dikes are heightened up to 1 m above initial height. (SOBEK model was designed for 50 and 100 return periods)

Models have been designed based on the SOBEK schematization which is described in details in the section 4.2. The initial conditions for upstream boundaries were derived from generated hydrographs for different return periods (10, 25, 50 and 100 y). Hydrographs for different recurrence interval are shown in section 5.3 (Figure. 5.16 and table 4-1). The DTMs as inputs for the overland 2D flow were generated for each scenario separately based on the methodologies described in section 3.2.2.

5. Results

5.1. Fieldwork and usage of the data

Field work results were analysed and based on the information obtained during two field works further will be discussed the resultants of this works; As it was mentioned in section 3.2.1, the field campaigns were focused on the collection of data relating to the embankments height, brides and/or tunnels' location and on previous inundation events (1987 and 2003). Also prevalent flooding types, flood triggering factors, flood frequency and related problems have been discussed with population and local authorities.

1 With assistance of local community (inquired population) and local municipalities' representatives, the area inundated by flood of 1987 was determined and mapped. The results can be found in section 5.6 (Figure. 5.1).

2 The water depth map was produced on the basis of information derived from population at different sites. The water depth map represents the water body height at the specified location above natural terrain and was performed based on the enquired population (94 locations). The map is represented in figure 5.2. The dippiest water levels were detected near collapsed dike and in the low altitude sites.

3 The measured embankments' height, location of the tunnels and bridges has crucial meaning for SOBEK schematization. Below is given the measured embankment height points and schematization of embankment (Figure 5.3).

4

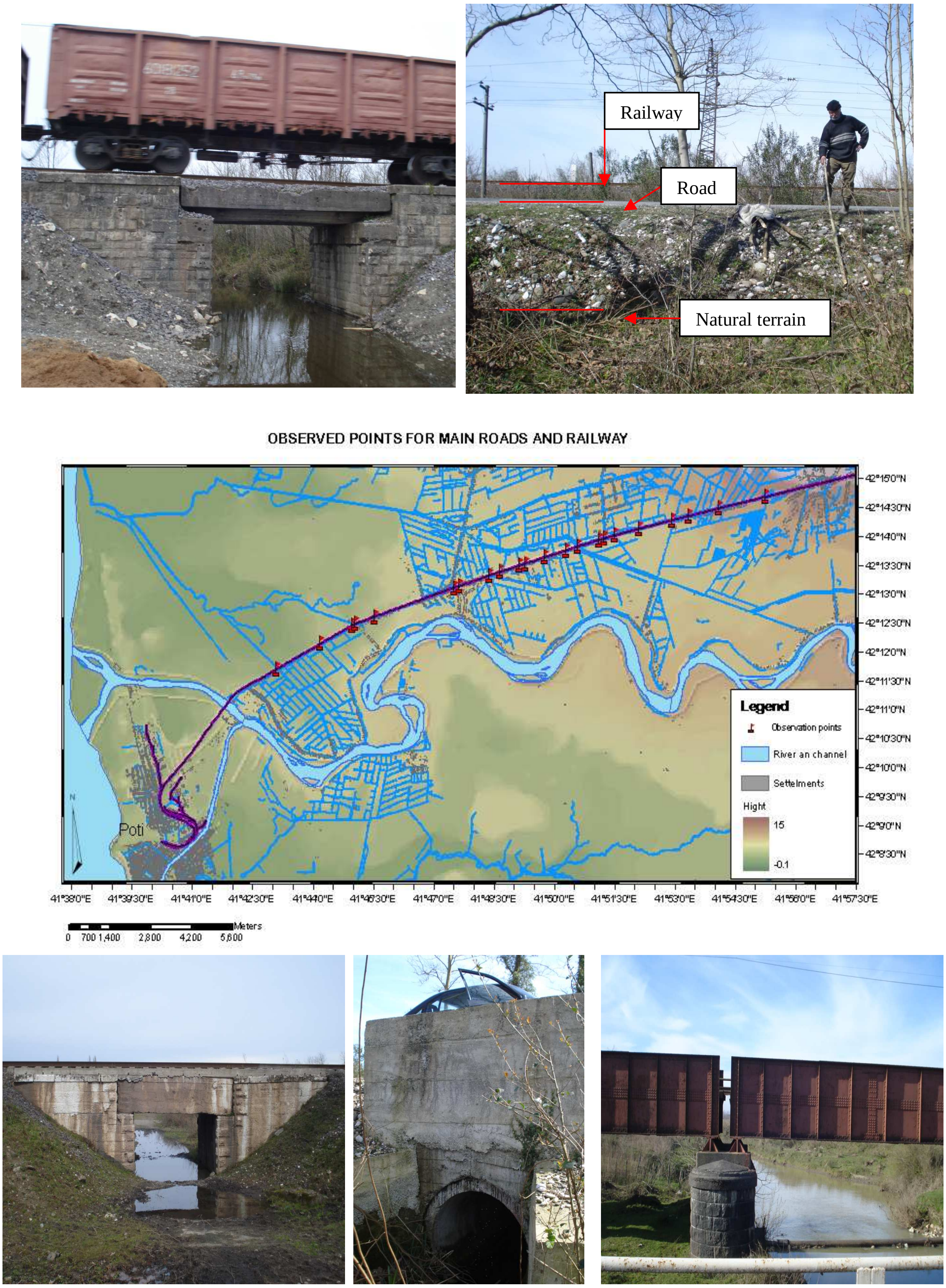


Figure 5.1 Observed points for main roads and railway, pictures represent the types of tunnels and bridges. In the upper left picture red lines indicate the altitude difference between Railway and main road

5.1.1. Meetings with local authorities and flood problem discussion with population

The discussion with local authorities and population has clarified that:

Mainly two types of flood occur in the investigated region:

1. Flood caused by rainfall and snowmelt during spring (pluvial flood)
2. Flood caused by embankment break (alluvial flood)

Totally 94 families were visited in different villages (Table 5.1) and following were concluded: rainfall and snowmelt floods mainly occur during the rainy season (spring, autumn); the main causative factor is high precipitation. If rainfall occurs during 1-2 days, this is a triggering factor for 10-40 cm flooding. According to population this happens several times per year. The channels in the region are not systematically maintained and the water flow in case of precipitations is heavy and is an additional factor of flood. Flood in the region causes the loss of crops, cattle, homestead and other constructions. Population cannot play any role in prevention of flood processes, since the manageable water level for flood is 10-15 cm and in case of 50-60 cm and above the population is forced to leave the houses and move to the safe places.

It is rare when population makes an attempt to manage husbandry, save crops and property or maintain the dikes and/or embankments. Moreover, the dikes are not safe from cattle and other animals, large plants like trees and bushes grown up on the dikes. This causes harm of handmade levee and increases the flood hazard.

The dike break is relatively rare event, but much more dangerous for population and their property. Main problems for protecting dikes are as follows: erosion processes caused by river and precipitation,

1. Not safe condition from chattels and other animals and disruption from their actions.
2. Large plants like trees and bushes growing up on the dikes.

Table 5-1: Population, householders and sample information

<table>
<tr><th>N</th><th colspan="2">Name</th><th>Population</th><th>Adult</th><th>Children</th><th>Nr householder</th><th>Sample size</th><th>Sample %</th></tr>
<tr><td>1</td><td colspan="2">Sagvichio</td><td>700</td><td>476</td><td>224</td><td>190</td><td>20</td><td>10.5</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Chaladidi</td><td>Sagvamicio</td><td rowspan="3">2683</td><td rowspan="3">2300</td><td rowspan="3">383</td><td rowspan="3">960</td><td rowspan="3">42</td><td rowspan="3">4.4</td></tr>
<tr><td>Sabadjo</td></tr>
<tr><td>Sachochuo</td></tr>
<tr><td>3</td><td colspan="2">Patara Poti</td><td>1944</td><td>1044</td><td>900</td><td>240</td><td>32</td><td>13.3</td></tr>
</table>

5.2. Natural Terrain and Manmade Terrain (DTM)

A Digital surface model (DTM) was generated with a resolution of 50m based on methods described in section 3.2.2-3.2.5 below in figure 5.2 and figure 5.3 are shown the digitized topo maps for the region in 1 : 25 000 and 1 : 5 000 respectively.

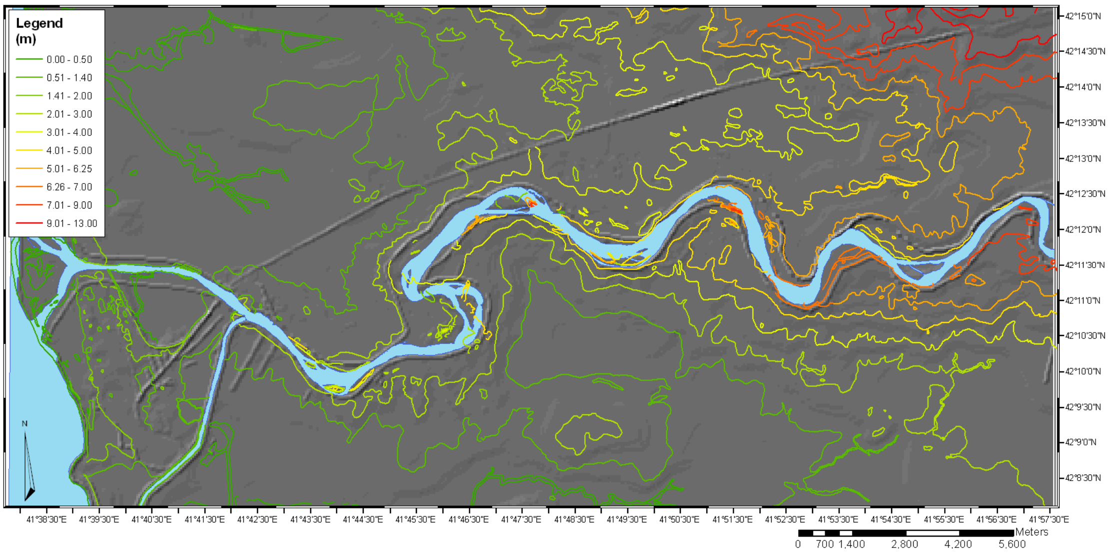


Figure 5.2. Contour lines derived from 1:25000 topo maps overlaid Hill shade

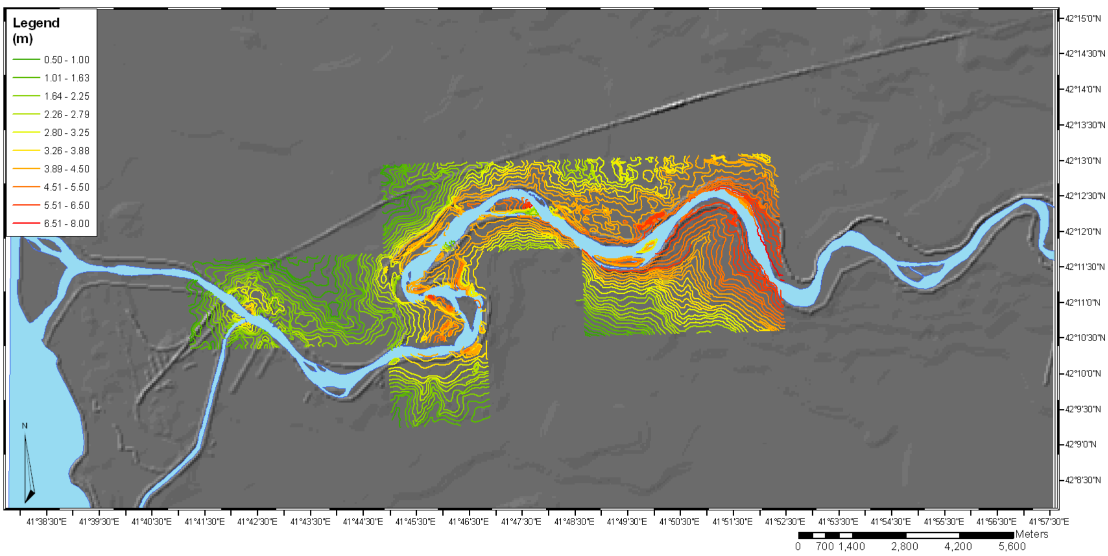


Figure 5.3. Contour liness derived from 1:50000 topo maps overlaid Hill shade (blocks include available maps sheets)

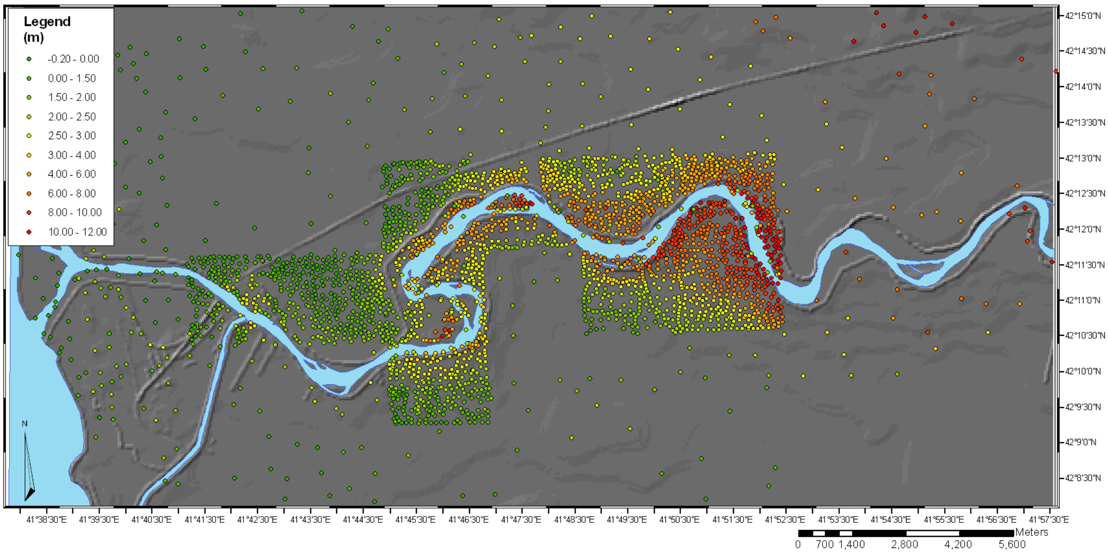


Figure 5.4. Points derived from topo maps overlaid Hill shade (1:25000 and 1:5000)

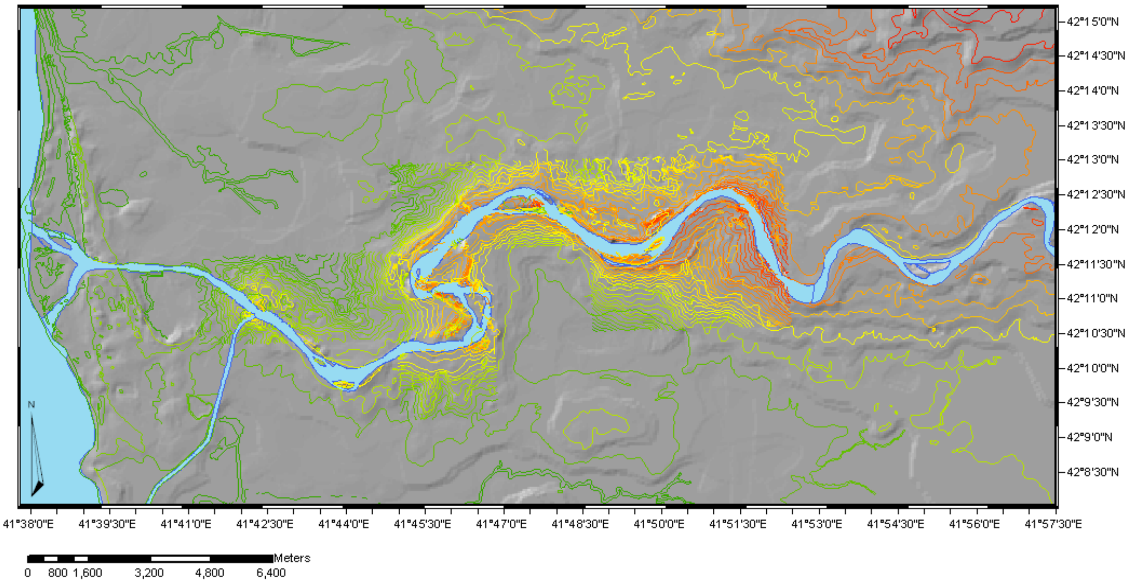


Figure 5.5. Conture lines derived from 1:500 and 1:25 000 maps

Two different scale maps were used to perform the DTM for flood simulation. As it can be indicated from the illustration (figure 5.5) the contourlines derived from the different scales maps overlies each other, furthermore during elaboration of the data the central part (duplicated data) have been reworked and contourlines from 1:5000 maps were used for this part of region and for left area conturlines from the 1:25000 scale map (figure 5.4).

Cadastral data as altitude points are represented on the figure 5.6, based on available cadastral records it became possible to make mathematical calculation for DEM accuracy assessment using RMSE application. Table 5.2 and table 5-3shows the RMSE result, the distribution of error is represented in Figure 5.7. As it can be concluded from table 5.2, the lowest RMSE was generated on the basis of analysis of comparative RMSE of 1:25 000 and 1:5 000 maps.

Table 5-2: RMSE test results for 50m DEM

50 m DEM	1:5000	1:25 000	Cadastral points
1:5000		**0.63** (21308 points)	**1.32** (2860 points)
1:25 000			**1.42** (21795 points)

Table 5-3: RMSE test results for 25m DEM

25 m DEM	1:5000	1:25 000	Cadastral points
1:25 000	**0.68** (85686 points)		
Cadastral points	**1.27** (2978 points)	**1.34** (8559 points)	

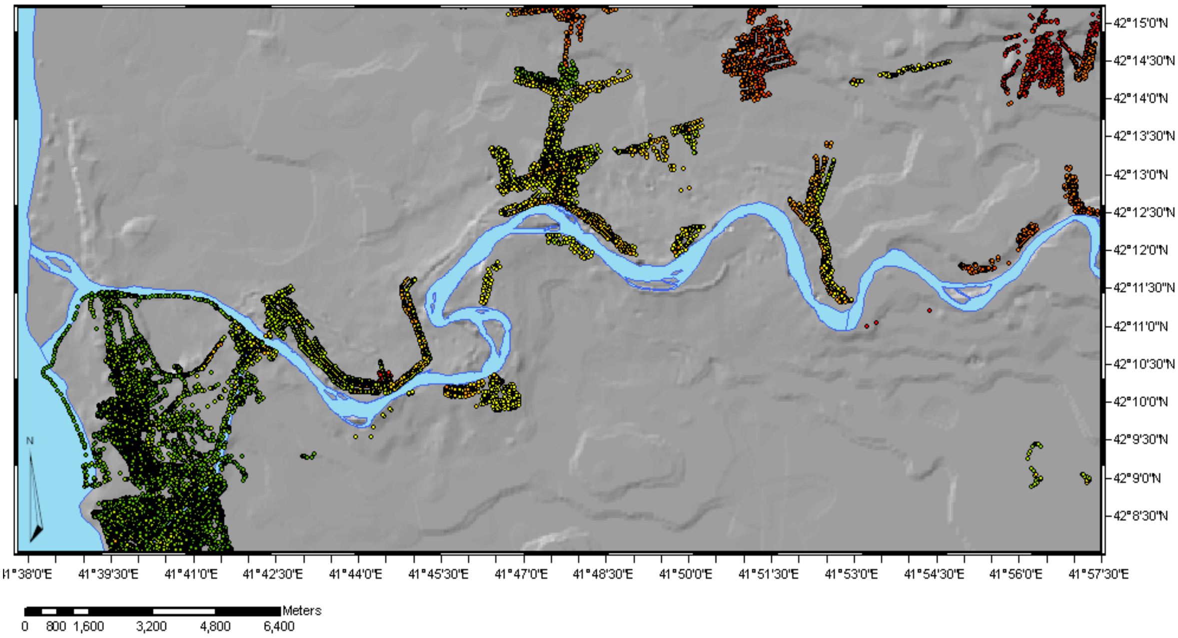


Figure 5.6. Cadastral data as altitude points

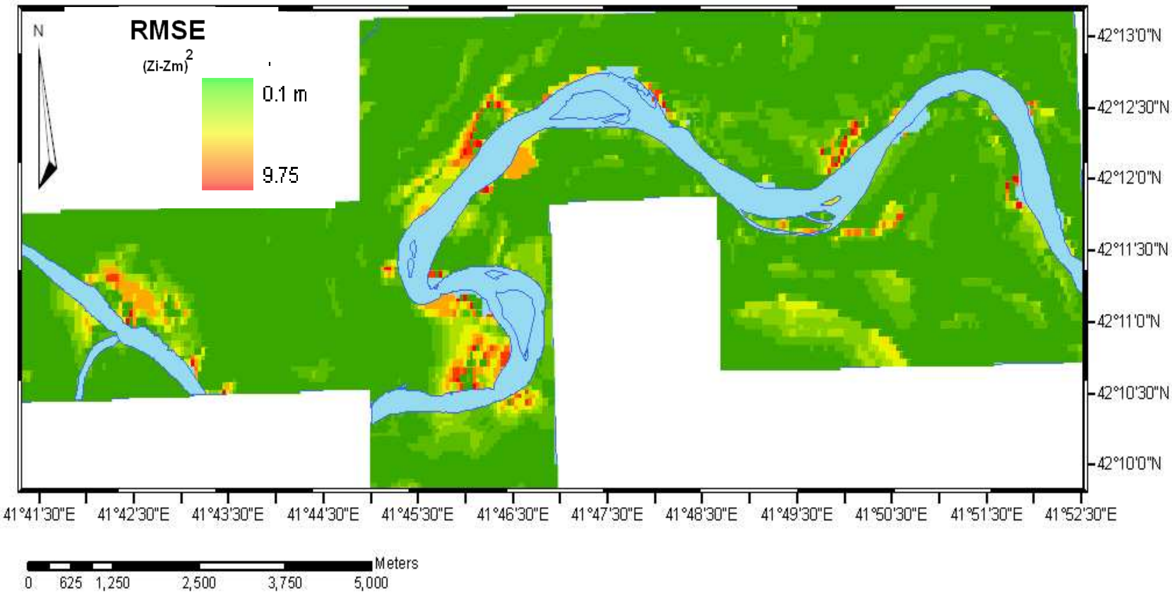


Figure 5.7 Distribution of RMSE for study area (1:5000 and 1:25000 maps)

The DTM for roads with tunnels and bridges in combination with dikes for hazard assessment is shown below. The difference within DTMs for the calibration is the destroyed dikes' height.

Finally, for the purposes of modeling, digital terrain model (DTM) of the study area, Pixel size 50m was counted up. Presented DTM includes the elements of embankments, dikes, roads, tunnels and bridges Figure 5.8.

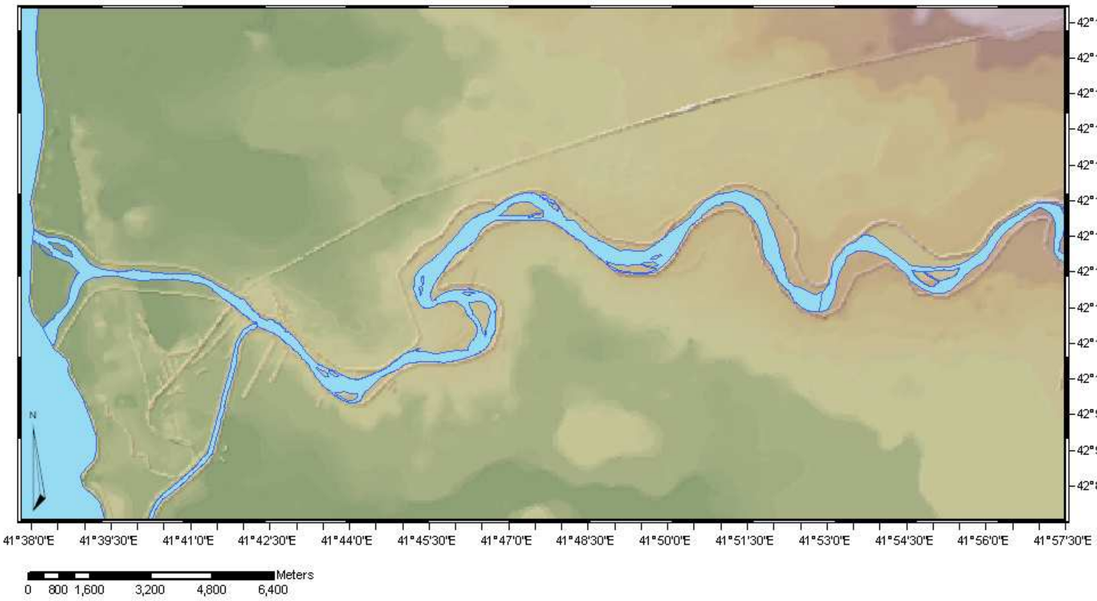


Figure 5.8 Developed DTM for flood moeling (includs roads,tunels, dikes)

The figure 5.8 illustrates the DTM for study area, it can be observed, that DTM is crossed by railways and roads, the embankment levees are visible along the river.

5.3. Magnitude frequence relationship

For flood frequency analysis (FFA): recurrence interval - magnitude relationship has been calculated using "RankPlot" application (for 48 years' data). Below is represented frequency distribution of annual peak discharge using Gumbel probability method for time series from 1939 till 1990 (Rioni River; hydrological station Mukhuri). Figure 5.9

Recurrence intervals were estimated on the basis of Gumbel probability statistical analysis of recorded floods for 10, 25, 50, 100 and 200 y return periods See table: 5-4

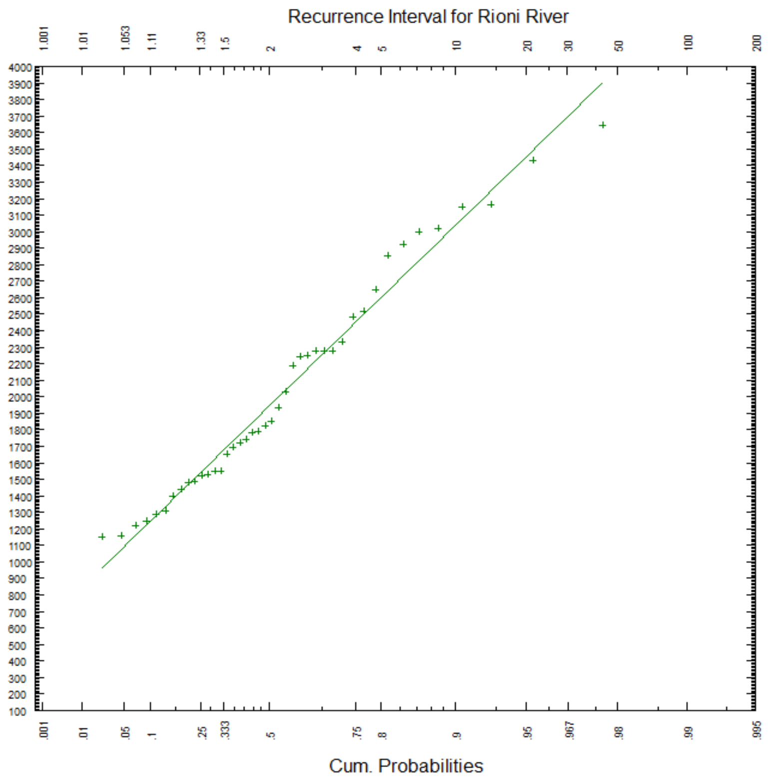


Figure *5.9* Recurrence intervals for Rioni River (hydrological station Mukhuri 1939-1990)

In the process of elaborating hydrological data, it was mentioned that the annual peak discharge increased starting from 1980 (period 1939-1990). Figure 2.7 represents the annual discharge for 1939-1976 and 1980-1990 time series.

In view of verifying the influence of this construction and exploitation of hydro power plant on discharge level, the whole period of 1939-1980 and 1980-1990 was subject to statistical analysis in order to compare the results. See figure 5.10, table 5-5

Table 5-4: Expected discharge for 25, 50, 100 and 200 y return periods

Return Period	Discharge m³/s (1939-1990)
10	2951
25	3500
50	3907
100	4311
200	4714

Table 5-5: Recurrence interval for different time intervals

Return Period	Discharge m³/s (1939-1990)	Discharge m³/s (1939-1976)	Discharge m³/s (1980-1990)
10	2951	1682	2560
25	3500	2502	3958
50	3907	3221	5184
100	4311	3525	5702
200	4714	3703	6004

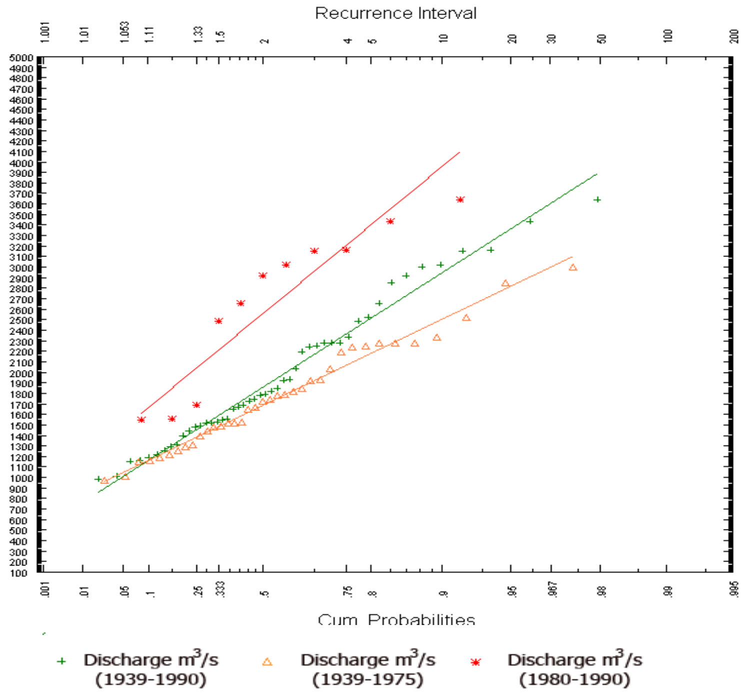


Figure 5.10 Recurrence intervals for different time periods

5.4. Hydrographs for different recurence period.

Hydrographs as key input for the hydraulic model should be close to reality. Based on the methods described in the methods section, the expected maximum discharge values and hydrographs were generated for different return periods. River discharge is a natural non predicted process and it is out of possibility to determine the future hydrograph shape with high precision. As an input data was used observed hydrograph recorded water amount for 1987 flood, daily measurements. The tables of expected discharge as well as hydrographs for different recurrence time intervals are presented below (Figure 5.11, Table 5-6).

Table 5-6: Observed flood daily discharge (1987) and expected discharge for 10, 25, 50, 100 and 200 y recurrence intervals

Recurrence interval / Days	10	25	1987 Observed Discharge m³/s	50	100	200
1	191	226	236	253	279	305
2	223	265	276	296	326	357
3	632	750	780	837	923	1010
4	1718	2038	2120	2275	2510	2745
5	**2951**	**3500**	**3640**	**3907**	**4311**	**4714**
6	1394	1653	1720	1846	2037	2227
7	1256	1490	1550	1663	1835	2007
8	859	1019	1060	1137	1255	1372
9	1029	1221	1270	1363	1504	1644
10	891	1057	1100	1180	1302	1424
11	535	634	660	708	781	854
12	429	509	530	568	627	686

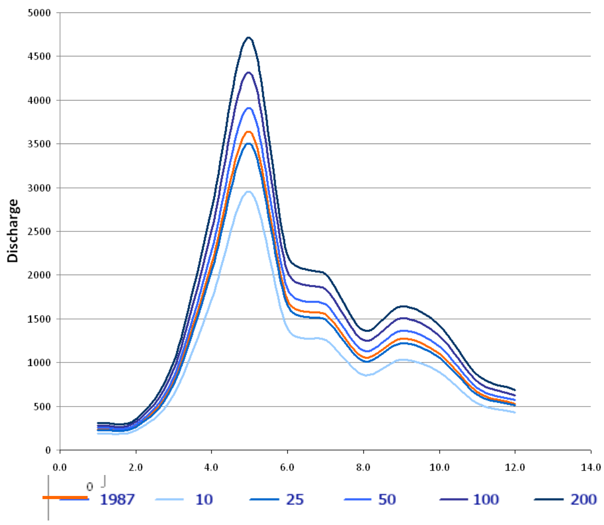


Figure 5.11 Hydrographs for 1987 flood and 25, 50, 100, 200 y recurrence intervals

5.5. Roughness coefficient

Figure 5.12 and figure 5.13 represent the land use maps and corresponding roughness coefficient map for the study area. As it can be seen, the area represents different classes of land use, mainly it is covered by swampy territory, forests and cultivated area.

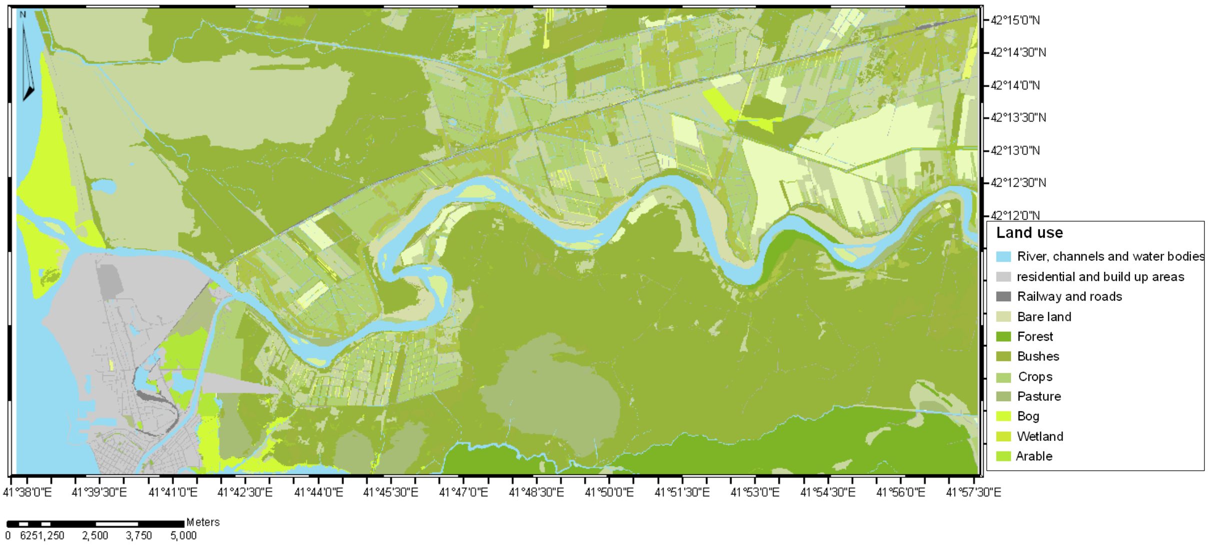


Figure 5.12 Land use map

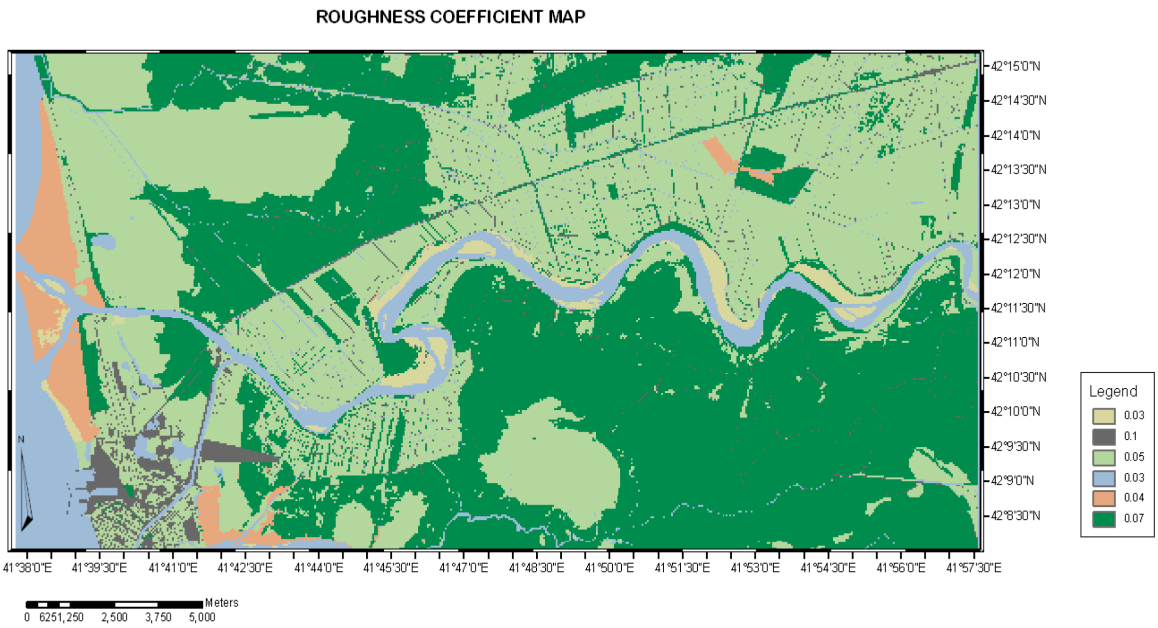


Figure 5.13 Roughness coefficient map

5.6. SOBEK modeling

Three forms of output were represented by SOBEK for calibration, flood hazard assessment and mitigation measure:

Dynamic output: - animation file of flood characteristics of propagation, depth and velocity at different time step of modelling;

Temporal output – Time series tables (water depth, velocity and discharge at measured points)

Spatio - temporal output. – Map series of water depth, water velocity and water level at different time intervals.

The flood characteristics obtained from the model results represented water depth, water velocity and impulse. All maps for different chosen return periods were obtained. They were generated in the form of parameter maps. These maps underwent further analysis with the view of generating hazard maps.

5.6.1. Calibration Validation

As it was mentioned above, in section 4.3 decrease of the roughness coefficient from 0.03 to 0.02 for 1D flow model gives the results better fitted to the water depth measurements made using PGIS approach. The differences between measurements and simulation results for tested different Manning values as well as RMSE have been calculated. Totally 92 measurements have been done during the field work but any 88 points are used for calculations and quantification of RMSE. Four points are not included in calculation during RMSE calculation, because of these measurements have been done in local deepening area, which are not represented in the DTM due to the resolution.

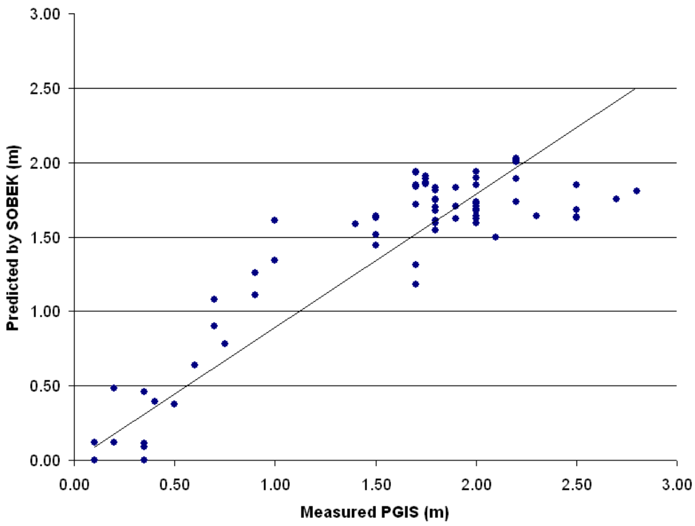


Figure 5.14 Relationship between SOBEK predicted and field work measurement water depth

The accuracy of the SOBEK simulation can be defined as RMSE value - 0.32 for 0.02 Manning roughness coefficient for channels and river bed.

Conclusively, for simulation has been decided to use the roughness coefficient 0.02 for 1D flow simulation in channels and river beds and have been defined as calibration parameter

Figure 5.14 represents relationship between predicted and measured water depth (for 1987 flood simulation). Dispersion in the samples wariest from -0.2 to 1.0 m and is related to the uncertainty of the model.

The comparative maps of flood propagation obtained from field work and generated by SOBEK simulation for the study area, show the good overlapping of generated results figure 5.15

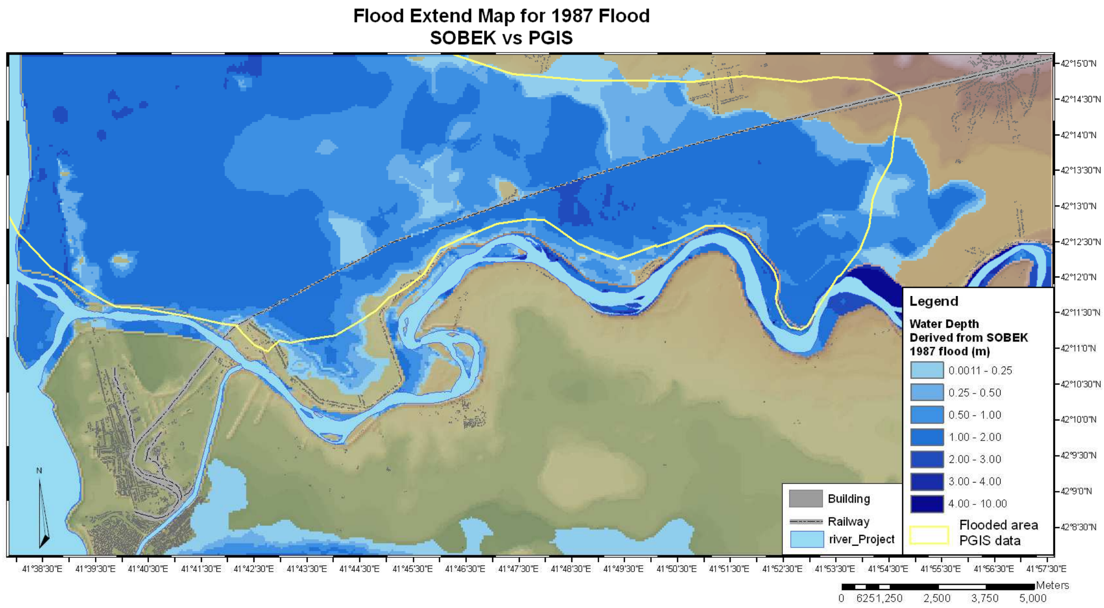


Figure 5.15 Flood extend map SOBEK versus filed work

The difference between simulated maps and map derived from local community can be explained by uncertainty in the flood modelling as well as by negligence of local community during mapping the flooded area.

The maximum water depth has been map based on community knowledge (PGIS approach) and compared with SOBEK simulation results. The resultant map is represented by figure 5.16.

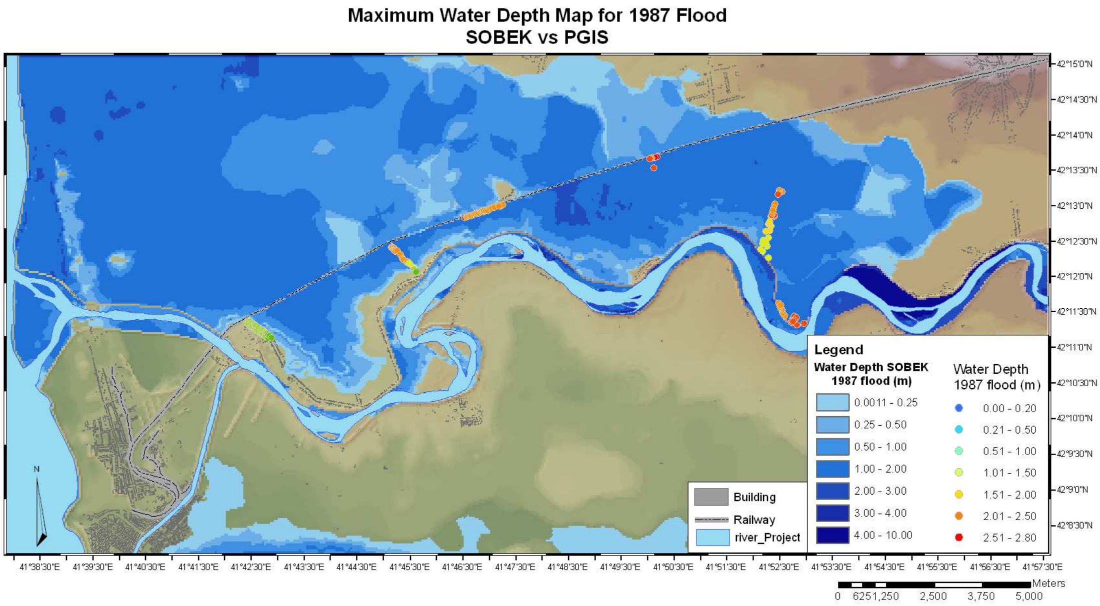


Figure 5.16 Maximum depth calculated by SOBEK and field work observations

Summarizes the outcome of the analysis the Manning's values with a vertical and horizontal friction of 0.02/0.02 have been identified as the most accurate results when compared to other models results followed by Manning coefficient from 0.01, 0.02, 0.2. The RMSE of the observed and simulated values of water depth ranges for different friction values from 1.26, 0.47, and 0.32 respectively. SOBEK1D2D model for flood hazard had predicted satisfactory result taking in to consideration the data availability and quality

5.6.2. Flood hazard assessment

The outputs from the flood modeling were represented as a set of flood characteristics maps in the form of the water depth, water velocity and first wetting time. All the maps were generated for different return periods (10, 25, 50 and 100 y). They were reworked in the form of parameter maps and further were analyzed in order to understand the flood hazard, define the spatial distribution of the depth, velocity, determine time of wetting and product hazard maps for the region.

The parameter maps: maximum depth, maximum velocity and time of wetting generated for 10, 25, 50 and 100 return y periods and are shown below, in figure 5.17, 5.18, 5.19 and 5.20.

All flood simulation designed for hazard assessment show fdow thriugh the breach in the embankment. in upstream section of the investigated region and lead to inundation of the river floodplain. Water propagation parameters vary for different recurrence interval the flooded area has been calculated and the results for different scenarios are represented in table 6.1.

The lower North West edge shows the inundation of the floodplain. This affects due to the boundary condition, which have been described in flood modeling section (section 4.1) and should be ignored during hazard assessment.

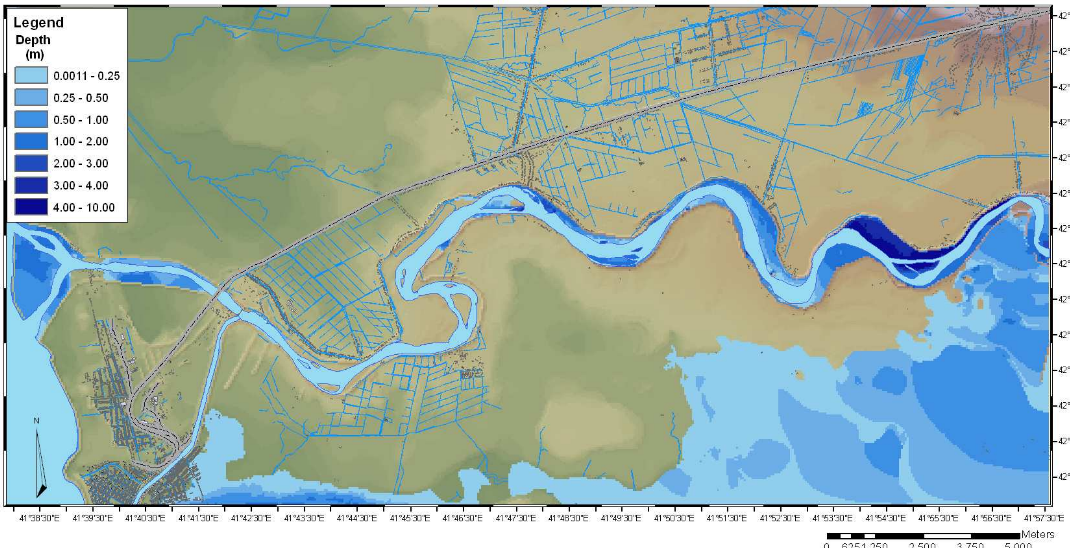
For 10, 25, 50 and 100 y recurrence interval the water flow thought south dike and flow over the south floodplain, with increasing of discharge the inundated area increase. For 100 recurrence interval overtopping occurs on the South side of river and overtops the edge of the dike in central part of the investigated region. Maximum depth is predicted near the dikes. Floodplain water depth varies e.g. for 10 recurrence interval 0.8 m water depth is the maximum and is recorded near dike break, whereas for 25, 50 and 100 y recurrence interval water depth increase in same location up to 4 meters.

The velocity parameter map for 10, 25, 50 and 100 y recurrence intervals show the low value of velocity (0.7 - 0.8 m/s); this fact could be explained by near flat geomorphology of the region. The observed sudden changes in velocity is corresponded to the area between two contour lines, giving the a sudden step in the morphology

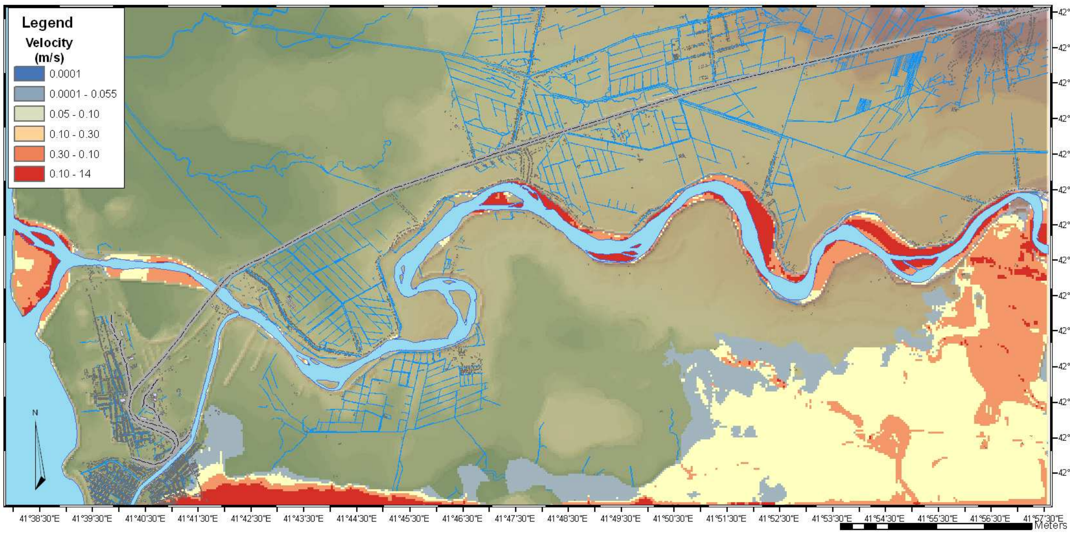
The water propagation time varies from minutes up to 4 - 4.5 hour for 100 return period, so all area which is affected by flood (54 km^2) will be inundated during 4-5 hours.

The figure 5.21 shows the flood hazard map of the region for 10, 25, 50 and 100 y return periods with corresponding probability of occurrence. Generated maps for all recurrence intervals were integrated in order to obtain the final flood hazard map and identify the zones for maximum hazard and zones with minimum hazard.

Flood Depth Map for Current Situation
0.1 probability



Maximum Velocity Map for Current Situation
0.1 probability



First Wetting Time Map for Current Situation
0.1 probability

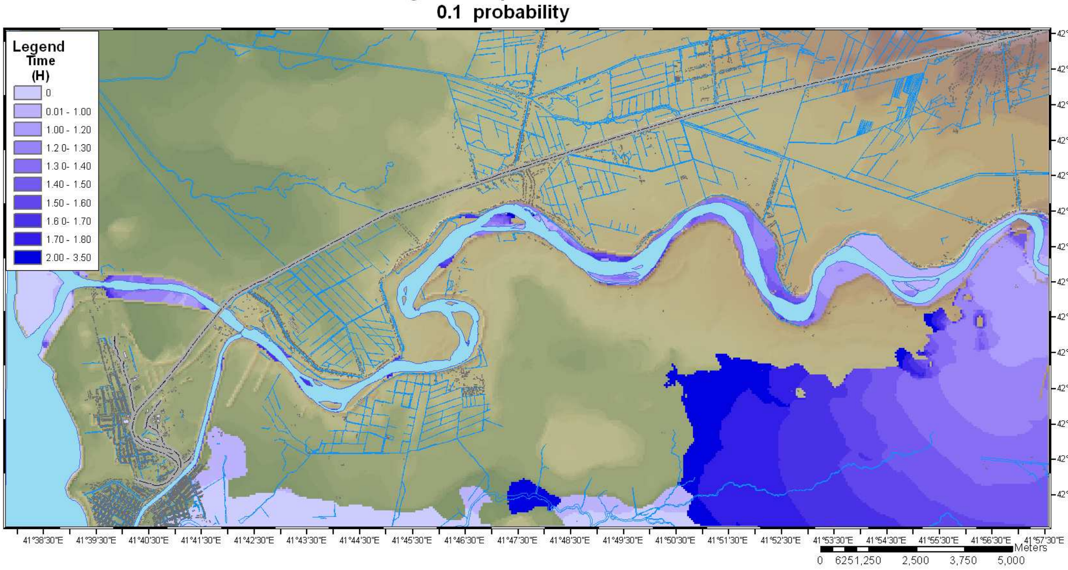
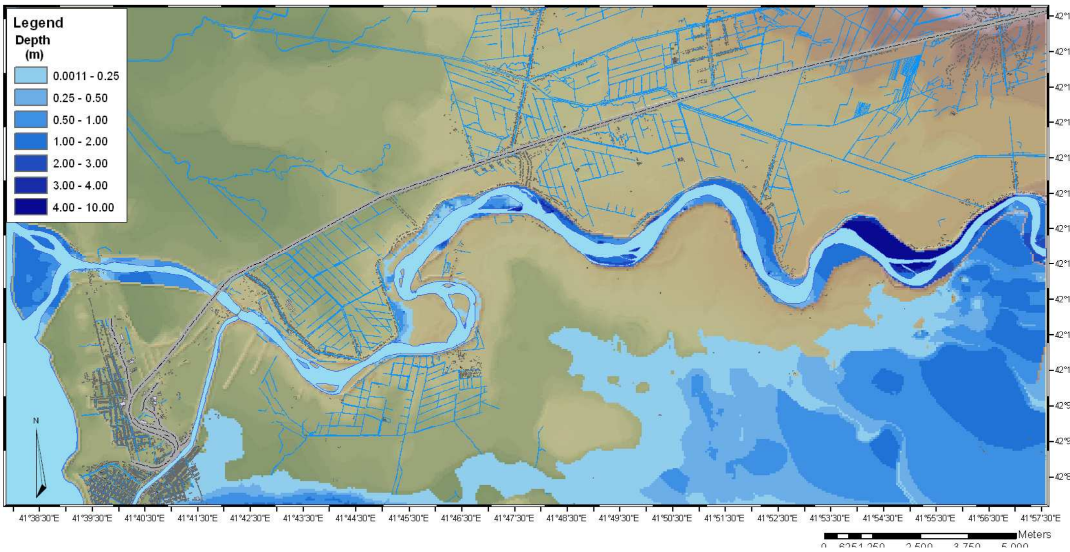
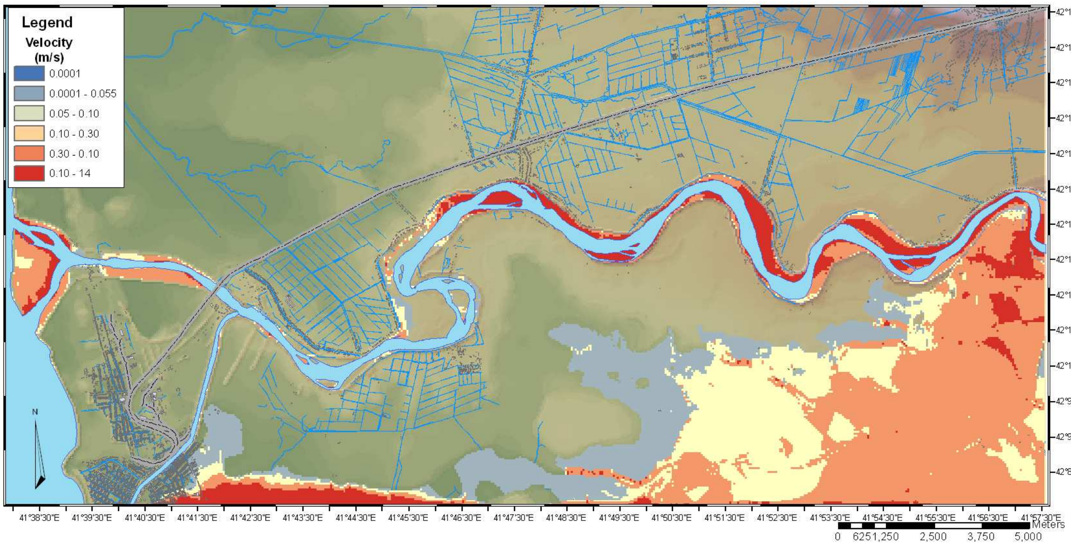


Figure 5.17 Flood parameter maps for 10 year return period event(current situation)

Flood Depth Map for Current Situation
0.04 probability



Maximum Velocity Map for Current Situation
0.04 probability



First Wetting Time Map for Current Situation
0.04 probability

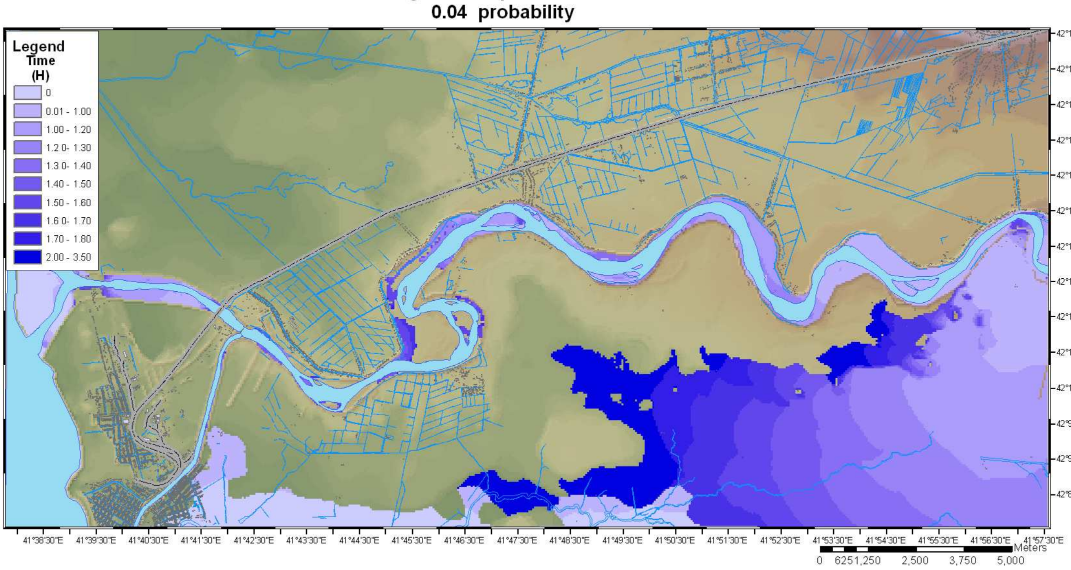
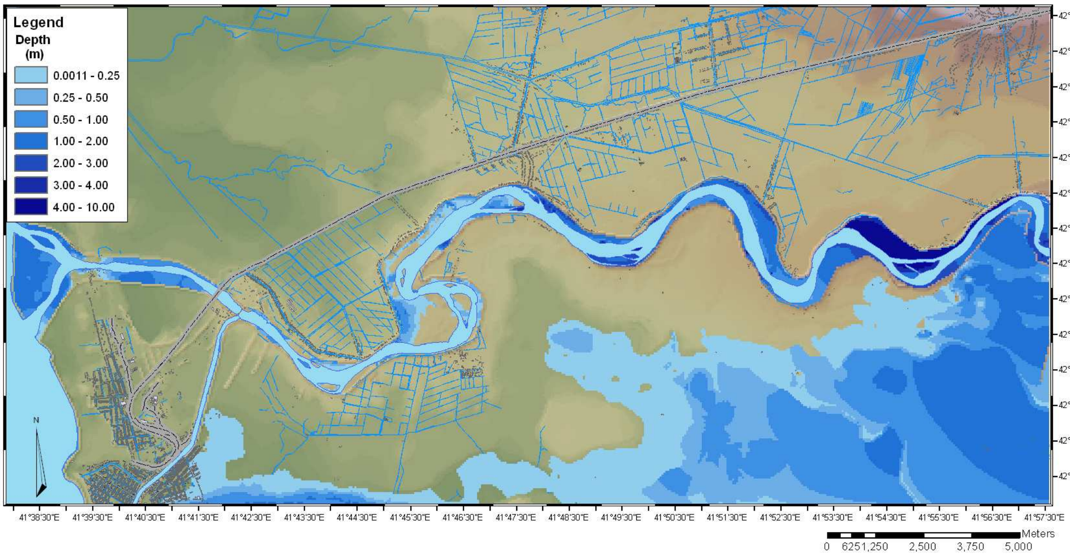
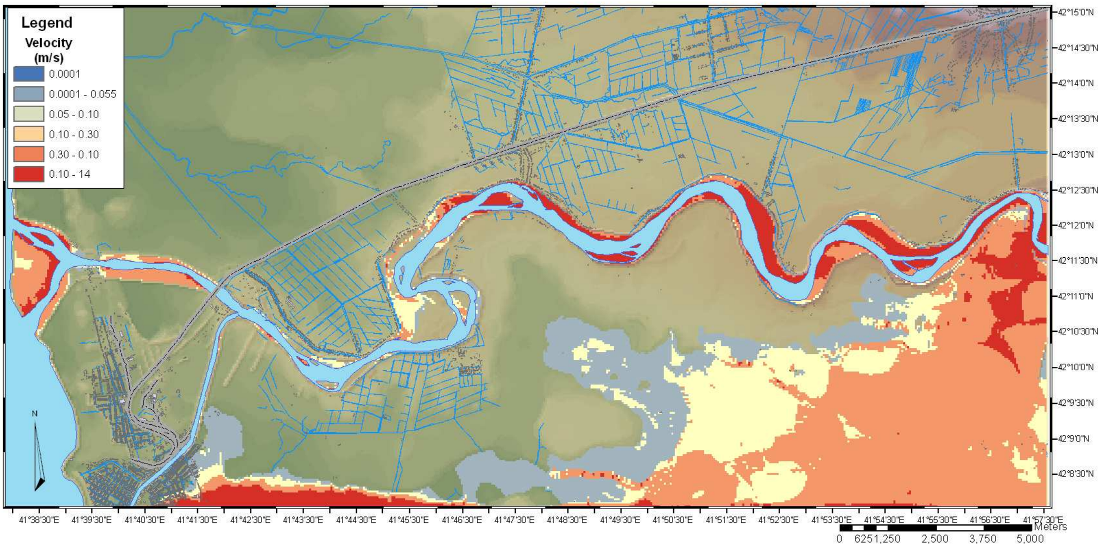


Figure 5.18 Flood parameter maps for 25 year return period event (current situation)

Flood Depth Map for Current Situation
0.02 probability



Maximum Velocity Map for Current Situation
0.02 probability



First Wetting Time Map for Current Situation
0.02 probability

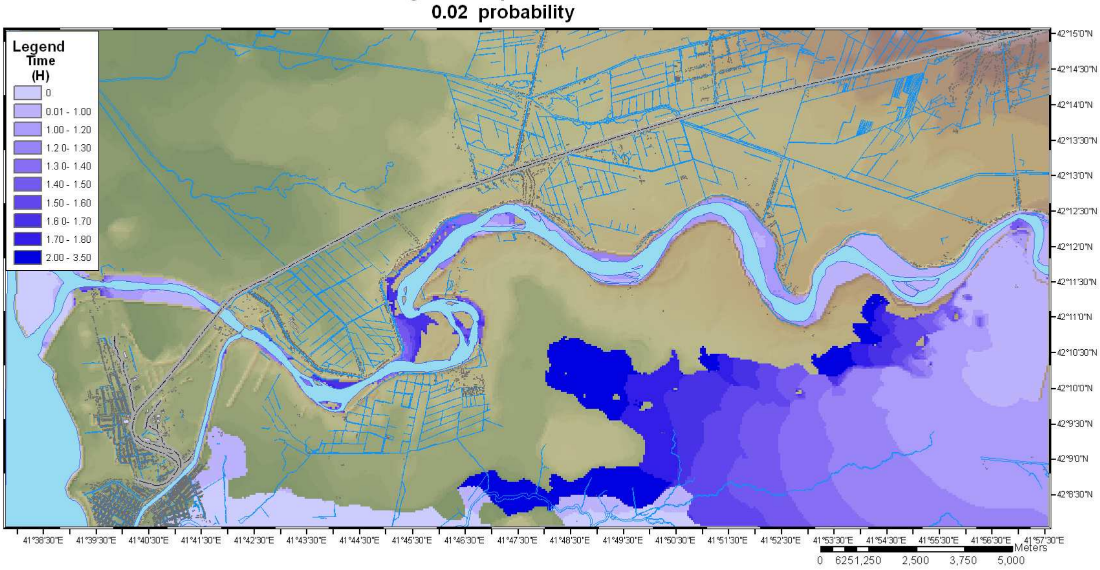
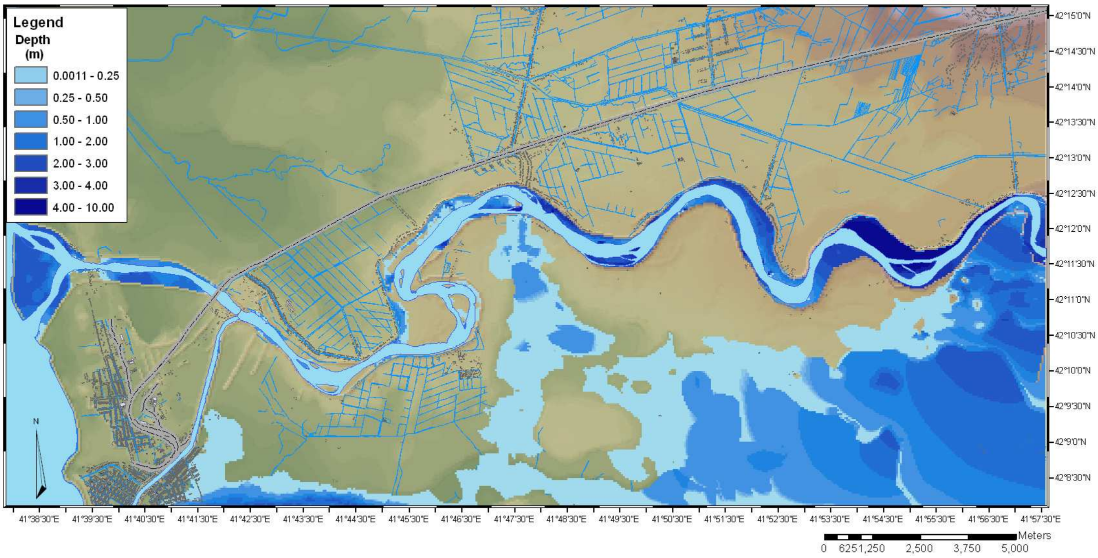
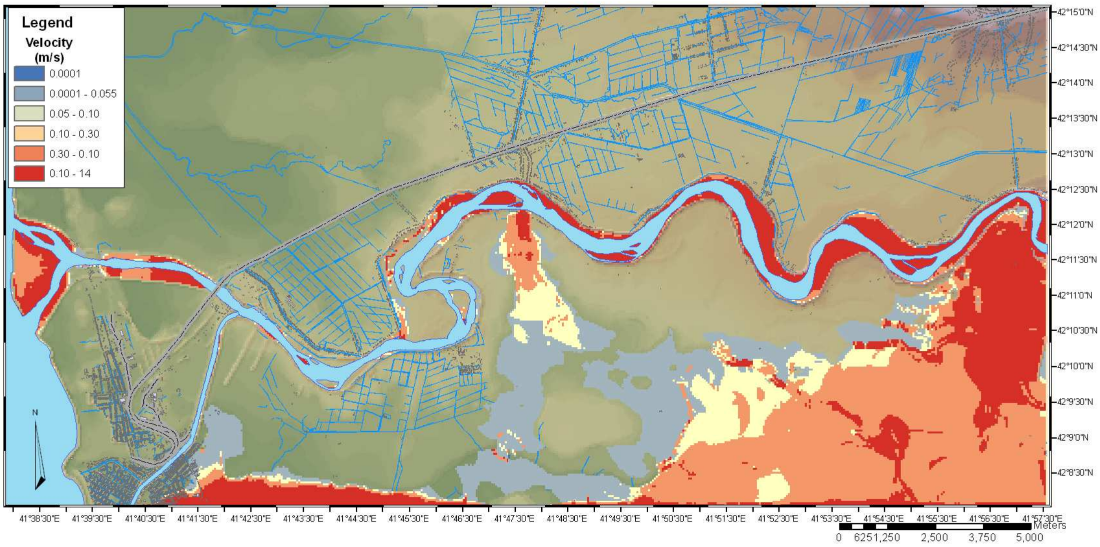


Figure 5.19 Flood parameter maps for 50 year return period event (current situation)

Flood Depth Map for Current Situation
0.01 probability



Maximum Velocity Map for Current Situation
0.01 probability



First Wetting Time Map for Current Situation
0.01 probability

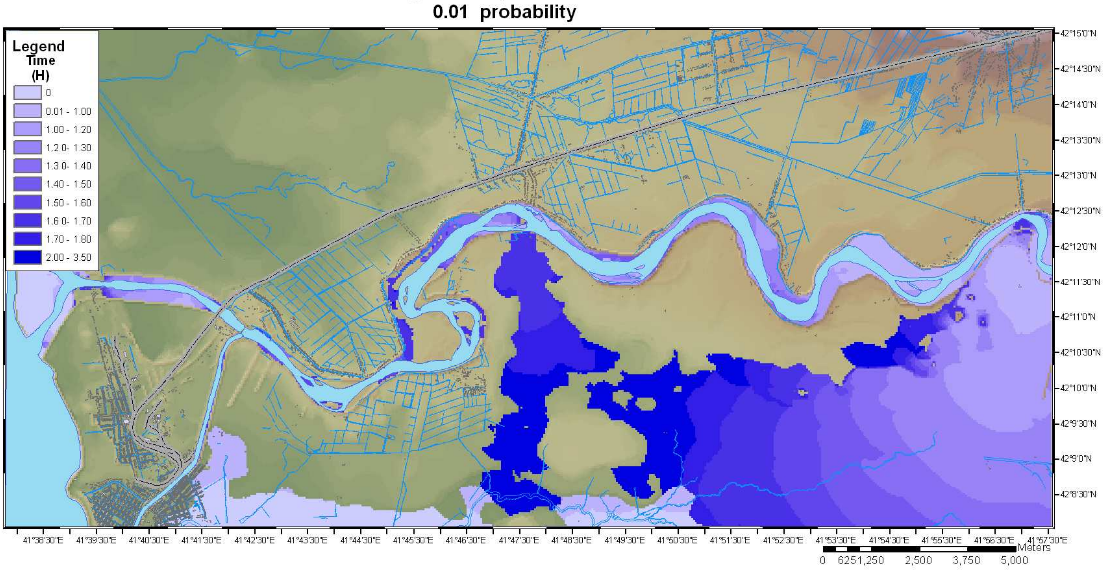


Figure 5.20 Flood parameter maps for 100 year return period (current situation)

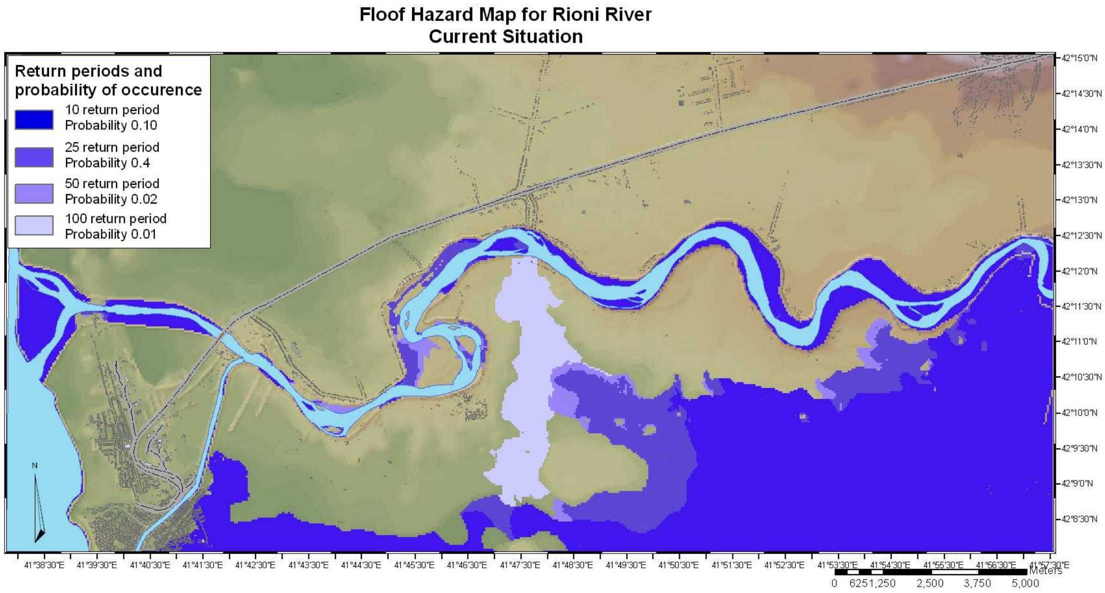


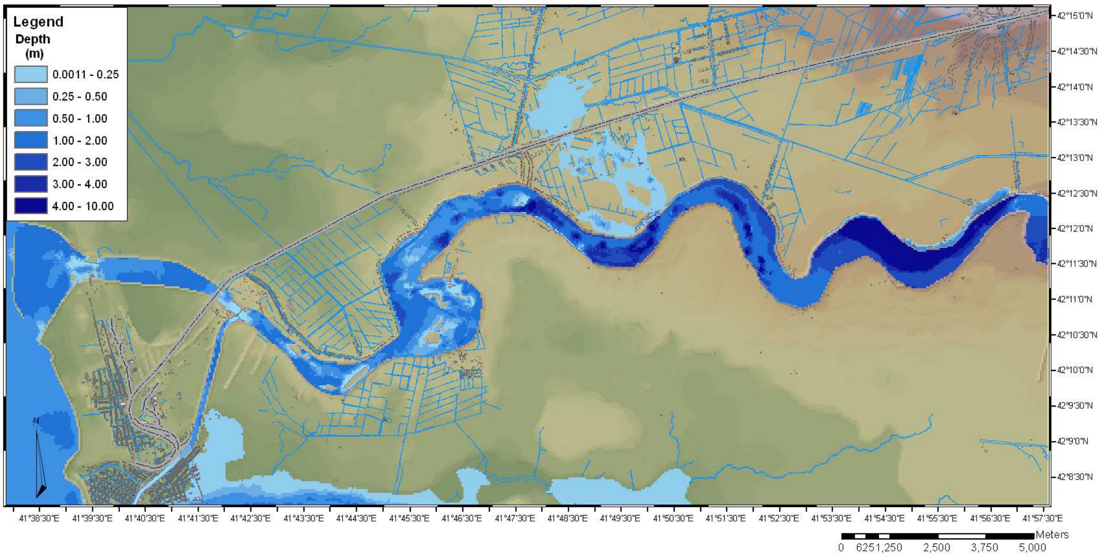
Figure 5.21 Flood hazard map for current situation

It is significant, and must be mentioned, that for current situation north side does not show any flood hazard in the region even for 100 y recurrence interval. And mainly flood occurs over the south floodplain with less economical activity and habitants.

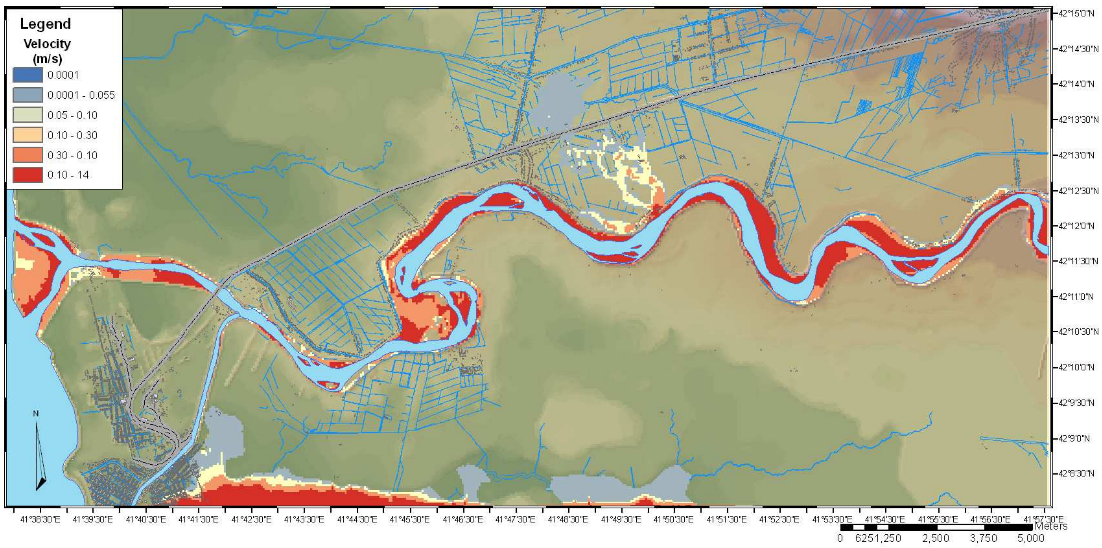
5.6.3. Mitigation Measure

For mitigation measures reconstructed dikes scenarios were performed. The models are described in details in section 4.4 and here the resulted parameter maps are represented for mitigation scenario:
Mitigation measure was defined as: dikes are reconstructed to the original height and location (the SOBEK model was designed for 25, 50, 100 y return periods).
The parameter maps: maximum depth, maximum velocity and time of wetting were generated for 10, 25, 50 and 100 y return periods. The model results for 50 and 100 recurrence intervals are shown below, in figure 5.22, and figure 5.23. The parameter maps for the 10 and 25 return periods were not shown as it can be observed from hazard map for mitigation measure (figure 5.24) the water does not overtop the embankment
The simulation designed for 50 and 100 return periods show the exceed of the embankment: for 50 return periods the overtopping occurs in the central part of the investigated region and water flows to the north direction, when in case of 100 return period scenario inundation of both north and south river floodplain occur and water overtop dikes in a different places.
The water depths observed in 50 return period scenario is varies from 0.11 m up to 1.2 m and the inundated area is to 7 km^2 while hazard map shows 66 km^2 flooded area . For 100 return period the water depth varies from few centimetres up to 1.5 meters for the both side of the river. The maximum water flow velocity for 50 recurrence intervals is 1.5 m/s in the location of overtopping dikes the far away from overtopping point the flow velocity decreases to 0.002m/s. For 100y recurrence interval observed water flow velocity is low in a floodprone area (0.01m/s) and increase up to 3 m/s near overtopped dike.
The water propagation time, like in hazard assessment varies from minutes up to 4.5 hour for 100 return periods, so all area which is affected by flood (120 km^2) will be inundated during 5 hours.
Mitigation measure scenario 2 shows the lower hazard for investigated segment of Rioni River, only 100 recurrence interval shows the overtopping of dikes, the parameter maps are represented in figure 5.23 and show lowest area of water propagation (3 km^2). The maximum dept in floodprone area is identified no more then 0.3 m with corresponding low flow area and velocity. The figure 5.24 and figure 5.25 show the flood hazard map for mitigation measure scenario 1 and 2 with corresponding probability of occurrence.

Flood Depth Map for Reconstructed Dikes (Initial Height)
0.02 probability



Maximum Velocity Map for Reconstructed Dikes (Initial Height)
0.02 probability



0.02 probability

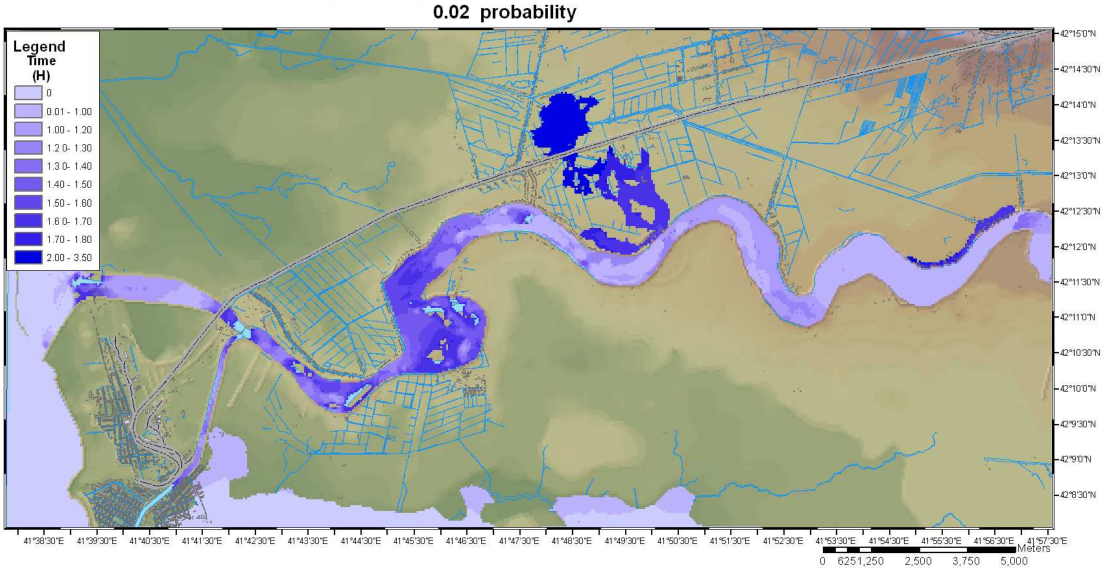


Figure 5.22 Flood parameter maps for 50 year return period (mitigation measure 1 scenario)

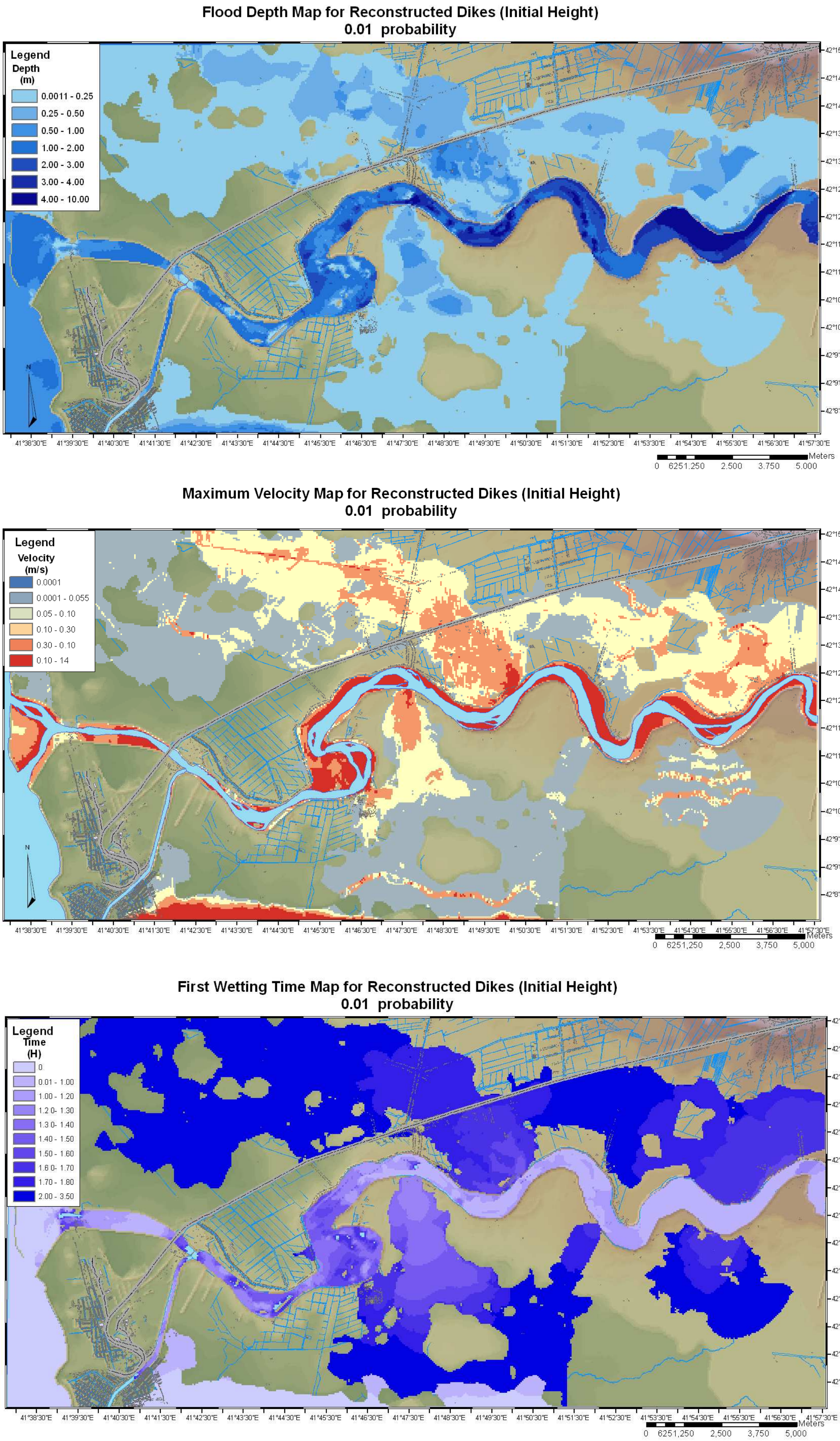


Figure 5.56 Flood parameter maps for 100 year return period (mitigation measure 1 scenario)

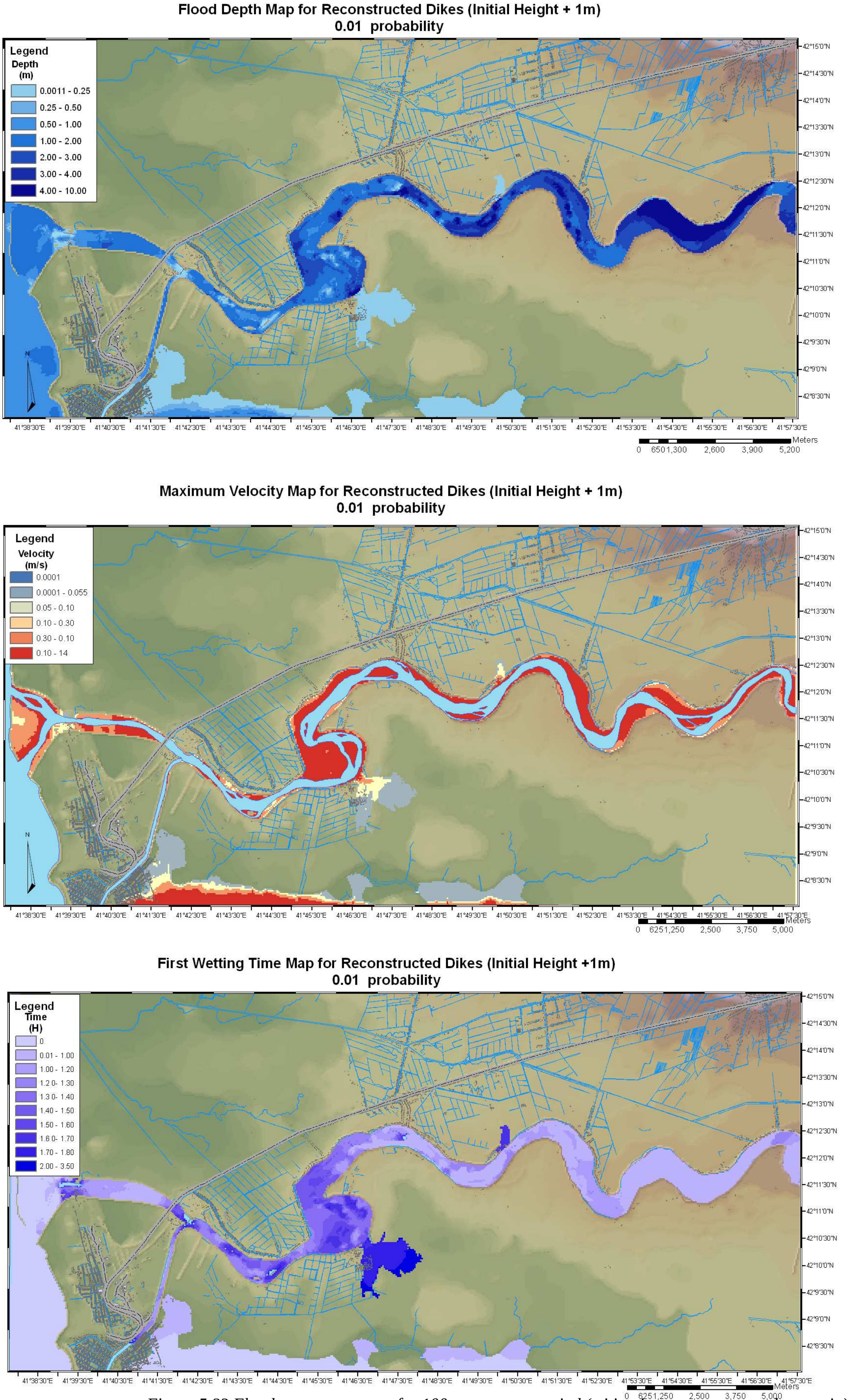


Figure 5.23 Flood parameter maps for 100 year return period (mitigation measure second scenario)

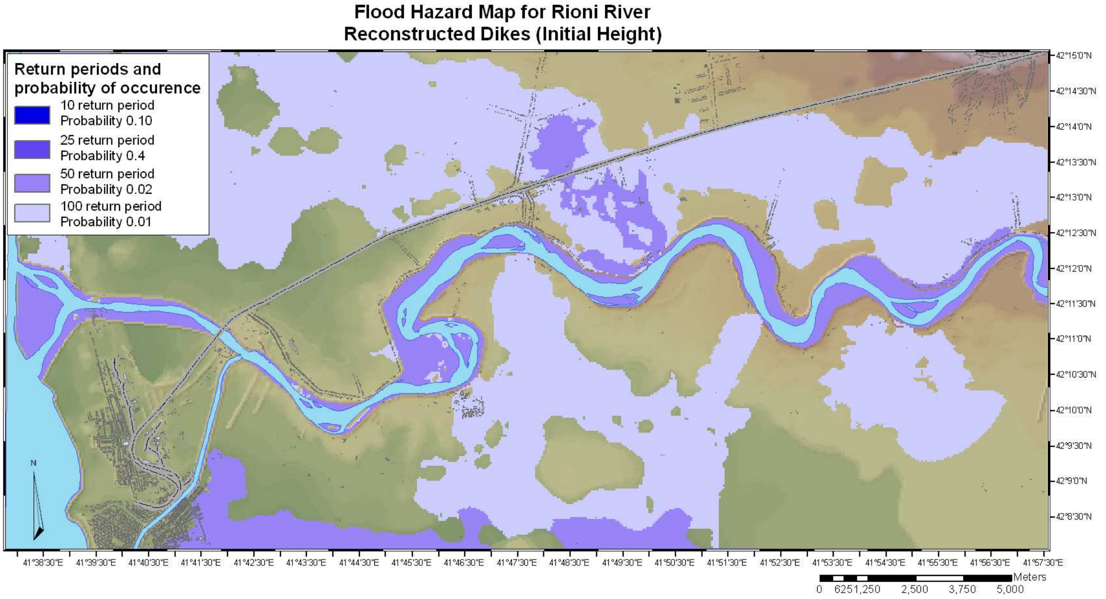


Figure 5.24 Flood hazard map for mitigation measure first scenario

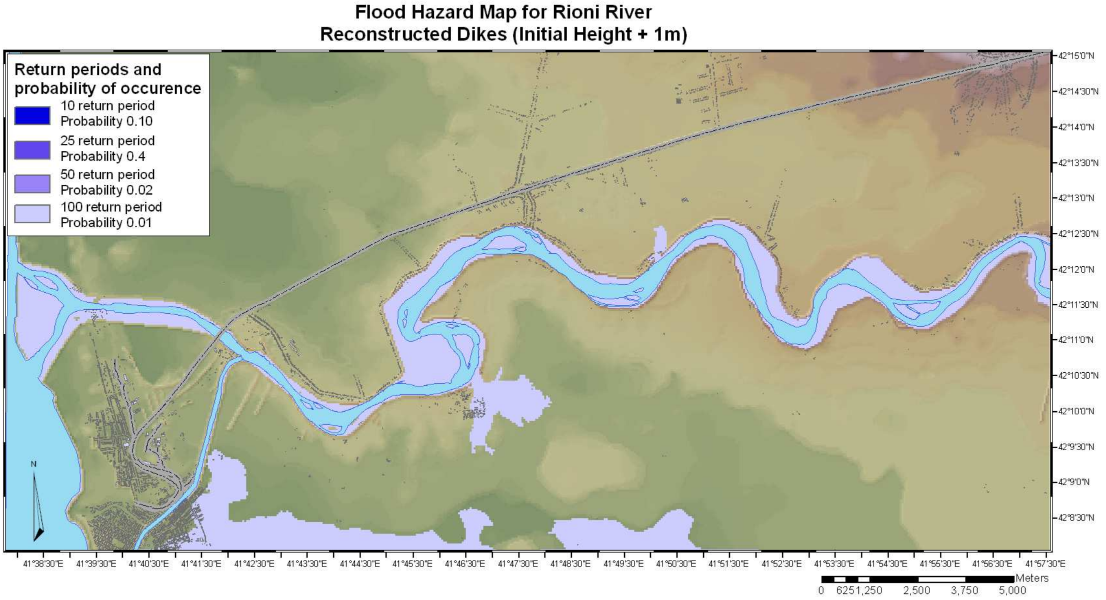


Figure 5.25 Flood hazard map for mitigation measure second scenario

6. Disscusions

6.1. Accuracy of the digital elevetion model

RMSE test for digital elevation models shows that DEM in 50 and 25 m size have error values of 0.68 for measured 85686 points and 0.63 for 21308 points respectively. The highest error is represented near the riverbed area, which can be explained by frequently changed geomorphology of the river. Additional important reason for the error is the unknown projection of 1:5000 maps (maps were classified as top secret map. Therefore, the projection has not been identified in the published version). Due to the unavailable detailed elevation information this problem forced to be ignored and make geo reference of the maps in Transverse Mercator projection.

For flood hazard assessment digital elevation model has crucial meaning, and best results could be derived from inundation models commutated based on DTM with low pixel resolution. However due to the unavailable more detailed dataset, the DTM 50 m were used. Largest part of DTM was calculated based on contourlines derived from 1:25000 topo maps and using even 25 m resolution DTM only increase the computation time and did not add any significant refinement or improvements in the flood models. So on have been decided to use 25 m DTM

Of source the quality of DTM in the regions where the DTM was calculated based on dense contourlines derived from 1:25 000 maps, in the central part of the region, where the DEM was calculated based on 1:5000 topo maps information, the variation of the flow velocity is smoother.

6.2. Magnitude frequence relationship

Analysis of presented hydrological data revealed that the hydrological regime of the River Rioni had been changed for the last decades. The significant increasing in discharge was indicated from 1980 (table 3-4). In order to understand the phenomenon of hydrology which took place in the history of the river, it should be noted that Vartsikhe hydro power station cascade was built up during 1976-1987 combining four power stations erected in a line along Rioni River, upstream from investigated region. This cascade occupies 27 km segment of Rioni River. Presumably discharge rate variation ann increasing linked to the incorrect exploitation of hydropower dams from the point of view of flood hazard. This fact doesn’t mean that exactly Vartsikhe hydro power station cascade influence on the discharge of the river. Moreover, the reservoir type dams are widely used for regulation of river discharge and reduction of flood risk. This issue is important for establishing hydrology of Rioni River and needs additional study that is beyond our scope of the work.

In additional, it should be noted that Janelidze (2009) in his article "Increasing occurrences of heavy floods of the Rioni River in the Kolcheti lowland" made mention of the fact according to which the highest discharge in Rioni River was measured in 1922 - 5484 m^3/s, also he notices that during 1982 flood the discharge was 4650 m^3/s; in 1987 - 4800 m^3/s above mentioned records (discharge values for 1982 and 1987 flood events) were not supported by daily discharge data obtained from NEA dataset. According to NEA the discharge for 1982 and 1987 flood events were 3430 m^3/s and 3640 m^3/s respectively. So on due to the lack of appropriate literature and/or data, above mentioned information failed to be rechecked and consequently, was not referred to during statistical analysis. The Gumbel statistical analysis was based only on the data provided by NEA and "Tskalkanalproject".

The significant changes in discharge rate for Rioni River (station Mukchuri) have been estimated during research and attention to this fact must be paid. From one hand we have two dataset:

1. 1939 – 1976 annual peak discharge information is not affected by number of hydropower dams build up after 1976 upstream of investigated region.
2. 1980 - 1990 annual peak discharge, the data which represents the reality.

Frome another hand: samples amount is an essential index for statistical analysis, and in order to calculate expected discharge for 100 recurrence interval, the calculation must be based on data more then 30 years of records and as a general rule frequency analysis should not be applied for data 10 years or less (Donker, 1990). Under the pressure of above mentioned circumstances possibility was simple: use all data (43 years) starting from 1937 up to 1980; measurements for 1939 - 1976 time interval (38 years) or use 1980 - 1990 time interval (11 years). Gumbel plot analyses clarify, that differences between expected discharge is sizeable in case of divided dataset: e.g. for 50 return period the difference in discharge value is 1960 m^3/s between 1980-1990 and 1939-1976 time period and 280 m^3/s for 1939-1976 and 1937-1990. In order to avoid overestimation or underestimation of the expected discharge values have been decided to use all available dataset.

6.3. Hazard assessment: generation of hazard maps using SOBEK1D2D output

As it was described above in result section, the flood characteristics derived from SOBEK models represent water depth, water velocity and first wetting time. All maps were obtained for 10, 25, 50 and 100 y return periods.

The maps show the inundation of the left floodplain for 10, 25, 50 and 100 y return period. The velocity is low for main area and is not dangerous for population and property for all scenarios. Higher hazard was observed for 100 return periods larger area was affected by flood processes. The maximum water depth maps demonstrate the dangerous water depth.

6.4. Mitigation measure scenario based hazard map

The hazard map for mitigation measure two scenarios for different return periods was developed (section 4.5). The analysis of the output make clear that for scenario reconstructed dikes up to the original height and location (10, 25, 50, 100 y return periods) we have the following situation: The parameter maps for 10 and 25 return period for reconstructed levees does not show the overtopping of the dikes, when in case of destroyed dike the left floodplain of the river is flooded. The hazard maps for 25 recurrence interval sows the low area of water propagation and 50 and 100 recurrence intervals show wider propagation of the water through the investigated region. Lower hazard is corresponded to mitigation measure strategy 2 (heightening of the original dikes for 1m).

Table 6-1: Flood extent for different return periods and different scenarios

Return period	Probability	Current situation		Reconstructed dikes		Reconstructed dikes	
		Flood	Maximum Extent of water outside the channel (m^2)	Flood	Maximum Extent of water outside the channel (m^2)	Flood	Maximum Extent of water outside the channel (m^2)
10	0.1	Yes	42	No	-	No	-
25	0.04	Yes	64	No	-	No	-
50	0.02	Yes	**68**	Yes	7	No	-
100	0.01	Yes	**72**	Yes	**120**	Yes	3

.

7. CONCLUSIONS AND RECOMMENDATION

Rioni River lowland is located in an area highly prone to flood hazard. In this research 1D and 2D flood modelling was used to assess the flood hazard in the region for the first time. This was performed with the view of understanding flood hazard and test mitigation measure for the Rioni River delta and supporting decision makers and local community with useful tool for spatial planning.

During research the flood hazard for Rioni River was estimated using magnitude frequency analysis and defined the probability of occurrences of different magnitude flood in the region. The hazard probability for 10 recurrence interval (2951m^3/s) is 0.01; for 25 recurrence interval (3500 m^3/s) – 0.25, for 50 recurrence interval (3907 m^3/s) – 0.5, for 100 recurrence interval (4311m^3/s) – 0.01 and for 200 year recurrence interval (4714 m^3/s) – 0.02.

The boundary conditions for the Rioni River investigated segment were defined: the maximum expected water discharge was estimated for 200 y recurrence interval and was defined as 4714 km^3/s.

The water depth, velocity, impulse and hazard maps were generated for 25, 50 100 and 200 y recurrence intervals. The area of inundation and water parameters were defined.

The effect of mitigation measures was determined for one scenario and results were presented in terms of different parameter maps: water depth, first wetting time and animation. Mitigation scenario for 10 recurrence interval was concluded as the appropriate mitigation measure strategy since water doesn't exceed dike's depth. It is relatively cheap (only one segment must be reconstructed) but additional investigation must be done in order to define the quality of water protective dikes. Monitoring of the dikes must be carried out systematically. Reconstruction of dikes for 50 recurrence interval can be also defined as sufficient strategy for mitigation measure. When for 50 and 100 return period the hazard is still high.

The mitigation measure scenario is appropriate choice to decrease the flood hazard for the region for 10 and 50 recurrence intervals. The negative effect of such kind of measurement can be the increasing of discharge rate downstream to Poti and increase the flood events.

Recommendations for future research:

The results of flood modelling and flood characteristics can be improved if better resolution and quality DEM is used for flood simulation. Research was based on the 50 m DEM because of unfeasibility of creation of more detailed DEM due to the available data. The usage of better resolution and quality DEM for future research must be expedient.

Important fact is that the area of research, as it was defined at the first step of study is not sufficient for so high discharge events simulation and in future study the larger area must be defined as a start point for flood modeling.

Flood hazard should be extended to detail risk assessment for the region in order to quantify the expected damage for different return periods.

The results of hazard and risk assessment should be represented to the local and regional decision makers.

Mitigation measure strategy based on scientific and multi criteria approach should be elaborated.

The effect of different scenarios as possible mitigation measure tool for high discharge (50 and 100 recurrence interval) and/or the effect of river and channel systems improvement for flood hazard management should be investigated using engineering and modelling approaches.

Besides, the effect of hydro power stations exploitation regarding to the River Rioni discharge pattern should be investigated as well.

Recommendations for the Local Administrative Authorities and local communities:

It should be improved the perception of local community regarding to flood process and its hazardous effect on population and their property.

New hazard maps should be represented to the population and they should be informed about probable results.

It should be prohibited to use dikes for cattle pasture.

Dikes should be cleaned from trees and should be protected through strengthening.

Water channels should be systematically cleaned.

Construction of small channels and rising vines with ground will decrease the water level on cultivated land and protect it from inundation.

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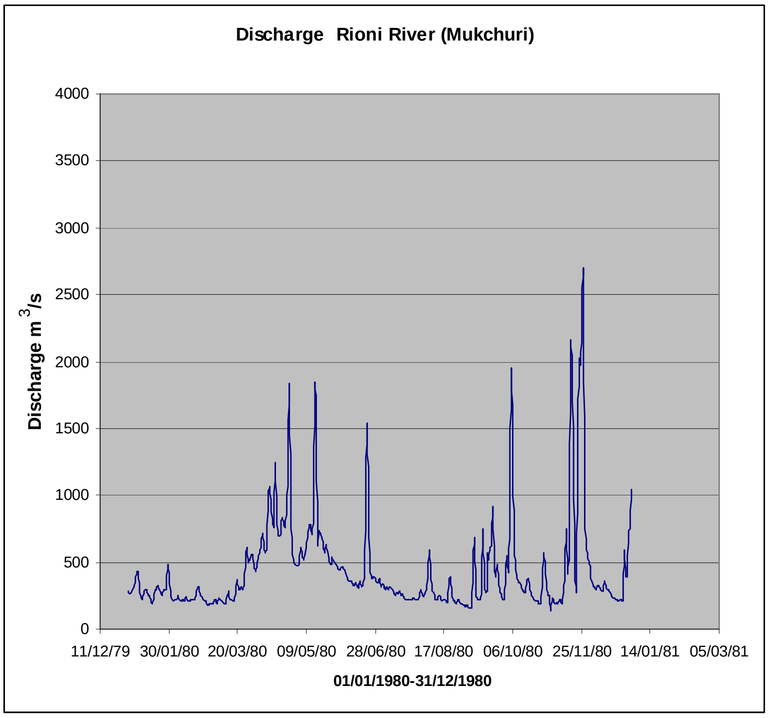
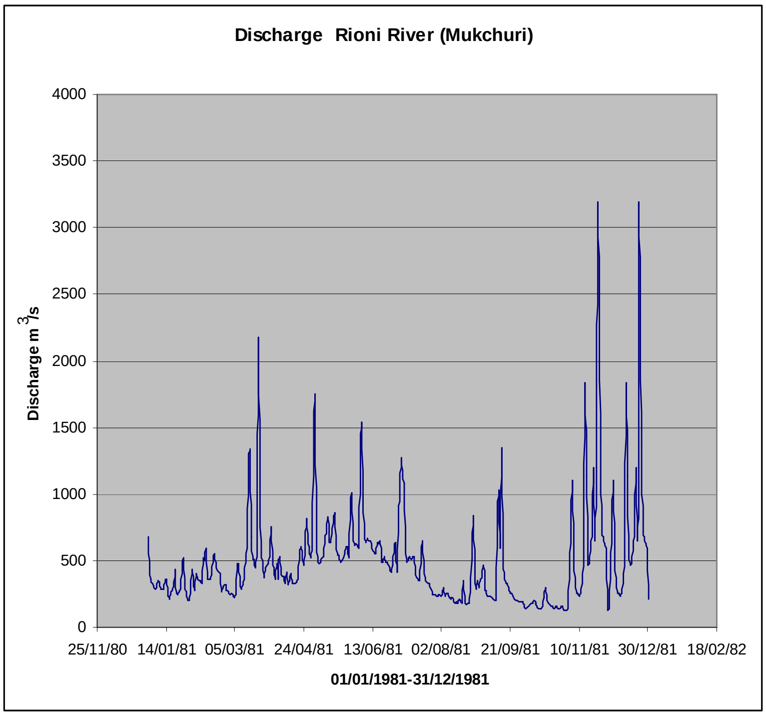
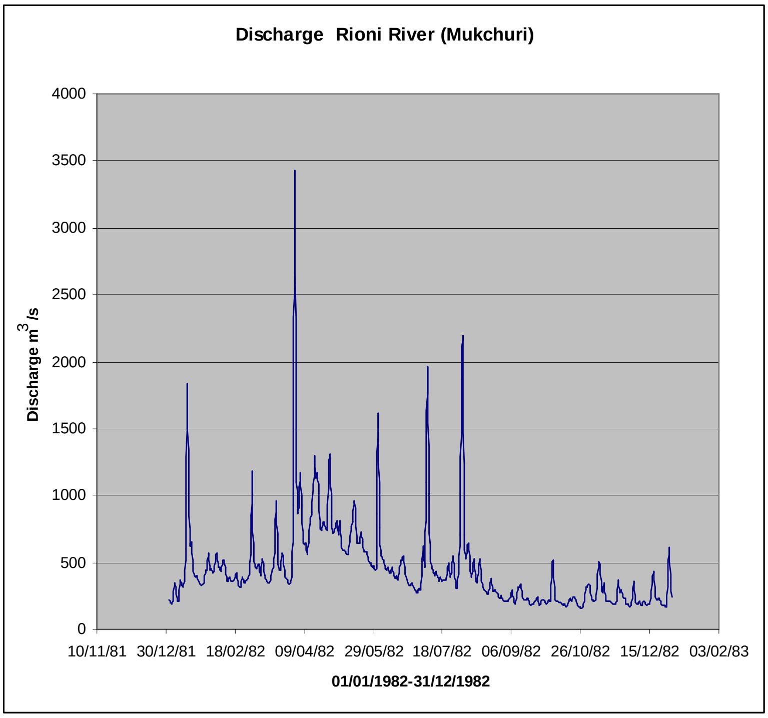
Appendices

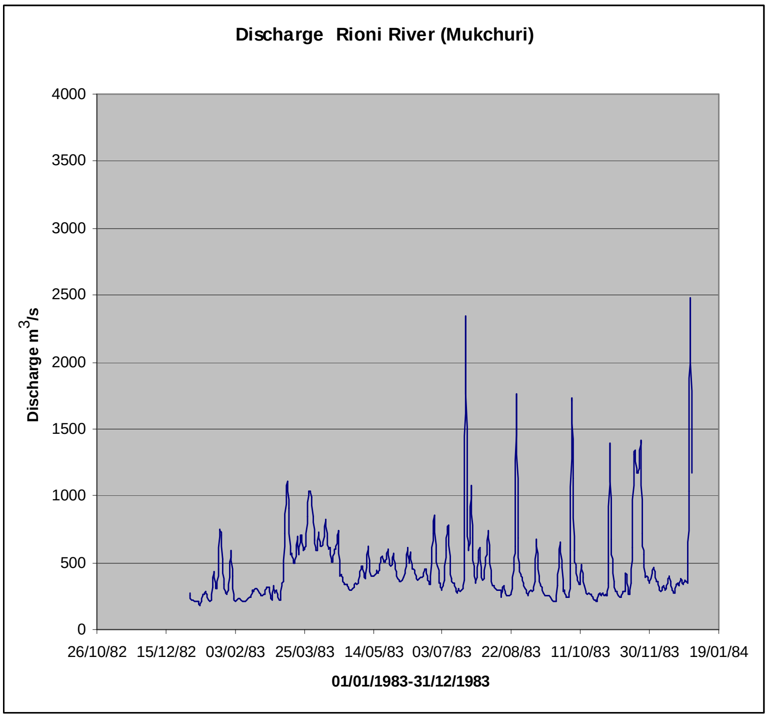
APPENDIX 1 a

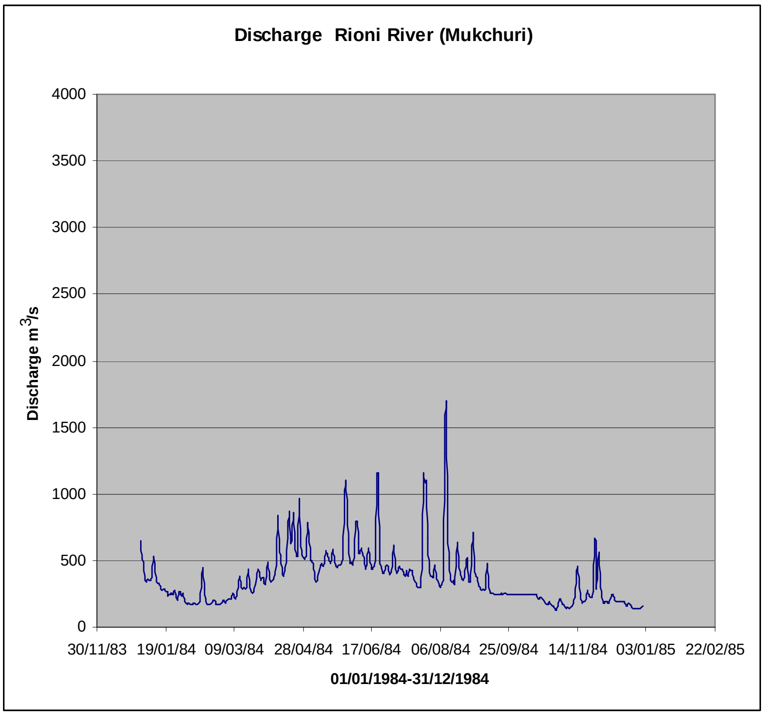
Discharge of Rioni River during 1980 – 1990 (daily measurements).

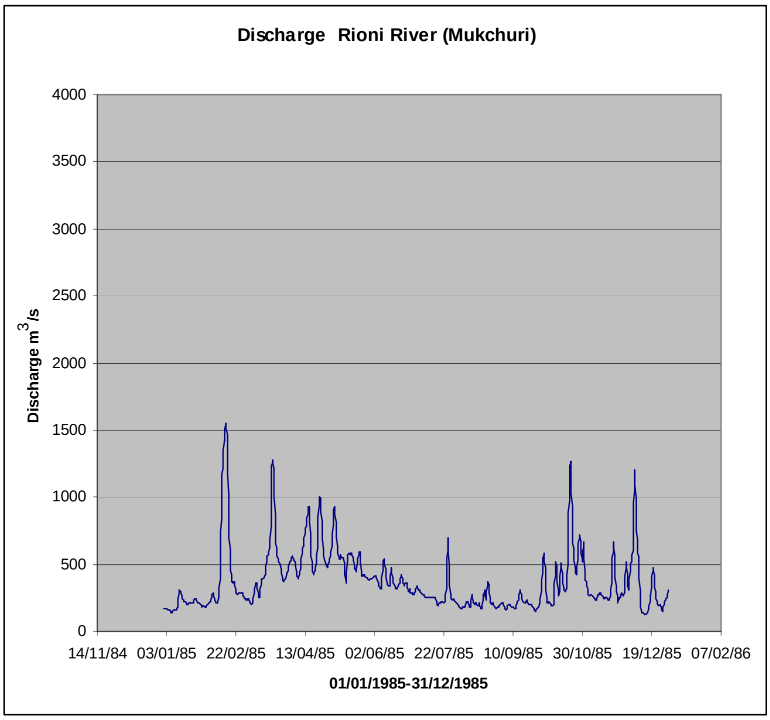


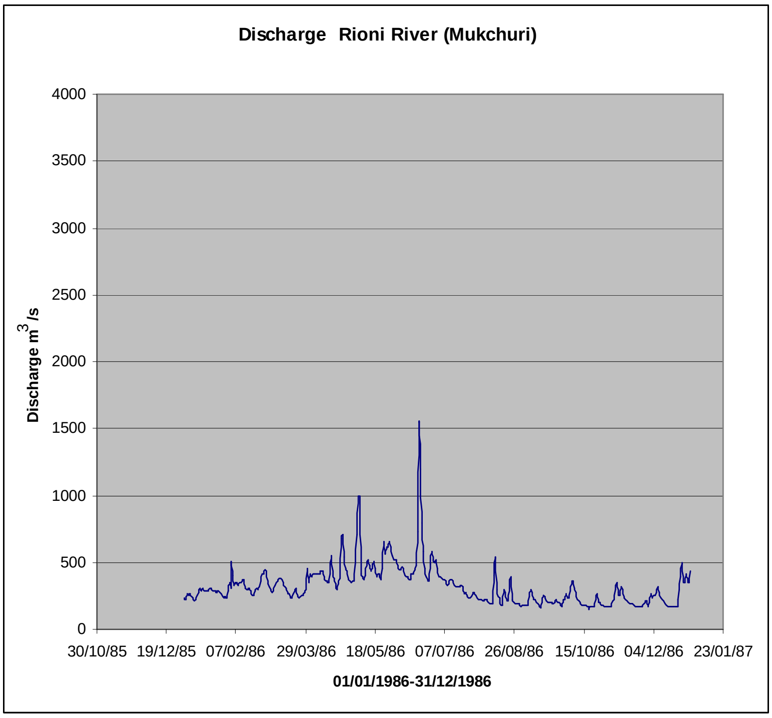



Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
10/11/81 30/12/81 18/02/82 09/04/82 29/05/82 18/07/82 06/09/82 26/10/82 15/12/82 03/02/83
01/01/1982-31/12/1982


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
26/10/82 15/12/82 03/02/83 25/03/83 14/05/83 03/07/83 22/08/83 11/10/83 30/11/83 19/01/84
01/01/1983-31/12/1983


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
30/11/83 19/01/84 09/03/84 28/04/84 17/06/84 06/08/84 25/09/84 14/11/84 03/01/85 22/02/85
01/01/1984-31/12/1984


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
14/11/84 03/01/85 22/02/85 13/04/85 02/06/85 22/07/85 10/09/85 30/10/85 19/12/85 07/02/86
01/01/1985-31/12/1985


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
30/10/85
19/12/85
07/02/86
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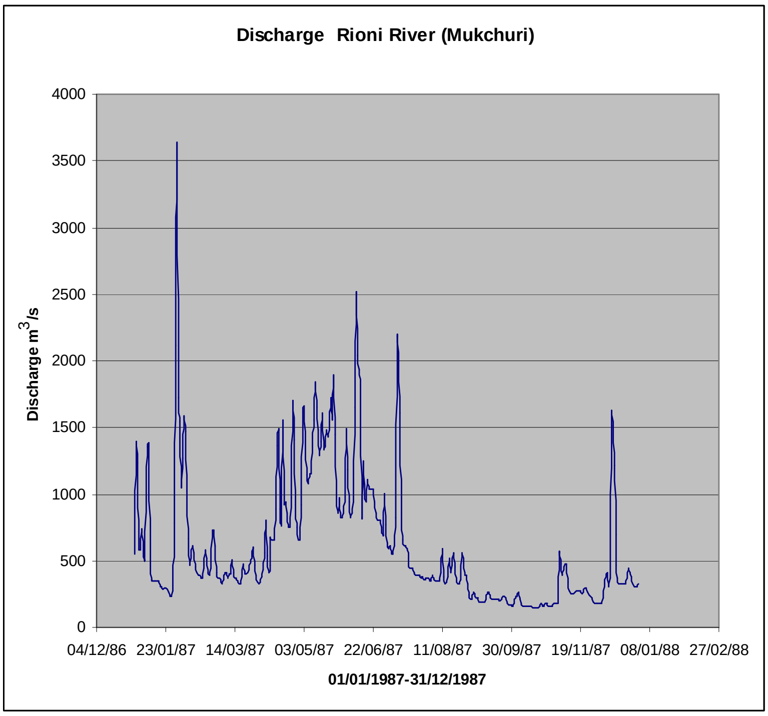
01/01/1986-31/12/1986


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
04/12/86
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14/03/87
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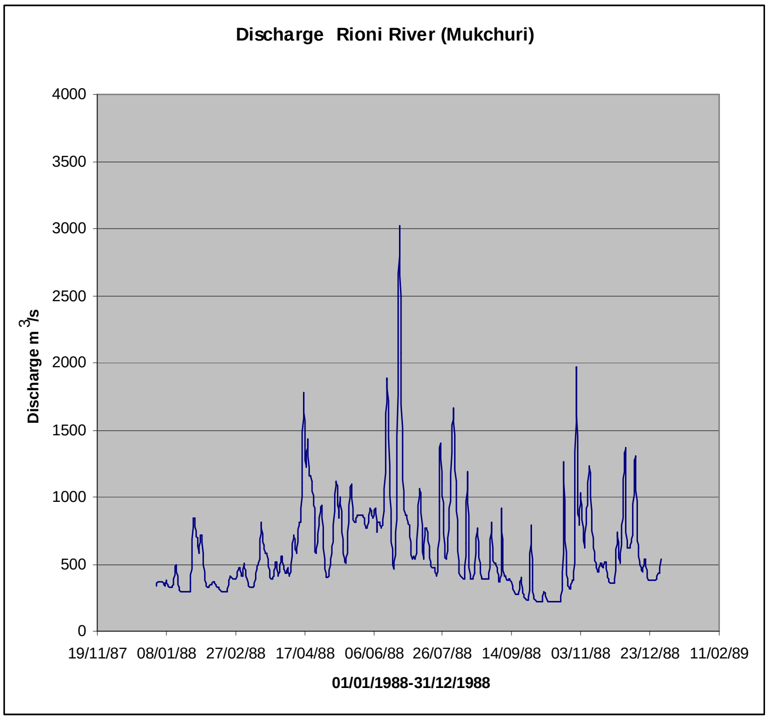
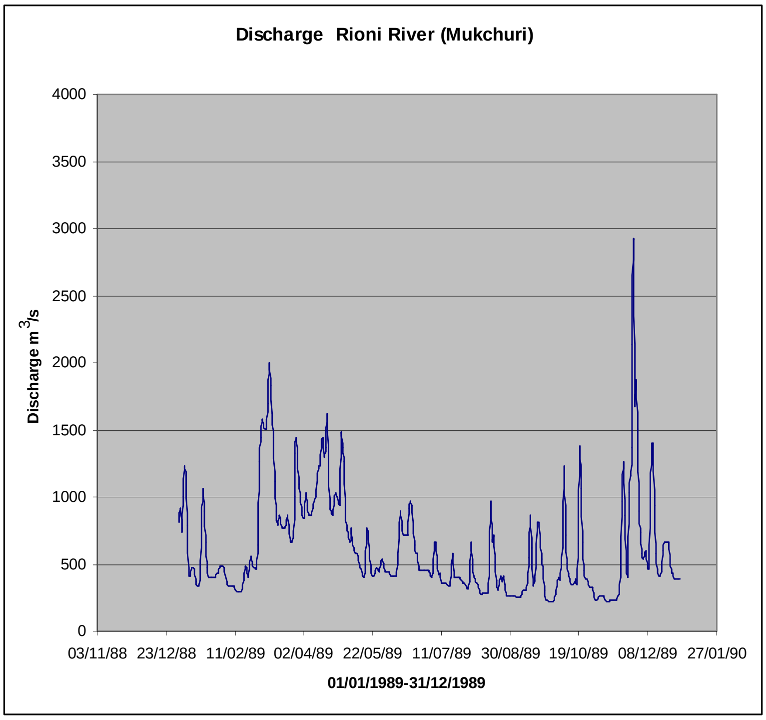
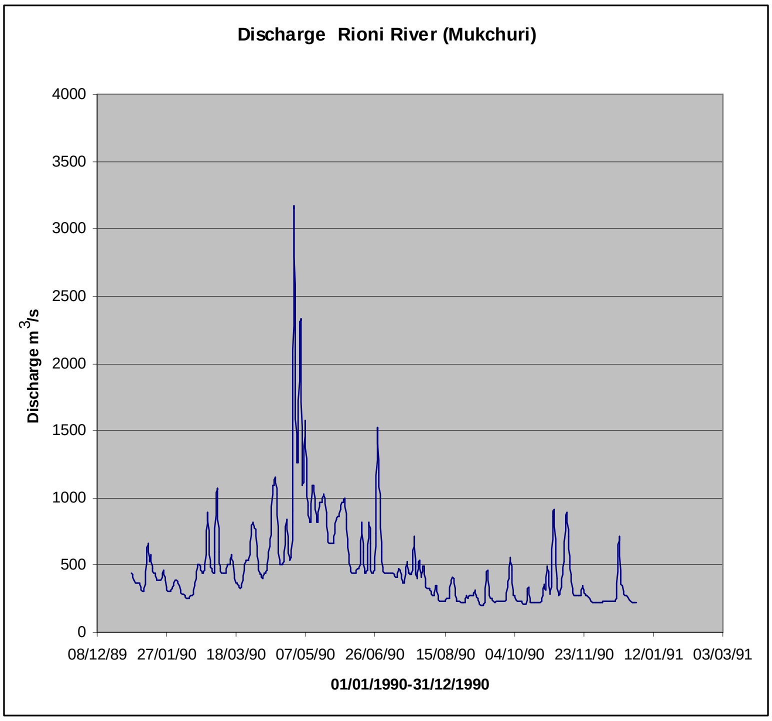
01/01/1987-31/12/1987


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
19/11/87 08/01/88 27/02/88 17/04/88 06/06/88 26/07/88 14/09/88 03/11/88 23/12/88 11/02/89
01/01/1988-31/12/1988


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
03/11/88 23/12/88 11/02/89 02/04/89 22/05/89 11/07/89 30/08/89 19/10/89 08/12/89 27/01/90
01/01/1989-31/12/1989


Discharge Rioni River (Mukchuri)
Discharge m3/s
4000
3500
3000
2500
2000
1500
1000
500
0
08/12/89
27/01/90
18/03/90
07/05/90
26/06/90
15/08/90
04/10/90
23/11/90
12/01/91
03/03/91
01/01/1990-31/12/1990

APPENDIX 1 b

N	Year	Discharge M^3/s
1	1939	1520
2	1940	1670
3	1941	1920
4	1942	1190
5	1943	979
6	1944	1010
7	1945	1160
8	1946	1220
9	1947	1400
10	1948	1150
11	1949	1250
12	1950	1930
13	1951	1740
14	1952	1520
15	1953	1790
16	1954	1490
17	1955	1530
18	1956	2850
19	1957	1720
20	1958	2280
21	1959	1820
22	1960	2190
23	1961	2030
24	1962	2520
25	1963	3000
26	1964	1850
27	1965	1290
28	1966	2330
29	1967	2250
30	1968	2280
31	1969	1310
32	1970	2240
33	1971	1650
34	1972	1480
35	1973	1440
36	1974	2280
37	1975	1780
38	1980	2650
39	1981	3160
40	1982	3430
41	1983	2480
42	1984	1690
43	1985	1550
44	1986	1552
45	1987	3640
46	1988	3020
47	1989	2920
48	1990	3150

APPENDIX 2

N 1		Sagvichio 1					X= 42*11'25.830			Y= 41*52'58.248										
Type of the building for 1987		Floor namber			Age of the house		Material			Quality			Water Level 87	Time of inundation in 1987	Damage in 1987	Population		Age		
Living	Another Type	1	2	3	1987	Now	Wood	Brick	Concrete	Good	Average	Poor		X		Day	Night	W	M	C
How often are they affected by flooding?																				
Which water level is acaptable (managable) for them?																				
Which water level is dangerouse by thyer opinion? And for which seasone?																				
Which water level is catastrophic by thyer opinion?																				
What do they think is important to avoid flooding. What they do																				
What would they do in case of flooding.																				
Coments																				

APPENDIX 3

Hydrological profiles map of Rioni Rive