Water supply and demand management

Flood Risk Management

Georgia

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Advancing Integrated Water Resource Management (IWRM) across the Kura river basin through implementation of the transboundary agreed actions and national plans

Flood Risk Management - Georgia

This document outlines the current practice for Flood Risk Management in Georgia. It is based on reports from and consultations with national experts.

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Consultant	Dr.-Ing. Hubert Lohr, International Consultant, Water supply and demand management expert
Client Representative	Dr. Mary Matthews, Chief Technical Advisor and Regional Project Coordinator; Ahmed Elseoud, Senior Capacity Building Expert
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ABBREVIATIONS

DEM	Digital Elevation Model
DEMP	Disaster Emergency Management Plans
DRR	Disaster Risk Reduction
DRM	Disater Risk Management
EMA	Emergency Management Agency
EPP	Emergency Preparedness Plan
EUFD	European Commission Floods Directive
FRMP	Flood Risk Management Plan
GCF	Green Climate Fund
GEF	Global Environment Facility
MENRP	Ministry of Environment and Natural Resources Protection
MEPA	Ministry of Environment Protection and Agriculture of Georgia
MHEWS	Multi Hazard Early Warning System
NEA	National Environmental Agency of Georgia
SSCMC	State Security and Crisis Management Council
UNDP	United Nations Development Program

1 EXECUTIVE SUMMARY

This report on flood risk management outlines the current practice for Flood Risk Management in Georgia and is based on data collection in the country, reports from and consultations with national experts.

Georgia is prone to natural disasters such as avalanches, landslides, mudflows, flash floods, wind and hail storms. The approved Green Climate Fund project on *Scaling-up Multi-Hazard Early Warning System and the Use of Climate Information in Georgia* is certainly a milestone in the effort to establish a comprehensive disaster risk reduction framework. Within this Green Climate Fund project, it is foreseen to develop a hydrological observation network as well as a unified methodology to assess natural disasters, to perform the assessment and to bring results in a harmonized structure. The project duration is seven years.

Georgia has not yet officially transposed EU Floods Directive (EUFD) in its national legal framework, but started a series of preparatory actions in order to approximate to the EUFD. However, Georgia signed the EU – Georgia Association Agreement and Association Agenda, which aims to promote the dialogue and approximation of EU legislation on items such as civil protection and flood management.

At this stage, is it important to allow for future necessities while implementing the GCF funded project. The focus of the GCF project is predominantly on water quantity, However, water quality should at least be considered when developing the hydrological observation network. Water quality is a mounting issue, in particular, with migration into cities, the aim to intensify agriculture and the lack of waste water treatment as it is the case in the country.

The current hydrological data availability in Georgia has room for improvement. Even the GCF project cannot compensate a lack of nearly 20 years of observation. As such, it is paramount to consider risk assessments as a periodic task since new records will evolve over time. It is also considered crucial that data are made publicly available free of charge. The development of water resources, be it for hydropower, agriculture of other purposes, requires proper data and thus access to consume it. The policy in Georgia should also consider to adopt EU principals in terms of data accessibility, which determine that governmental entities, whose responsibility is to collect hydro-meteorological data, are obliged to grant free access to observed hydro-meteorological records, especially precipitation, temperature, water level and discharge data at all observation points, including historic records. Hence, data observation is not a business case but a sovereign function with the obligation to make it public for research, water resources development, no matter it is state-owned or private.

The document also provides suggestions in terms of flood risk assessments. Some might be captured by the GCF project some not. The suggestions are based on best practice standards. They are tailored to match necessities in Georgia and most of them are easy to implement at low costs.

The report closes with a collection of critical issues when assessing flood risks, in particular when large areas are investigated within a tight time schedule. These examples stem from real world projects and reflect possible and frequent mistakes. It is easier to detect and avoid these kinds of mistakes once they are known and perceived as possible sources of error.

2 INTRODUCTION

Flood management cuts across different sectors like water resources management, agriculture, land use management, rural and urban planning and jurisdiction. It involves legal, institutional, planning and operational aspects and requires coordination among stakeholders with different background, different priorities and different planning horizons.

The specifics of geography and natural landscape of Georgia make this country prone to natural hazards. The Greater Caucasus stretches along the border to Russia in the north and the Lesser Caucasus builds the southern border to Turkey and Armenia. Flash floods, mudflows, landslides and avalanches are the hazards, which strike most in Georgia, predominantly in the mountain valleys with steep slopes. This is exacerbated by rising temperatures causing instability of formerly frozen permafrost areas giving rise to glacial flooding triggering more and stronger mudflows.

These hazards have caused serious problems in different regions throughout the country with social and economic implications and require attention and action.

Another aspect in terms of flood risk management is the interest in the development of hydropower dams in the country. Quite a number of new dams are in the pipeline. If they are built, they will play a role in flood management. Dams must be operated with flood protection as a major purpose, releases need to be coordinated between dams to avoid man-made flooding downstream. On top of that, rising water levels during first filling phase pose a risk regarding instability of slopes in the immediate surrounding of the reservoir and could potentially cause landslides.

This report outlines the current practice for Flood Risk Management in Georgia. It is based on reports from and consultations with national experts of Georgia. The report summarizes the current status, sheds light on gaps and outlines possible improvements but also mentions achievements. This report also addresses different flood risk management scales one of which is the transboundary aspect.

3 FLOODS AND FLASH FLOODS

The origin of flash floods in Georgia can be classified as follows:

A. Intensive melting of snow by high temperatures
B. Melting of snow triggered by rain
C. Intensive rainfall
D. Instability of rock and glaciers causing rock falls, avalanches, landslides, mudflows

While A and B are limited to high altitudes C can happen everywhere in Georgia. D is more or less restricted to the valleys surrounding the very high mountains.

Riverine floods affecting Mtkvari or Kura River have a different origin. In general, a combination of snow in the headwater areas, warm temperatures and rain is responsible for high discharge.

The highest number of the flash-flood events occurs in West Georgia between June to August and in East Georgia in May to June. In both cases it coincides with the period of months with the highest rainfall.

Catastrophic flash-floods events happened 1968, 1987, 1996, 2005, 2014 and 2015. In 1987 (31st of January), the discharge of the river Rioni has reached 4800 m³/s. In the course of this event a dam failure occurred and flooded settlements. The Paliastomi lake was also affected. Its water level increased, reached a dangerous level and flooded the city of Poti. River Rioni inundated 5500 ha of agricultural land, 6200 people had to be evacuated, 350 buildings were destroyed, 1265 damaged, 1617 families became homeless, 4480 cattle died, 16 km railway and 1300 km roads were destroyed, basic infrastructure like bridges and communication lines were damaged beyond repair. The flood events had a death toll of 27. In total, damage worth 300 Mio. USD was reported.

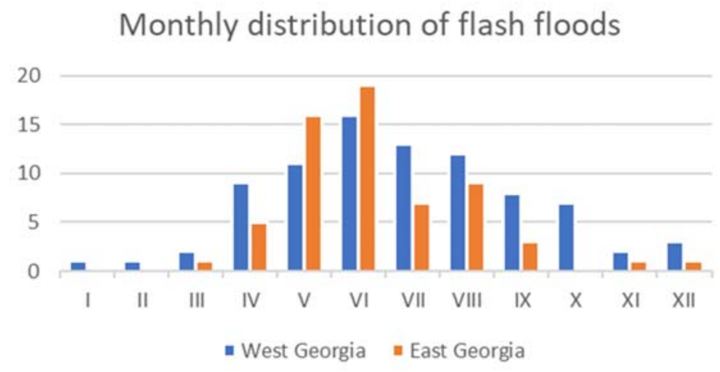


Figure 1: Distribution of flash floods in Georgia (Megrelidze, 2019)

The risk of being affected by flash floods is especially high in the river basins of Imereti, Samegrelo, Guria, Mtskheta-Mtianeti rivers, as well as territories along the River Mtkvari and the left bank of the Alazani River.

Statistical data of the National Environmental Agency (NEA) shows a significant increase in flood/flash flood events. The reason could be twofold: firstly, climate change processes lead to more severe snow melt and higher rainfall intensities situations, secondly, data collection has improved.

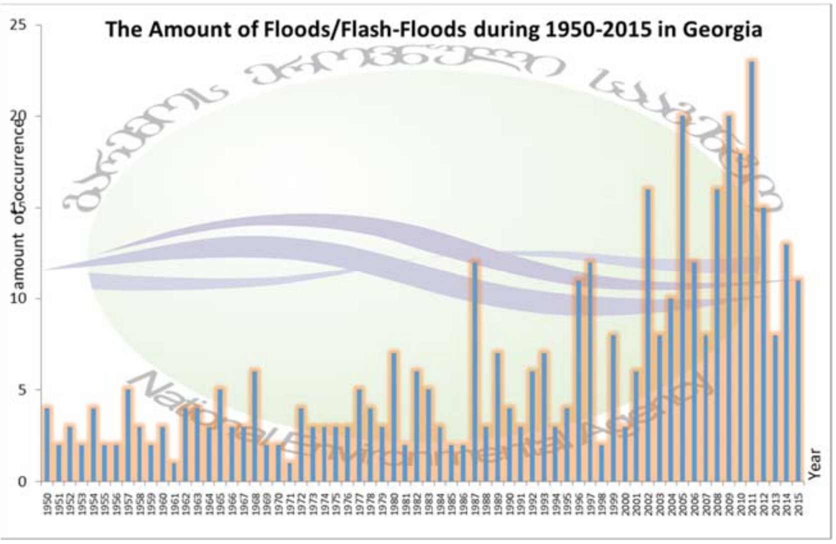


Figure 2: Distribution of flash floods in Georgia (Megrelidze, 2016)

Following the national report (Megrelidze, 2019), major incidents of floods are described in detail. Although the described events are the largest and most devastating events in recent years, they are still representative for these kinds of hazards.

A flood event happened 2014 in the Tergi (Dariali) gorge, originating from rock-ice avalanche and glacier mudflow from the Devdoraki Glacier near Mount Kazbeg. The characteristic of this type of event is:

- The avalanche and mudflow find its way down by following a naturally incised valley
- It has the potential to block the valley and builds a dam with debris
- Once the event starts it happens fast
- The area is not monitored or is not under permanent survey
- There is little to zero time for warning and evacuation
- The affected area is hit more or less unprepared

Interestingly, these kinds of events are not necessarily caused by antecedent heavy rainfall. The trigger could also stem from a seismic activity. Although some areas might be more prone to this type of event, it can happen everywhere in the surrounding of glaciers, in particular when temperatures become higher and permafrost area start unfreezing.

A major landslide triggered a flood event 2015 in the Vere River affecting Tbilisi. Rainfall smaller than than a 1% return interval in June caused a flood event higher than a 100 years flood. The flow itself was exacerbated by large amounts of sediment and debris. A major problem was the blockage of cross sections and culverts resulting in rising water levels to unprecedented elevations. Summarizing this event leads to the following conclusions:

- Return interval for rain and discharge are not identical
- Sediment and debris exacerbate the flow
- Culverts cannot be assumed as open and fully passable
- Flow can follow unexpected pathways when debris load is high.

The Mtkvari or Kura River had two remarkable flood events in the past 50 years in Georgia, one in 1968, the other in 2005. Both events are characterised by the combination of large amounts of snow in the tributaries' headwater areas, snowmelt and rain. As the area is large and weather forecasts are able to predict approaching warm and humid air masses, events like this are predictable and give enough time for preparation. Reservoir operation plays a role as well since time for foresighted operation and coordinated releases to obtain additional flood buffers is given.

NEA has generated a flash flood risk map of Georgia indicating four different risk levels.

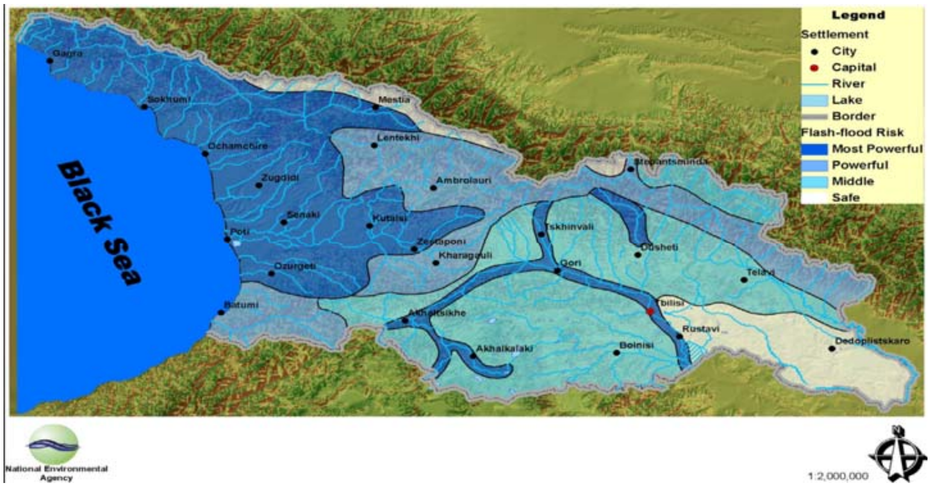


Figure 3: Flash flood risk map of Georgia from NEA (Megrelidze, 2016)

(Megrelidze, 2019) provides an overview of historical events in the Kura River Basin.

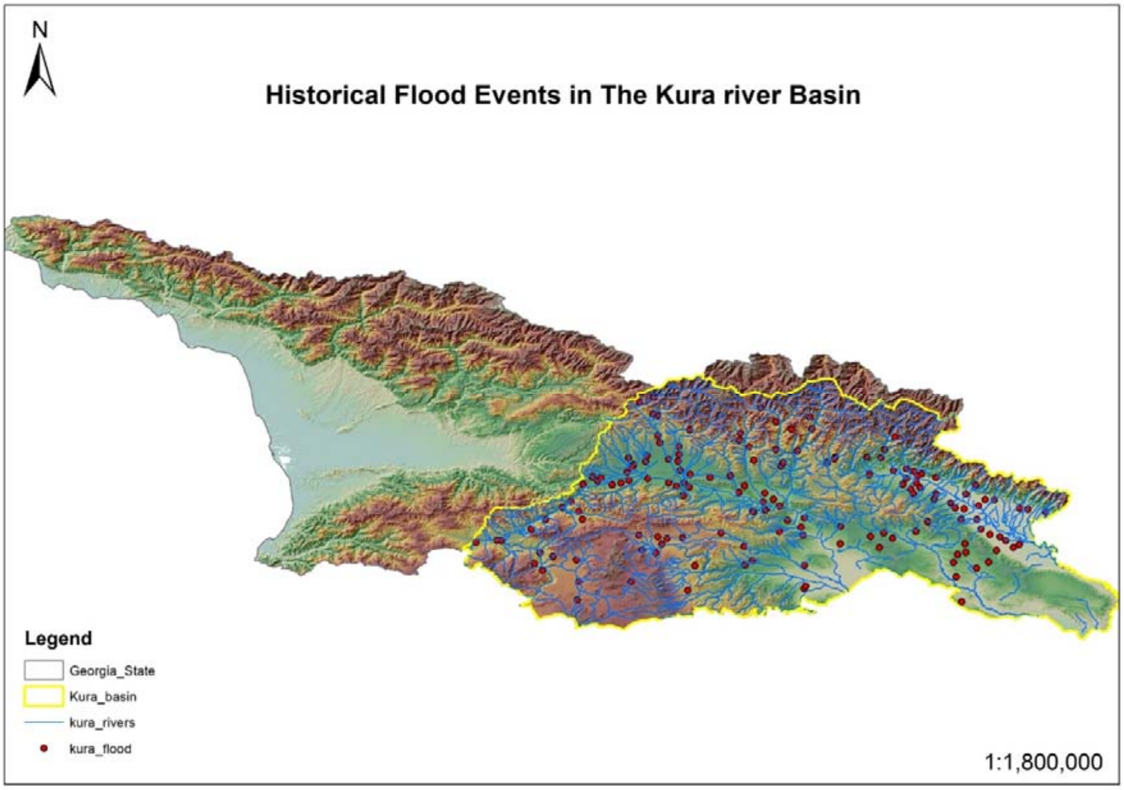


Figure 4: Flood events in the Kura River Basin (Megrelidze, 2016)

The largest compilation of hazard, exposure and risk maps of the country is contained in the opensource renewable Geoportal of Natural Hazards and Risks of Georgia created by CENN and available at http://drm.cenn.org/index.php/en/. However, these maps date back to 2012, contain small-scale maps and maps show up when the language is switched to Georgian. In the meantime, the majority of hazard maps kept by NEA are of 1:100 000 and smaller scale, while 1:5 000 and 1:10 000 scale maps are not yet processed.

4 CURRENT PRACTICE IN FLOOD RISK MANAGEMENT

4.1 Governmental bodies with respect to flood risk management

This section summarizes the findings from (Megrelidze, 2019).

There are several institutions who are responsible for DRR and response issues, including floods:

- National Environmental Agency (NEA) of the Ministry of Environment Protection and Agriculture of Georgia, responsible for hazard assessment and early warnings
- Ministry of Regional Development and Infrastructure, responsible for infrastructure for DRR mitigation (shore protection structure, drainage systems etc.)
- Emergency Management Department (EMA) of the Ministry of Internal Affairs of Georgia, responsible for the risk assessment and response activities.
- Local municipalities with the responsibility of assessing, implementing, responding during and recovering after a disaster within their boundaries, supported by governmental agencies.

The Ministry of Environment Protection and Agriculture of Georgia (MEPA) issues every 4 years the *National Report of the State of the Environment of Georgia*, in which the current situation about natural disasters are reviewed and future plans are outlined.

Currently, the main action plan regarding natural hazards is the *National Disaster Risk Reduction Strategy of Georgia 2017-2020*. It was prepared by The State Security and Crisis Management Council (legal successor of EMA). All governmental bodies that are affected by natural hazards were involved in a consultation process. The strategy lists measures and requirements with priorities based on the risk that was assigned to rivers and areas.

Annex A.1 is a comprehensive list of governmental and regional organisations who receive weather and water related updates from NEA by SMS as part of disaster risk management practice:

4.2 Disaster risk reduction at the local level

One of the priority directions of the Government of Georgia is to introduce the methodology for identification, analysis and assessment of natural disaster risk at the local level and the development and implementation of risk reduction measures.

The government assists the local self-governing bodies in implementing a harmonized national methodology of risk assessment and the development of a local strategy and action plan.

The assessment of threats at local level is paramount. Local self-governing bodies are supported in order to carry out risk assessments to evaluate the type of threat, risk factors, probabilities of occurrence and vulnerabilities. It is their responsibilities to set priorities for implementation.

It is the aim to strengthen the capabilities of local self-governing bodies so that they are able to prepare financial and material resources including implementation plans. Implementation shall be carried out at the local level.

During the recovery and rehabilitation process in the aftermath of a natural disaster event, local self-governing bodies shall carry out the collection of data and the evaluation of economic damages and losses.

At national level, a unified state policy on compensation and recovery measures will be established based on the widely accepted approaches adopted from UN and EU.

4.3 Adoption of EU legislation like the Flood Directive.

Georgia has not yet officially transposed EU Floods Directive (EUFD) in its national legal framework, but started a series of preparatory actions in order to approximate to the EUFD. However, Georgia signed the EU – Georgia Association Agreement and Association Agenda, which aims to promote the dialogue and approximation of EU legislation on items such as civil protection and flood management.

There are two main players responsible for the adoption of the EUFD:

- Emergency Management Agency (EMA) within the Ministry of Internal Affairs
- State Security and Crisis Management Council (SSCMC) under the Prime Minister Office

While EMA takes the lead in determining the contents of Disaster Emergency Management Plans (DEMP) and Flood Risk Management Plans (FRMP), SSCMC is in the process of drafting and approving a National DRR Strategy and a DRR Action Plan. All topics are required according to EUFD and determine the requirement in tems of hazard assessments, generating hazard, risk, actions maps and flood management plans and its implementation.

What is not yet considered in Georgia is to understand watersheds as administrative units. Current practice is still to use political borders. This hampers the process of developing FRMP and leads to irritation and/or conflicts about responsibilities amongst governmental bodies.

4.4 Ongoing activities

Since more than five years, UNDP has been supporting Georgia with respect to floods and flash floods. The project Developing Climate Resilient Flood and Flash Flood Management Practices to Protect Vulnerable Communities of Georgia was carried out between 2012-2016 with a budget of 5 Million funded through the Adaptation Fund and UNDP. The target region was the Rioni basin and its communities The project worked on development of floodplain policy to incentivize long term resilience to flood and flash flood risks; designing and implementation of climate resilient practices of flood management for reducing vulnerability of highly exposed communities; and supporting in the improvement of early warning systems to enhance preparedness and adaptive capacities of the communities.

Georgia was successful with a proposal to obtain fund from the Green Climate Fund (GC). The project *Scaling-up Multi-Hazard Early Warning System and the Use of Climate Information in Georgia* started in 2018 and aims at establishing a multi hazard early warning system (MHEWS) and increasing national capacities for DRR. There are three major project outputs/components:

i. Enhance or establish a climate-induced natural hazard observation network and modelling capacities to secure reliable information on climate-induced hazards, vulnerability and risks
ii. Implement a multi-hazard early warning system and new climate information products with in combination with effective national regulations, coordination mechanism and institutional capacities;
iii. Improve community resilience through the implementation of the MHEWS and priority risk reduction measures

The project has a life-time of seven years and a budget of more than 70 Mio USD.

The role of the MEPA is to set up the fully automatized hydrometeorological monitoring systems and to implement hydraulic and hydrological modelling. The mentioned document has a legislative form regulated by the governmental decree #4 (11.01.2017).

5 SUGGESTIONS FOR INTEGRATED FLOOD MANAGEMENT

5.1 Introduction

Governmental authorities and communities are commonly understood as the entities who take the lead in responding to flooding. If their capacity is weak, flood management will be weak and response mechanisms are most likely not adequately in place. This means that flood management has two components, namely

- water resources engineering with risk assessment, design of measures

and

- institutional development determining clear roles and responsibilities, capacticy development, financing mechanisms and an appropriate regulatory framework

This is reflected in the ongoing approximation to the EUFD and is also an expected outcome of the GCF project.

5.1.1 The mountainous region

In Georgia, major components which favour runoff and thus flood and flash flood formation are steep slopes, poor vegetation cover, less permeable and shallow soils, instability of unfreezing ice covers.

These factors together with unfavourable geological conditions like glide planes are root causes for natural hazards like floods, landslides and mudflows. The formation of such hazards is promoted when human-made factors come on top like land-use alterations, inappropriate drainage structures, overgrazing and effects of urbanisation. In addition, climate change increases the number of intensive rainfall events and thus exacerbate flash floods, erosion, landslides and mudflows.

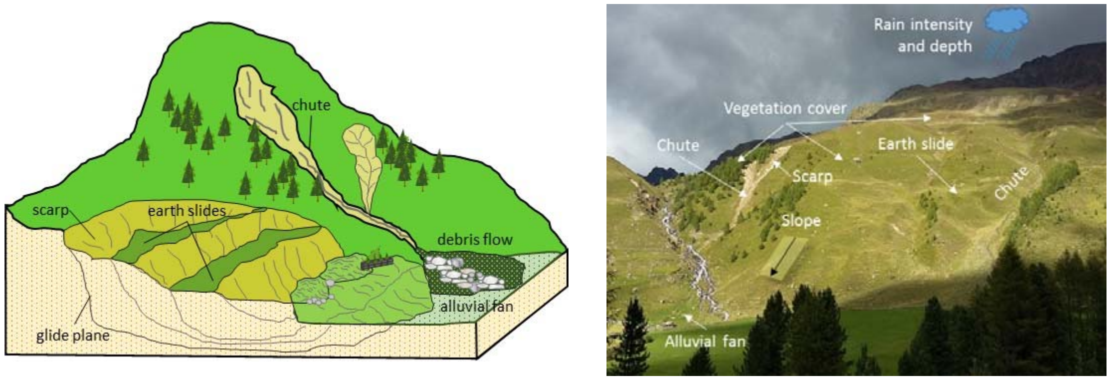


Figure 5: Hydrological features associated with floods, erosion, landslides and mudflows

The question is to what extent is it possible to alleviate floods and to prepare for natural hazards in a hazard prone environment? In order to embark on successful flood management, four pillars need to be considered:

- Design
- Monitoring
- Operation
- Preparedness

It is unrealistic to believe that 100% flood protection is achievable. It is also unrealistic to believe that just building enough flood protection measures alone is enough to cope with floods. A holistic approach is required in which engineered measures, nature-based solutions, environmental safeguard and adequate and thoughtful rural and urban planning must go hand in hand. If one of aforementioned components is ignored or forgotten, flood management will not reach a successful implementation.

5.1.2 Plains

The focus in the plains is on riverine floods and how to protect urban and rural areas. Planning, monitoring, operation and emergency response differs from mountainous areas in terms of the tools that are applied for assessments and monitoring devices and the lead time, which allows for early warning and preparedness.

5.2 Types of natural hazards in mountainous areas

Flood management should look at these types of hazards since one often triggers the other:

- **Flash floods** are normally local events affecting small to medium sized areas. The flow is characterized by a very fast onset and a short duration but high flow volumes. Hydrologic processes leading to flash flood are intensive rainfall where the soils infiltration capacity is exceeded very quickly, rain on frozen or iced areas (⇒ rain on ice flooding), rapid snowmelt or the breakup of jams in the water course. Manmade triggers for flash floods can be sudden releases from dams, dam or levee failures. Due to the high amounts of flow volumes, flash floods have high erosive power and often carry high sediment and debris load (⇒ Mudflow/Debris flow). Due to the high transport capacity and the fast process of flash floods, the damage potential is high.
- **Mudflows/Debris flows** are floods with heavy loads of sediments and coarse debris. They can also be described as a special form of landslides, where the flow has enough viscosity to transport coarse debris within the matrix of water and smaller sediments. Debris flow can occur on hill slopes and continue into drainage channels or water streams. One of the main reasons for the development of a debris flow is deforestation or the removal of other natural ground cover in steeper catchment parts, which decreases soil stability. Debris flow may begin as clear water-flows and accumulates debris on their course or directly even starts with a mixture of soil, debris and water. The high density of the flow matrix (water, soils, large boulders, debris) develops high destructive forces and can destroy structures and even protective measures in its way.
- **Rain on ice/snow flooding** occurs, when high precipitation volumes fall on frozen grounds and become surface discharge directly and in total. The potential for rain on ice flooding is especially high in late winter before snow and ice are melted and with the occurrence of spring storms. Due to the ice cover and frozen grounds, retention is low and the rain on ice floods generally travels fast. If normal drainage pathways or natural waterways are blocked by ice or snow, the damage potential of rain on ice floods is increased.
- **Landslides** can be related to or associated with intensive rainfall or earthquakes. If landslides are triggered by high precipitation or flood events, they often transform into matrix flow of soils, boulders and water (⇒ Mudflow/debris flow).

5.3 Assessment in stages and as periodic task

The development of an effective and sustainable hazard protection plan depends on a proper identification of the potential hazard(s), the respective catchment characteristics and their interaction with human land use. The assessment for flash floods and mudflows should consider stages from a first risk analysis to periodic re-evaluation.

1. The **risk analysis** combines information about possible hazards with current or planned land use and damage potential. In this step, a clear understanding of the physical processes and effects

leading to (flood) hazards is very important as this knowledge is crucial for selection effective and long-lasting mitigation measures. In areas, where exposure to a flood hazard is determined, a risk arises.

Depending on the risk area, a desired protection level needs to be determined. The level of protection may and should vary depending on e.g. damage potential, necessary protection effort, physical limits of protection, etc. If a protection deficit exists, the planning of mitigation measures follows.

2. Based on the risk analysis, the **action planning** follows, where suitable mitigation measures are selected. The different measures need to be considered in an integrated manner in order to exploit synergy effects and prevent counteracting processes between the different measures.
3. The next step is the action plan **evaluation**. Critical questions that need to be answered are the achieved protection level and the residual risks, the cost-effectiveness and the technical feasibility of the measures and their impacts in the socio-political sector. If the outcome of the evaluation is unsatisfactory, either the selection of measures (action planning), the risk analysis (verification of boundary conditions, selection of desired protection levels) or both need to be re-evaluated. In case that the evaluation of the action plan is satisfactory, the selected measures can be implemented.
4. During the **implementation** phase, the mitigation measures are realised. Based on the type of the measure, the implementation of measures can range from building protective structures to policy changes or stakeholder training courses. In all cases, it must include emergency planning and a maintenance plan of the protective structures.
5. Once implemented, the hazard risk management approach should undergo a **periodic checking**. This includes a repetition of the risk analysis to evaluate if the level of protection is still sufficient or not. If it is still sufficient, the current state of the catchment (land-use and spatial planning, maintenance of infrastructure, stakeholder engagement, policy compliance, etc.) should be safeguarded. This is important as changes of the current state may lead to a major increase of hazard potential, damage potential or both. If the level of protection becomes insufficient over time, the hazard risk management plan needs to be extended until an evaluation is satisfactory again.

5.4 Adaptation of hydraulic approaches

5.4.1 Flash floods and mudflows

Due to the terrain in Georgia, flash floods will carry large proportions of sediment and debris. Hence, ordinary hydraulic calculations will underestimate the power of flows. Flash floods assessments should allow for varying viscosity and increased density of flows, meaning that viscosity and density should be adjustable parameters rather than fixed constants.

Considering the load of sediment in steep torrents, the discharge requires an adaptation and the sediment load must be included. This can be accounted for by multiplying the discharge with an intensity factor, representing the additional load in the water-sediment mixture. (Bergmeister, 2009) suggests the following intensity factors:

Table 1: Increase of discharge due to sediment load (Bergmeister, 2009)

Process	Proportion of sediment	Intensity factor IF
Flood (low sediment)	0 – 5%	1 – 1.05
Fluviatile sediment load	5 – 20%	1.05 – 1.4
Mudflows	20 – 40&	1.4 – 3.5
Debris flow	50 – 80%	3.5 - 100

For estimating the sediment load or amount of material during mudflows, several empirical formulas were developed. These formulas contain a high degree of uncertainty and serve only as rough estimates in the absence of more reliable information.

$M = 27000 \cdot A^{0.78}$ (Bergmeister, 2009)
$M = L_c \cdot \left(110 - 250 \cdot J_f - 3\right)$ (Bergmeister, 2009)

All empirical formulas stem from field investigations in the Alpine region. A good overview about assessment and torrent control provides (Llano, 1993). Detailed information on hydrologic and hydraulic assessment for flash floods, mudflows with planning and design of prevention measures with step-by-step guidance can be found here (Lohr, 2018).

5.4.2 1D or 2D modelling

When it comes to assessing flood extent, inundation and flow velocities, the question arises which tools are appropriate. Generally, a 1D hydraulic approach is certainly suitable for mountainous areas with high gradients and narrow valleys. A 2D hydraulic model is necessary if the gradient is low and flow is largely affected by lateral flow components, interacting flow paths. However, the strength of 2D models is often overestimated as models can only be as good as the underlying data is. Even the Kura River must not necessarily be modelled in 2D if no lateral flow components prevail.

5.4.3 Steady-state or non-steady-state modelling

An important question is about steady-state or non-steady-state conditions. In a steady-state modelling approach flow does not change and an unlimited flow volume is assumed. A non-steady-state approach requires a hydrograph with a given flow volume. Steady state conditions have the advantage that calculations deliver a maximum flood extent. This is definitely appropriate in steep terrain. Unrealistic flow volumes cannot occur in steep terrain.

In a plain, however, steady state conditions result in unrealistic inundation so that non-steady-state conditions are the alternative. The issue with non-steady-state or dynamic conditions is to find a hydrograph that is representative. When a long river section with lateral inflow is modelled, it is very unlikely that only one hydrograph results in a maximum flood extent along the entire river section. The process of identifying relevant hydrographs for maximum flood extent is complex and requires different flood hydrographs. The more tributaries come in, the more complex is the assessment of finding a representative event for a given return period. The question about finding the right hydrographs is about the rain event behind the hydrographs and the distribution of rain over the catchment. A short rain duration with extremely high intensities form a fast rising and fast falling hydrograph with a high peak but a rather moderate flood volume. Such an event is not representative for a large catchment. A long rain duration with less intensities give rise to a hydrograph with a large flood volume but does not reflect hazardous events in small catchments. The crucial point is which rain intensity must be used to be representative for a desired return period and for specific catchment area. Which rain event and thus, which hydrograph is relevant for a particular river section in terms or maximum flood extent must be tested.

Another issue with non-steady-state conditions is water retention. Retention of water upstream reduces the amount of water downstream and thus creates favourable conditions downstream. If retention of water upstream is not 100% guaranteed in all circumstances, a non-steady-state approach results in an underestimation. Each structure, natural or man-made, causing retention must be checked as to whether it will always and under all circumstances retain water. If this cannot be clearly confirmed, the ability to retain water for this particular structure should be omitted during the calculations. If the ability to retain water is confirmed, it should be incorporated into the model.

5.5 Flow trajectories and hazard mapping

A very important step in assessing exposure and risk of flash floods and mudflows is to derive potential trajectories flash floods and mudflows can take. Risk maps can significantly be improved when freely and open data sources and GIS tools are used. It is highly recommended to apply an approach as it is explained below.

The common approach is to use a DEM (Digital Elevation Model) to derive the pathways of flash floods and mudflows and to overlay that with land use like settlements, infrastructure, agricultural areas. Usually, a steepest path (or single flow direction) approach along adjacent cells is applied. The assumption is that flash floods and mudflows follow the steepest path downstream. This approach must be extended to a Multi Flow Direction approach to better represent multiple flood and mudflow trajectories when slopes in the accumulation zone are reduced. The approach distributes the flow to the cells with the highest likelihood of movement according to the slope from the central cell to each of the downstream adjacent cells. This accounts for the power flash floods and mudflows have to form new trajectories.

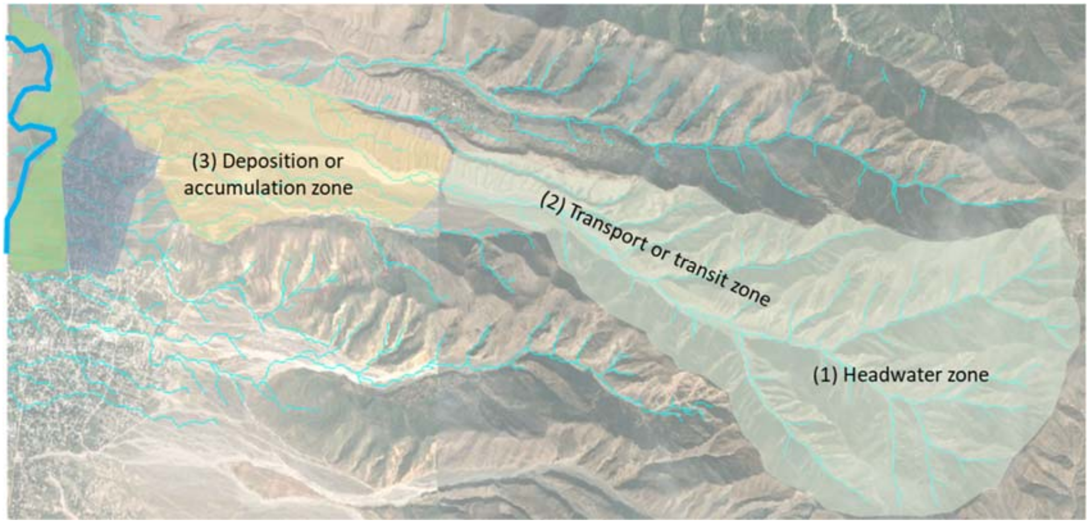


Figure 6: Different zones for flash flood and mudflow analysis

The colour in Figure 7 indicates the probability a mudflow runs along a trajectory where light blue indicates a low probability and dark blue a high probability. The calculation of the runout length and the loss of volume along trajectories with an empirical function of the flood volume should complement the analysis by using reduced intensities towards the length of the runout zone along the trajectories due to a loss of volume in each cell. The analysis constitutes the basis from which hazard maps can be derived with intensity (volume and peak from the hydrological model) and probability (GIS-based trajectory analysis). The probability is the parameter to be used for exposure and risk.

Single flow direction (for transit zone) Multi flow direction (for runout zone)

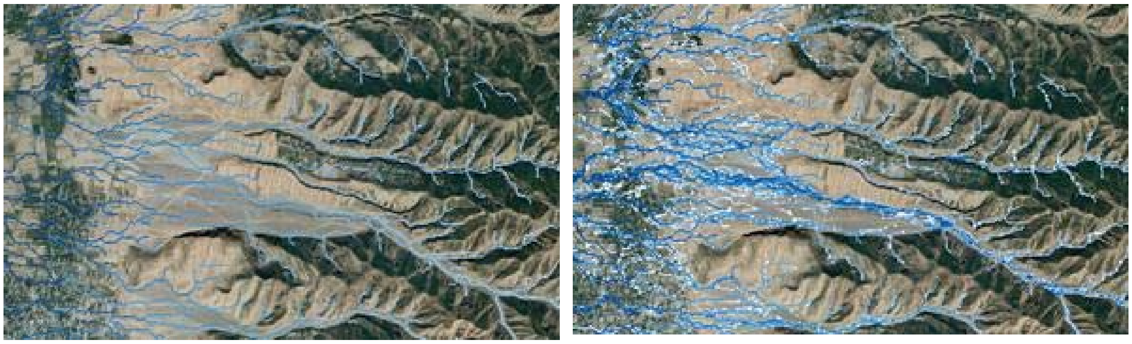


Figure 7: GIS-based flash flood and mudflow trajectory analysis (Lohr, 2018)

It is obvious that a hazard, exposure and risk map varies significantly when using the simple single flow or the more realistic multiple flow direction approach.

It is recommended to perform this type of analysis to generate hazard and risk maps for the mountainous areas. The approach requires a DEM and GIS. A DEM with a 30x30 m resolution is available free of charge. It could be improved with licensed products showing higher resolutions if need be. The advantage is that the method yields detailed hazard and risk maps and provides probabilities of exposure. If the approach is combined with a hydrological model and design storms, the method turns into a probabilistic approach where results show probabilities of occurrence (return periods). This is the state-of-the-art methodology international organisations like the World Bank propose.

5.6 Community based risk assessment

Activity 3.1 of the GCF project addresses the implementation of community-based early warning schemes and community-based disaster risk management. It is the last topic in the seven years project timeframe. Communities and/or rural villages have not yet development full capacity to generate hazard maps or early warning systems, but they need to understand hazards maps, flood mitigation plans, early warning schemes as to create ownership and to enable them to act accordingly.

Understanding and awareness can be achieved if they play an active role in the process. It is strongly recommended to conduct a community-based risk assessment approach as early as possible. An effective way of reaching out to communities and rural areas is a simple risk assessment task as described below.

The process of assessing the risk is the first task to be done. It is carried out by the community and/or the villagers on its own assisted by experienced disaster risk managers. It is paramount to assess the magnitude and extent of flood hazards, to identify locations where hazards would strike and what kind of countermeasures are useful. The risk assessment should also identify which factors favour hazards, for example poor watershed management with high runoff rates and erosion. The community-based risk assessment consists of five topics.

1 Inventory of past flood events

The process should start with an inventory of all hazard related knowledge about the watershed, which exists in the community/villages. The result of the inventory is displayed on a map.

- Collect events that have occurred in the past including spatial and temporal extent frequency, month, duration
- Draw the spatial extent on a map and indicate severity with colours
- Draw the duration of the flood with different colours on a map

- Indicate points of known or estimated water levels in a map
- Indicate major flood formation areas in a map
- Draw damages on a map
- Draw where people died or were missed after the hazard

Figure 8: Example of a simple flood inventory map based on knowledge from past events

Local knowledge usually exists to pinpoint problems in a watershed. Most likely people are aware of areas exposed to erosion, scarps indicating potential zones for landslides, gullies and channels prone to debris flow, mudflow and so on. This knowledge is invaluable, must be compiled and indicated on maps. The same is true for the extent of inundation and damages due to past floods. The inventory should be supported by a water resources engineer or disaster risk manager.

It is worth mentioning that hazard maps could be used to show exposure and areas at risk.

2 Factors contributing to flooding

Factors contributing to flooding need to be listed and drawn on a map. This is:

- Deforestation
- Open and bare land
- Areas frequently used for livestock
- Roads and drainage of roads
- Areas with poor vegetation
- Areas of impermeable soil
- others

In a second step they can be classified as anthropogenic – as a result of human action – or natural.

3 Vulnerable groups

A list of the groups that have been most affected by flooding in the past and/or could be affected by future flooding should be developed. Vulnerable groups are those who do not have the resources to protect themselves or to recover with own resources after a hazard strikes (e.g. less wealthy, elderly people, people with disabilities, frequently exposed to dangerous ground, frequently cut off from communitation, etc.) These groups should be marked on the map and special attention should be paid while dealing with planning meeting points, shelters, notification procedures, protective measures. Questions need to be followed up like: who can give support, how can they be informed in case of an emergency, who can provide assistance in preparing for emergencies, where can they hide during hazards, how can they be reached and provided with goods when thea are cut off after a hazard has hit, etc. This is the part where gender issues need to be addressed.

5 Capacities to respond to flooding

Capacity is the ability to resist or respond to damage caused by flooding. What can a community/village do to enhance their capacity to respond to floods? Is equipment available, what kind of knowledge and professionals reside in the area? Who can guide and oversee actions? Where is high and safe ground? Where are safe escape routes and/or evacuation routes and how long does it take for fit, old and people with handicaps to follow these routes? What are safe meeting points, shelters, strong buildings, monestries, etc. All items must be drawn on a separate map.

Another apsect is to look at prevention. Buildings must withstand potential events, should not be built in mudflow trajectories and shuld be exposed to unsafe ground.

5 Synthesize the findings

Synthesizing findings is usually part of a workshop with the community and villagers in which results are presented based on point 1 to 4. It is important to communicate in the language of the locals and to avoid technical terms.

The outcome of the procedure is twofold: Firstly, the process provides valuable information for the assessment, map generating and emergency planning process in total. Secondly, it is a strong awareness raising process and training for those who are exposed to the hazards. One objective among others is to identify local disaster managers, who take on responsiblities in the community and villages and act as communicator within the communities/villages itself and in relation to the governmental or district level.

5.7 Flood maps

Maps of actual or potential flood areas are paramount in the assessment and planning process. Flood maps help proof flood risk, verify actual flood damage, indicate changes in flood impact if based on scenarios with and without measures. Different types of flood maps should be developed to support the selection process of proper measures but also to account for emergency preparedness.

With respect to community-based risk assessment, it is mandatory that representatives of communities and villages understand these maps (see 5.6). It is not necessary that they are able to develop them. Understanding means that they are able to identify risk zones and to realize where buildings and infrastructure are affected.

For flood management, four maps are of importance with different information.

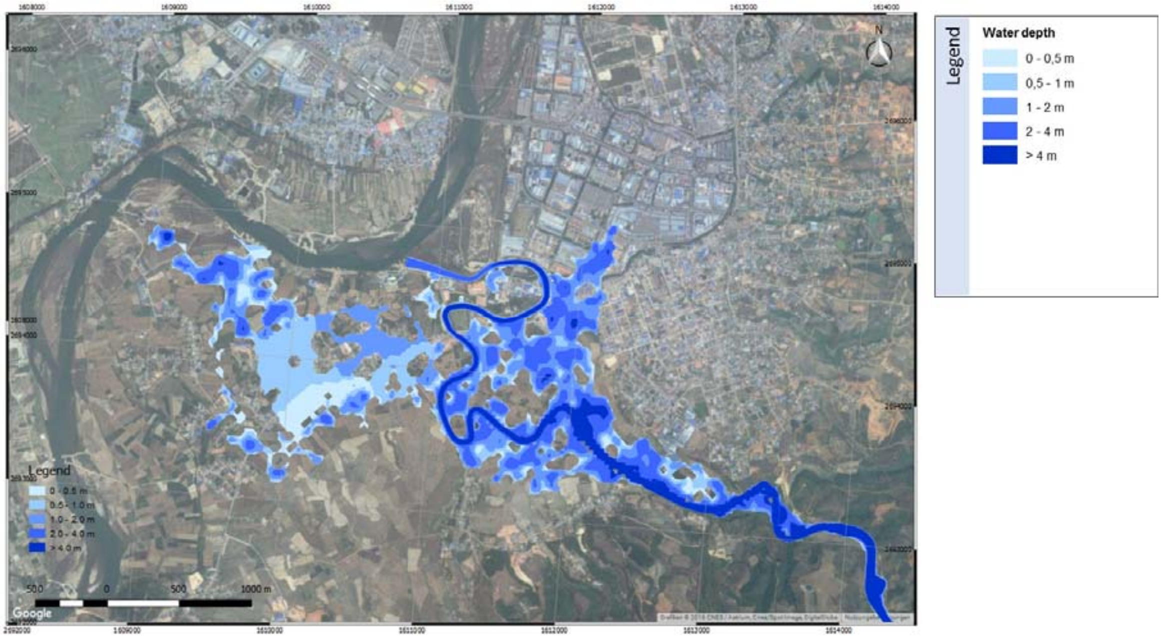


Figure 9: Inundation map with water depth categorised in 5 classes (SYDRO, 2017).

The different classes give a rough estimate about access and potential danger.

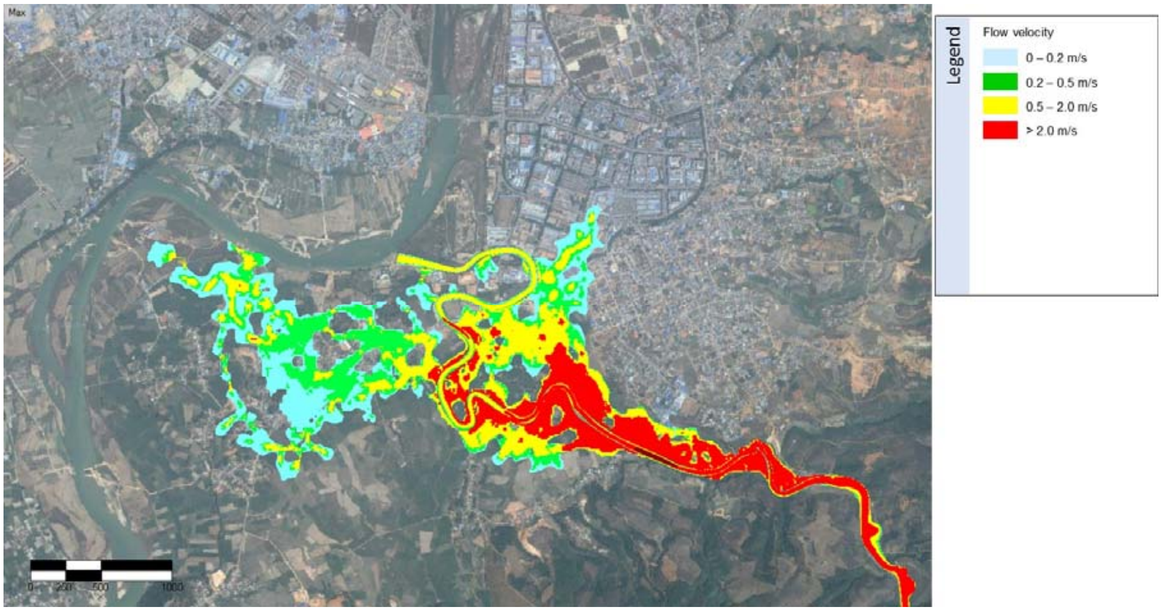


Figure 10: Flow velocity map (SYDRO, 2017)

Flood velocity maps indicate the risk if an area is accessible or not. Inundation in combination with flow velocity allow the generation of impact maps, where the forces are calculated that arise from water depth with flow velocity. This is important for task forces to know where rescue measures are possible and where not.

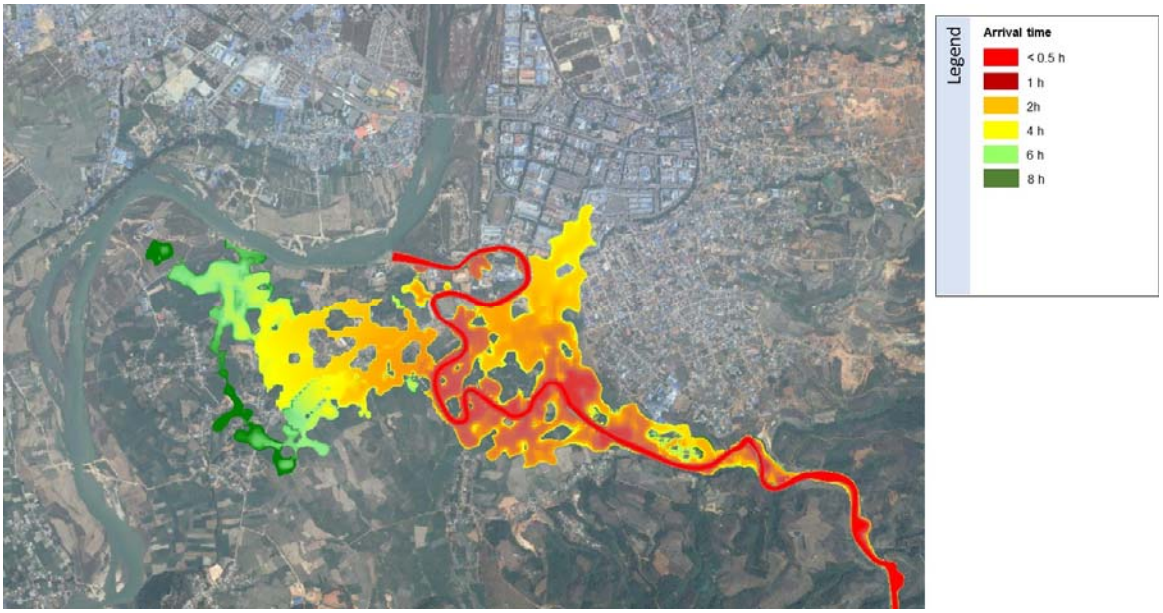


Figure 11: Map of arrival time indicating time for preparation (SYDRO, 2017)

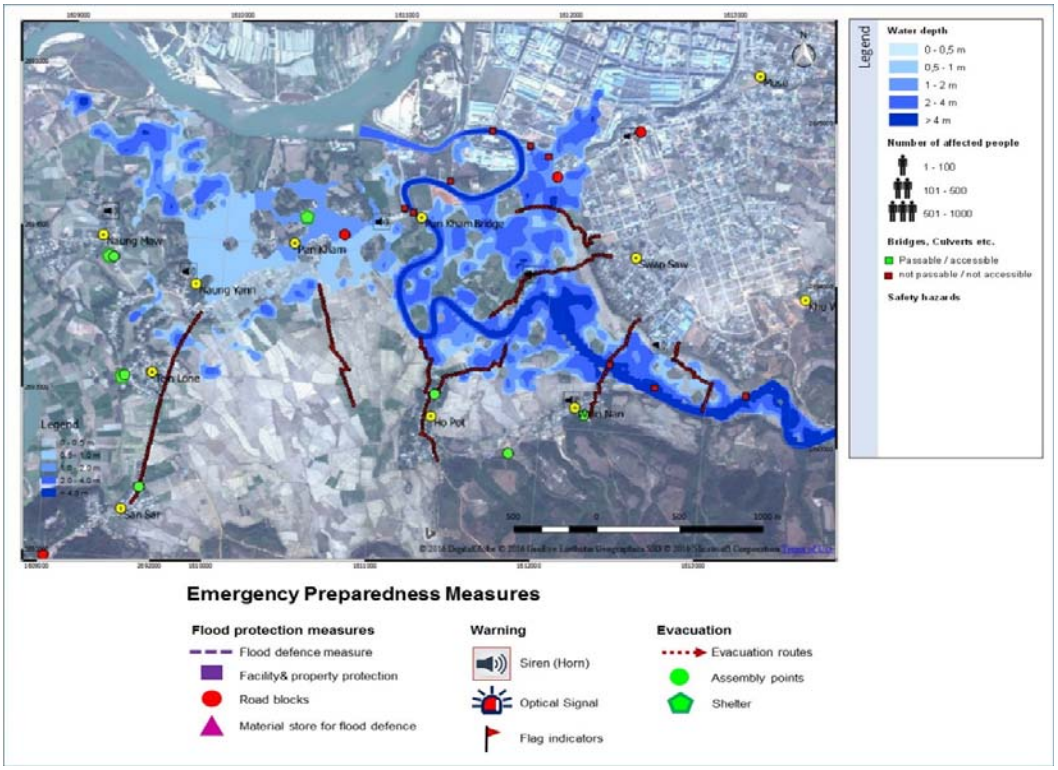
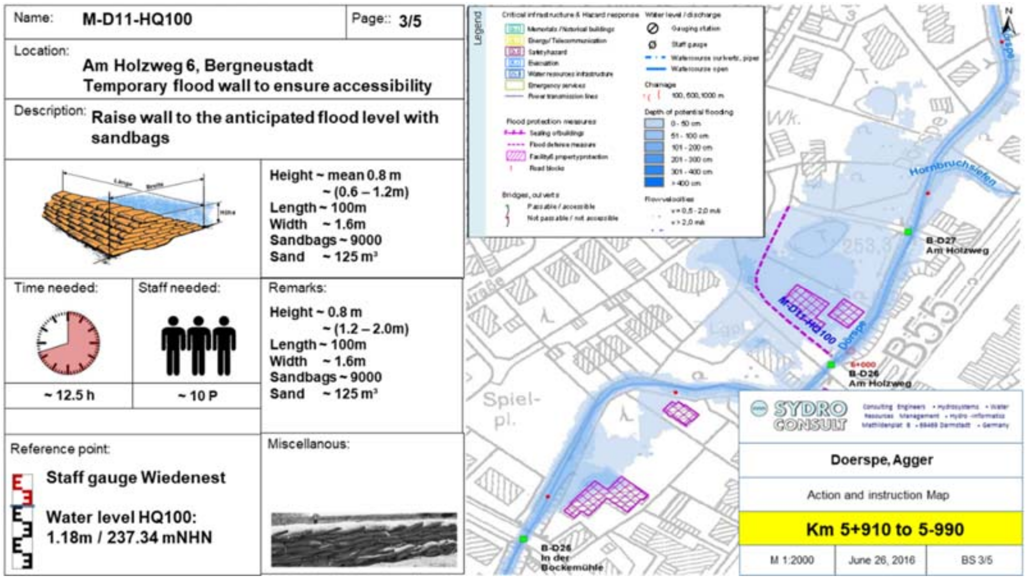


Figure 12: Emergency preparedness map (SYDRO, 2017)

This map ideally contains everything, which is required to organize flood counter measures and evacuation. Bridges, roads and places should be marked as accessible/passable. Meeting points should be added as well as evacuation routes. If these maps are handed over to task forces to be used during actions, they should not be larger than A3.



Name: **M-D11-HQ100**

Page:: **3/5**

Location: **Am Holzweg 6, Bergneustadt**
Temporary flood wall to ensure accessibility

Description: **Raise wall to the anticipated flood level with sandbags**

Height ~ mean 0.8 m
~ (0.6 – 1.2m)
Length ~ 100m
Width ~ 1.6m
Sandbags ~ 9000
Sand ~ 125 m³

Time needed: **~ 12.5 h**

Staff needed: **~ 10 P**

Remarks:
Height ~ 0.8 m
~ (1.2 – 2.0m)
Length ~ 100m
Width ~ 1.6m
Sandbags ~ 9000
Sand ~ 125 m³

Reference point:
Staff gauge Wiedenest
Water level HQ100:
1.18m / 237.34 mNHN

Miscellanous:

Figure 13: Flood action and instruction map (SYDRO, 2010)

If these maps are handed over to task forces to be used during actions, they should not be larger than A3.

5.8 Cost-benefit analysis of flood mitigation measures

Flood protection costs money. Prior to construct measures the expected damage and the costs for the construction must be determined in a cost-benefit analysis. The analysis is positive if costs for the construction of a flood mitigation measure is less than the damage that is prevented through the measure. This means that damage as a result of flooding must be calculated without and with the measure for different return periods of floods. Comparing the *No Measure* scenarios with the *With Measure* scenarios in monetary terms shows whether or not a particular measure is worth constructing.

The first step is to model The *No Measure* scenario. All flood affected locations must be indicated on a map and expected damage must be listed with as much detail as possible. After the catalogue of damage is developed, a monetary value should be determined for each type of loss based on replacement costs. In a second step, the damage inventory is used to support the development of inundation-damage functions, which ideally determine damage as a function of water depth. The following tasks are suggested (adopted and modified from (Mays, 2010)):

1. Identify and categorize each structure in the study area based upon its use and construction
2. Estimate the value of each structure (real estate appraisals, recent sales prices, etc.)
3. Establish the value of the contents of each structure
4. Estimate damage to each structure due to flooding to various water depths using a depth-percent damage function
5. Try to verify the damage function as best as possible with the damage catalogue developed at the beginning
6. Transform each structure’s depth-damage function to a stage-damage function at an index location
7. Aggregate the estimated damage for all structures for floods of different return periods

The result of the procedure is depicted in Figure 14. It enables water resources engineers and planners to compare effects of different measures in terms of damage incurred by flood events. The procedure requires the knowledge of the magnitude and extent of flood events with various return periods. Hydrological and hydraulic modelling is a prerequisite.

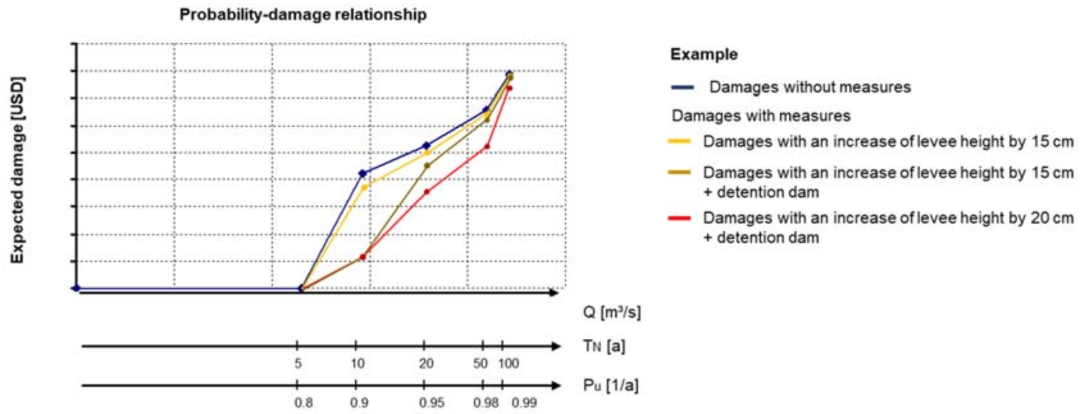


Figure 14: Probability-damage relationship for different scenarios

The next step is to calculate expected damage as a function of return periods for each scenario. The result is a damage cost function for each scenario that accounts for the likelihood of flood events.

The final step is the costs-benefits analysis for each scenario. It rests upon the comparison of benefits (reduction of damage due to the measures) with investment costs (needed to build the measures). Costs for investment are accumulated, benefits are discounted. The accumulation period reflects the time it takes to build the measure, the discounting period reflects the life time of the measure. The scheme in Figure 15 illustrates the timeframe and terms. Parameters are:

- life time of the measure (here = 80 years)
- interest rate
- costs for operation and maintenance (O&M costs)

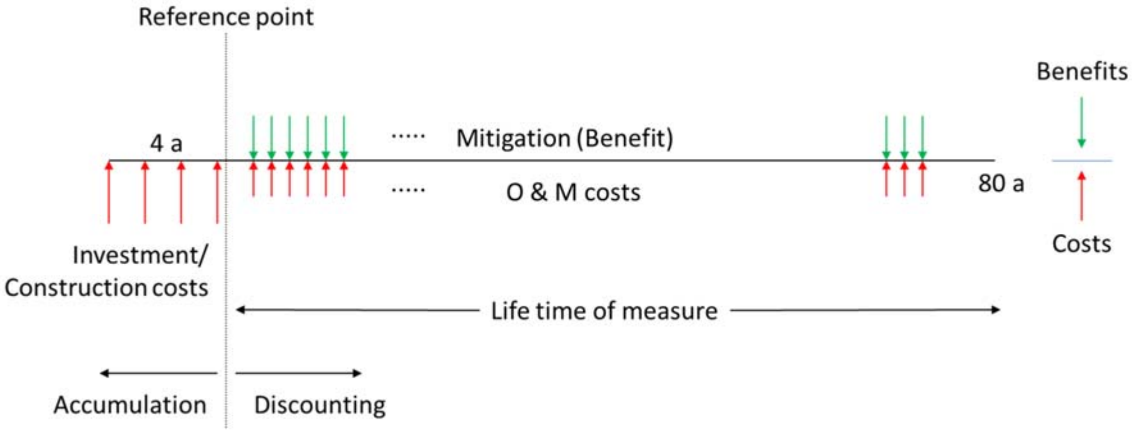


Figure 15: Timeframe and terms of a cost-benefit analysis

A table is provided as an example how to calculate damage as a function of return periods. Column E is the expected damage associated with a flood events of a specific return period (column A). In the example a five years flood does not cause any damages.

A	B	C	D	E	F	G	H
Return period	Pu	Pi	delta Pi	Damage	(S[i-1]+S[i]) / 2	D * F	Sum G
[a]	[1/a]	[1/a]	[1/a]	[10^3 Mio €]	[10^3 Mio €]	[10^3 Mio €/a]	[10^3 Mio €/a]
5	0.8	0.200		-			
7.5	0.85		0.100		0.2126	0.0213	0.0213
10	0.9	0.100		0.4252			
15	0.925		0.050		0.4761	0.0238	0.0451
20	0.95	0.050		0.5270			
35	0.965		0.030		0.5920	0.0178	0.0628
50	0.98	0.020		0.6570			
75	0.985		0.010		0.7226	0.0072	0.0700
100	0.99	0.010		0.7882			
150	0.9925		0.005		0.8538	0.0043	0.0743
200	0.995	0.005		*0.9194*			

In terms of cost effectiveness in rural areas, it is often the best solution to develop measures that contain frequent flood events (2 to 10-year return interval) if these floods cause significant damage. Flood protection against rare and extreme events in high risk areas, e.g. a 100-year flood or more, is so expensive and often associated with negative environmental impacts, that no solution fulfilling the following five criteria can be found:

1. Effectiveness: The solution is effective and will solve the problem
2. Technical feasibility: The solution can be implemented, technology and resources are available
3. Desirability: The solution is wanted, accepted and does not impose undesirable effects.
4. Affordability: Costs for implementing the solution are affordable.
5. Preferability: The solution selected is better or preferred over any other alternatives.

Cost-benefit analysis must be taken with care as not everything can be monetised. Other incommensurable factors might play a role and must be incorporated into the decision-making process.

5.9 Institutional arrangement

Flood management requires strong regulative and executive bodies. Whether or not they should be governmental entities is not discussed in this report. From the perspective of Integrated Water Resources Management, a body taking care of design, monitoring, operation and preparedness planning, could have a structure like the following:

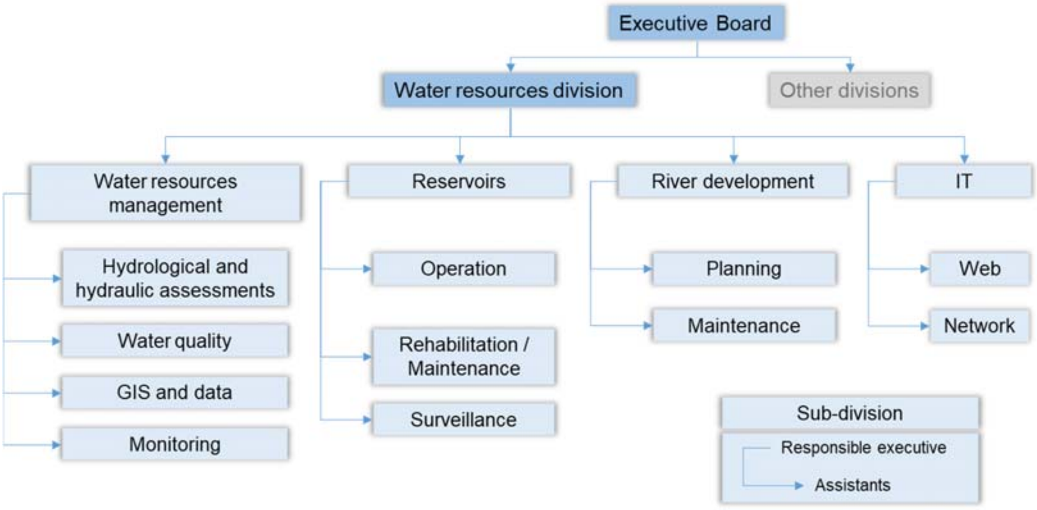


Figure 16: Example of a structure for flood management planning

Other divisions are rural and urban planning, agriculture, maybe transportation and traffic, since all of them are affected by flood events and in turn give rise to damages due to floods in one way or another. Ideally, an executive board oversees all divisions and coordinates flood management plans among the sectors. In doing so, it should be possible to ensure urban planning is aware of flood prone areas and agriculture is aware of frequency of inundation so that the departments are able to account for flood risks in their planning process. Unfortunately, the reality often shows a different picture and urban and agricultural sectors make plans without considering flood risks. The result is often a costly flood protection programme.

The example above reflects a typical structure of river basin associations in Germany, UK, Canada and the US. Their role is to coordinate the implementation of flood management plans for a basin. They perform flood related assessments and are responsible for implementation, operation and maintenance. They are subject to authorities and must report to them.

The authorities itself set forth general principles on flood protection levels, develop priority plans, setting out guidelines to ensure homogeneous procedures and oversee and guide all actions. The authorities are responsible for quality control and for collecting, providing access and archiving all maps and plans.

There should be one governmental entity that is responsible for the implementation. They should determine

- technical and style guides to ensure homogeneous maps and quality
- methods for assessments
- time frames for implementation

5.10 Legal prerequisites

The responsible entity described in Section 5.9 should have the mandate to perform and enforce the tasks. A legal framework must be in place to enable this process. It is beyond the scope of this document to shape legal arrangements necessary to facilitate flood risk management plans. However, there is one point that deserves full attention and is prone to legal disputes and conflicts: Encroachment of flood prone areas. Without the political willingness to prevent controlled or uncontrolled settlements being built in flood prone areas, authorities, flood manager and water resource engineers cannot safeguard flood plains. It is clear that the extent of flood-prone areas, whatever return period is applied, will affect existing buildings, properties and impacts on future urban or rural development plans. Resistance from different stakeholders can be expected. As such, the legal framework must be very clear in that municipalities must not be allowed to develop residential or industrial areas within flood-prone zones and must pay special attention to already existing infrastructure and buildings. If municipality proactively allowed or even encouraged the construction of buildings in these areas in the past, compensation will be required when these buildings are damaged due to a flood. From experience in EU countries subject to EUFD, this is the tricky part of flood risk management.

5.11 Reservoir operation

Reservoir operation should be a component within a flood management plan. Flood buffers and releases must be included in flood mitigation plans and during emergencies. It is mandatory to communicate with reservoir operators and to be clear what needs to be done and when. Therefore, procedures must be developed as part of flood prevention and mitigation strategies. Triggers that launch actions should be derived and assigned to warning levels. Triggers have to be carefully designed based on the individual conditions of a dam site and the related catchment. Utilization of combinations of triggers may be advisable for optimum decision making. In general, triggers that can be used for floods including, but are not limited to:

- Inflow to the reservoir
- Rate of reservoir water level rise or fall
- Expected inflow volume based on gauge measurements
- Upstream gauge measurements
- Upstream meteorological observations
- Overflow depth over spillway
- Seepage water quantity

Considering the multi-purpose tasks a reservoir often needs to fulfil, the trade-off between the needs for water storage and flood retention is critical. Reservoirs often generate direct economic benefits, which can be increased with maximizing impoundment levels, i.e. the volume of water stored. On the other hand, flood retention with its benefit of potentially reducing flood damage, requires storage capacity that cannot be used for direct benefits. This must be balanced and determined in a flood management plan. It is important to take the accuracy of readings into account when defining triggers.

5.12 Emergency Preparedness Plans (EPP)

An EPP is a fine-grained plan that helps to deal with hazards. Its task is to assemble relevant information in a concise form and to be clear about emergency identification, notification and preventive actions. A possible structure based on international best practice for dams and flood operation is shown below. It stems from practical work in Germany, Swaziland and Myanmar.

1 DOCUMENT INFORMATION

1.1 VISION AND REVIEW

1.2 PURPOSE OF DOCUMENT

1.3 HOW TO USE THIS EMERGENCY PREPAREDNESS PLAN (EPP):

1.4 NOTIFICATION FLOWCHARTS

2 THE CATCHMENT AREA

2.1 GENERAL INFORMATION

2.2 DESCRIPTION OF HAZARDS THIS EPP IS MADE FOR

2.3 ACCESS TO THE RISK AREAS

2.4 DESCRIPTION OF THE EXPOSED AREAS

3 EMERGENCY RESPONSE PROCESS

3.1 EMERGENCY IDENTIFICATION, EVALUATION AND CLASSIFICATION

3.2 NOTIFICATION FLOWCHARTS AND COMMUNICATION

3.3 EMERGENCY ACTIONS

4 PREPAREDNESS AND PREVENTIVE ACTIONS

4.1 STANDARD MONITORING PROCEDURES

4.2 SURVEILLANCE IN THE WATERSHED

4.3 POWER FAILURE AND ALTERNATIVES

4.4 ADVERSE WEATHER

4.5 ALTERNATIVE SYSTEM OF COMMUNICATION

4.6 MATERIAL AND EQUIPMENT

4.7 TRAINING

5 HAZARD MAPS, RISK MAPS, ACTION MAPS

6 APPENDICES

6.1 GENERAL RESPONSIBILITIES

6.2 METEOROLOGY

6.3 HYDROLOGY AND DESIGN

6.4 MONITORING OPERATIONS

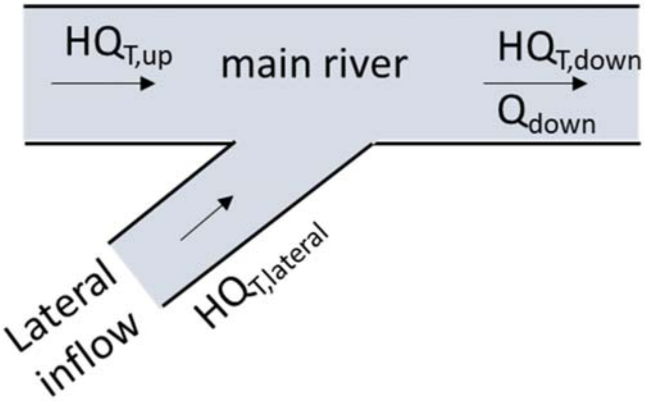
6.5 INFORMATION AND DATA ACCESS

6 ASSESSING FLOODS - EXAMPLES OF CRITICAL ISSUES

A set of examples is provided below pinpointing issues and sensitive aspects when floods are assessed and flood maps and flood risk maps are generated. All examples stem from (SYDRO Consult, 2019)

6.1 Flow and return periods below confluences

When considering the 100 year-flow of a stream that flows into a larger stream, how much flow should be assumed in the receiving stream?



A simple but reasonable approach is to relate the flood peaks of the main river and the tributary according to the formula below. This formula is called *confluence formula* and is widely used in Germany (Bender, 2015).

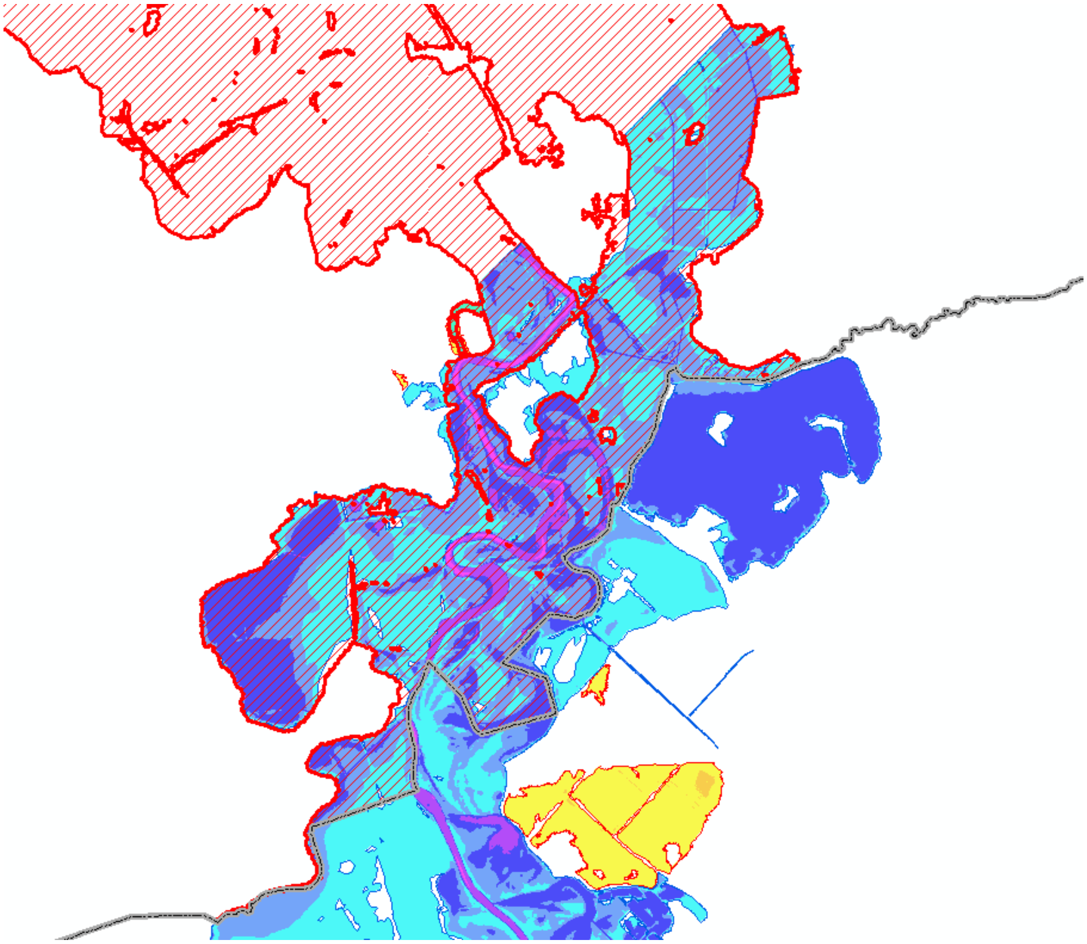
$$Q_{down} = \frac{ln(HQ_{T,lateral})}{ln(HQ_{T,main\ river})} \cdot HQ_{T,main\ river}$$

More complex approaches require sophisticated multi-variate statistical methods.

6.2 Conformity of results across borders and studies

Flood assessments must be consistent even when a river crosses a border. It also worth mentioning that different studies conducted by different authors must be homogeneous in terms of flood extent and flood depth.

The example below shows the flood extent for a 100-year flood in Germany (blue) which fits to the flood extent assessed in the Netherlands (red).

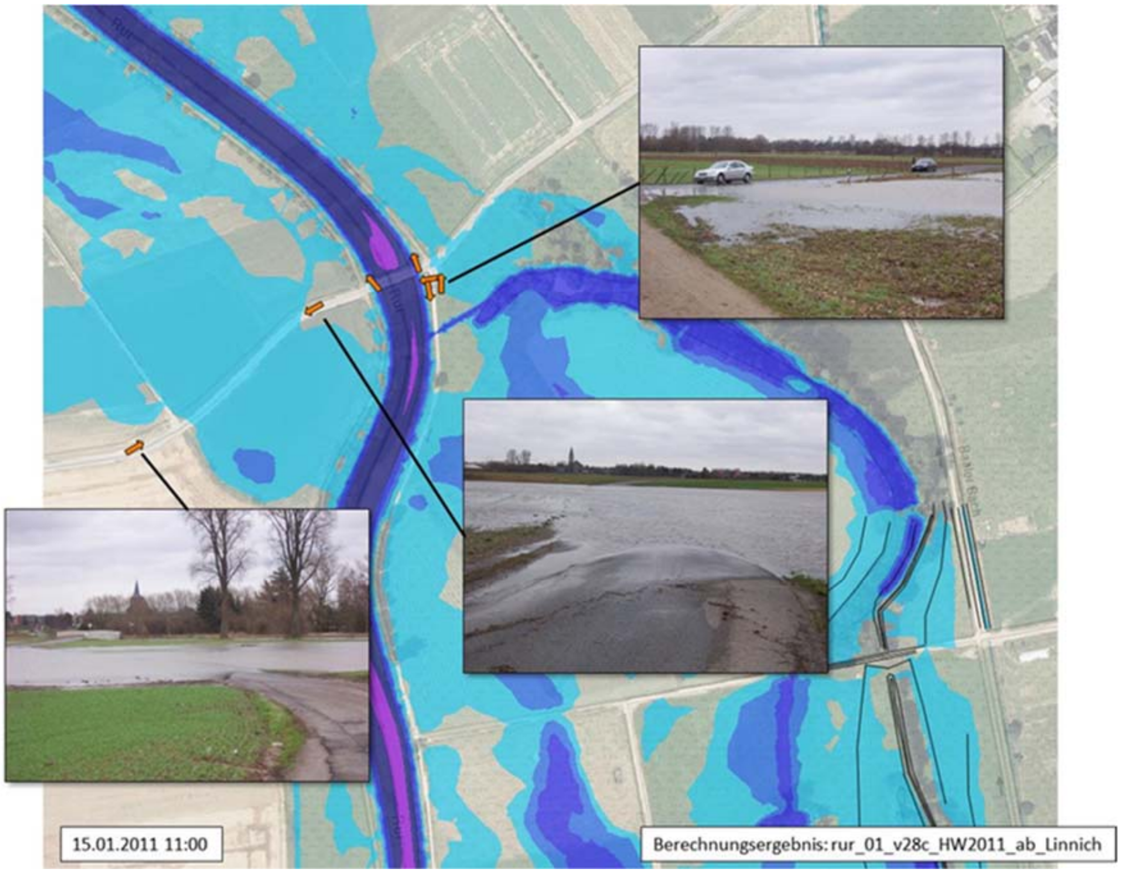


6.3 Details and quality of data

Small errors in details like culverts and dyke elevations may affect the extent of inundation significantly. Data availability can be a key issue! In the example below, water can flow through the culvert and can reach the settlement during extreme events. If the culvert is not identified and a closed structure is assumed, flood risk maps will not show the exposure of the settlement. Unexpected flooding of the residential area may be the result.

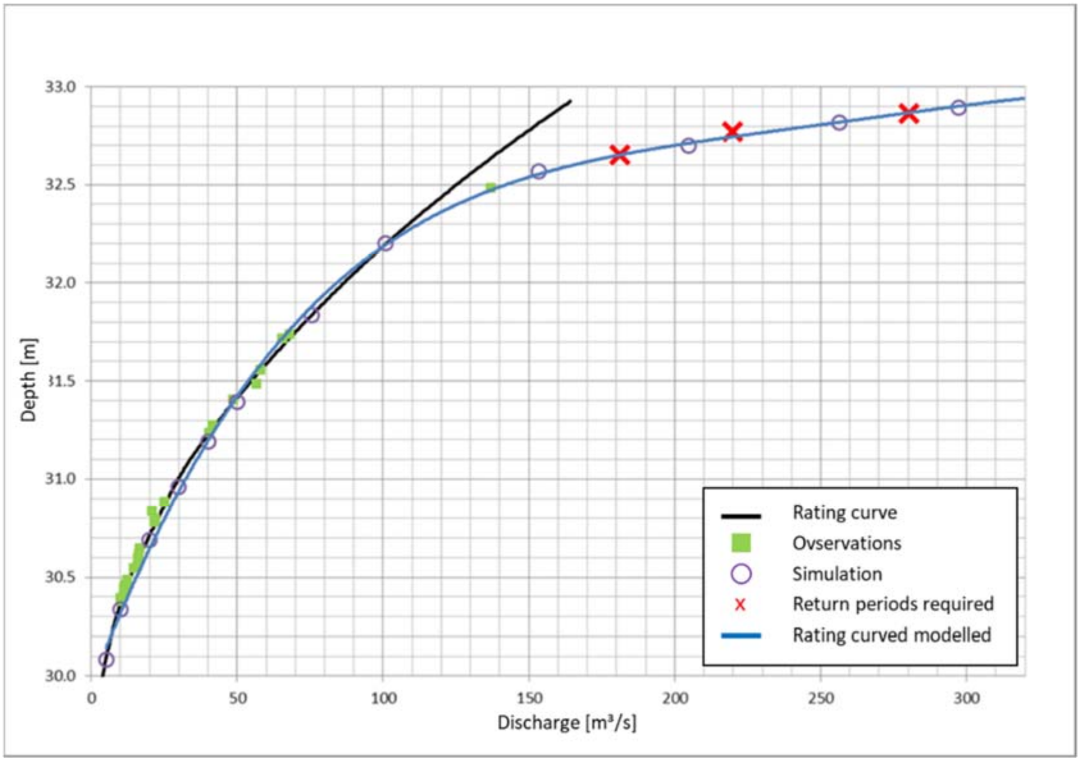
6.4 Match observations with calculations

One key problem is often insufficient data for calibration. The value of recording flood events while they happen is often underestimated. Field work during flood events is difficult but pays off.



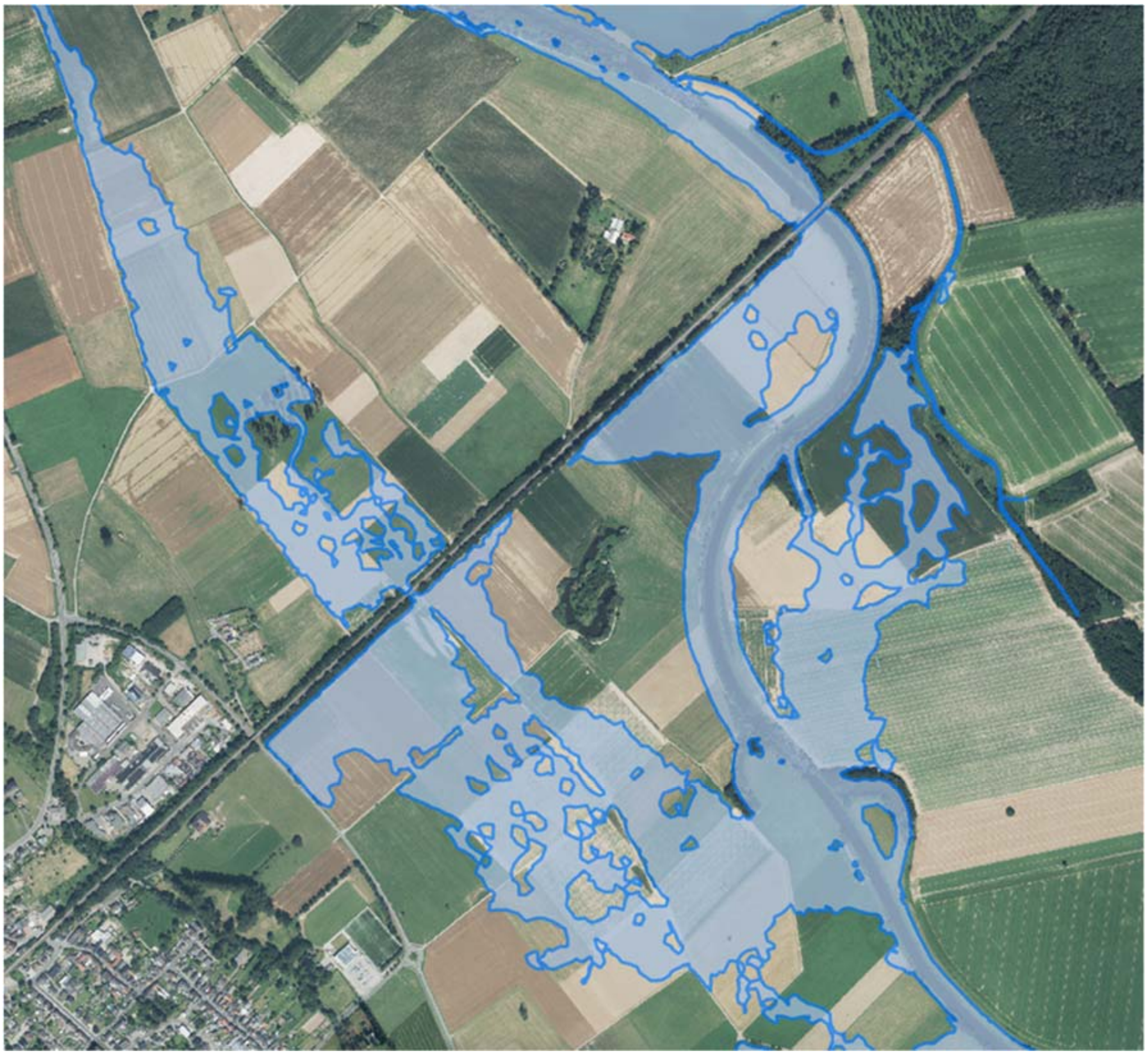
6.5 Errors/uncertainties in rating curves

Attention must be paid to rating curves. Rating curves must be verified by observations. However, observations usually do not cover the range of required return periods. A hydraulic calculation often helps avoid errors due to unverified rating curves.



6.6 Identification of flow paths and retention

Estimation of retention and flow paths in flood plains is only really a problem if no 2D-simulations is carried out. The complex flow pattern can be assessed with a 2D modelling approach.



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Annex A.1 List of Governmental and Regional Organisations with involvement in DRM practice in Georgia

General

- Patrol
- State Security Special Service
- Emergency Situations Agency
- Crisis Management Board
- Department of Regional Relations with Government Administration
- 112 Firefighter Department
- Road Department
- Tbilisi City Hall
- Chancellery of the Government
- LTD Energy-Pro-Georgia

Tbilisi Municipalities

- Administration - ISANI
- Administration - Mtatsminda
- Administration - Saburtalo
- Administration - Chughureti
- Administration - Vake
- Administration - Gldani
- Administration - Samgori
- Administration - Krtsanisi

Provinces, Municipalities

- Mtskheta City Hall
- Administration of Mtskheta City
- Mstkheta – Mtianeti Province
- Kazbegi Municipality Administration
- Dusheti Municipality Administration
- Tianeti Municipality Administration
- Akhalgori Municipality Administration
- Mstkheta Local Assembly
- Lazbegi Local Assembly
- Dusheti Local Assembly
- Kakheti Province Administration
- Imeti Province Administration
- Guria Province Administration
- Shida Kartli Province Administration
- Kakheti Province Administration
- Amstkhe-Javakheti Province Administration
- Racha-Leckhumi Province Administration
- Samtskhe-Javakheti Local Assembly
- Akhaltsikhe City Hall

- Adigeni City Hall
- Aspindza Local Assembly
- Aspindza Local Assembly
- Akhalkalaqi Local Assembly
- Borjomi Local Assembly
- Ninotsminda Local Assembly
- Samegrelo-Zemo Svaneti Province Administration
- Zugdidi City Hall
- Khobi Local Assembly
- Chkhorotsku Local Assembly
- Senaki Local Assembly
- Absha Local Assembly
- Martvili Local Assembly
- Tsalendjikha Local Assembly
- Poti City Hall
- Mestia Local Assembly
- Kiutaisi City Hall
- Tskaltubo Local Assembly
- Samtredia Local Assembly
- Khoni Local Assembly
- Vani Local Assembly
- Bagdati Local Assembly
- Terjola Local Assembly
- Zestaponi Local Assembly
- Tkibuli Local Assembly
- Chiatura Local Assembly
- Sachkhere Local Assembly
- Kharagauli Local Assembly
- Signaghi Local Assembly
- Akhmeta Local Assembly
- Telavi Local Assembly
- Gurjaani Local Assembly
- Lanchkhuti Local Assembly
- Chokhatauri Local Assembly
- Ozurgeti City Hall
- Dedoflistskaro Local Assembly and Administration Units
- Zemo Machkhaani Administration Units
- Sagarejo Local Assembly
- Kvareli Local Assembly
- Shida Kartli Province Administration
- Gori City Hall
- Quareli Local Assembly
- Kaspi City Hall
- Khashuri Local Assembly
- Lagodekhi Local Assembly
- Qvemo Kartli Province Administration

- Bolnisi Local Assembly
- Gardabani Local Assembly
- Dmanisi Local Assembly
- Tetritskaro Local Assembly
- Marneuli Local Assembly
- Tsalka Local Assembly
- Rustavi City Hall

Ministries

- Ministry of Justice of Georgia
- National Agency of Public Registry
- Ministry of Education of Georgia
- Ministry of Sport of Georgia
- Ministry of Internal Affairs of Georgia
- Ministry of Refugees of Georgia
- Ministry of Infrastructure of Georgia
- Ministry of Health of Georgia
- Ministry of Agriculture of Georgia
- Deputy of Head of Agriculture Minister of Georgia
- Marine-Rescue Coordination Centre of the Ministry of Economy of Georgia
- Department of Meteorology, Air Navigation Services of the Ministry of Economy of Georgia
- Ministry of Environmental and Natural Resources Protection of Georgia