Water supply and demand management

Flood Risk Management

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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 - Azerbaijan

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

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ABBREVIATIONS

ANAS	Azerbaijan National Academy of Sciences
AWM	Amelioration and Water Management
DEM	Digital Elevation Model
DEMP	Disaster Emergency Management Plans
DRM	Disater Risk Management
DRR	Disaster Risk Reduction
EPP	Emergency Preparedness Plan
EUFD	European Commission Floods Directive
EUWFD	European Commission Water Framework Directive
FRMP	Flood Risk Management Plan
MENR	Ministry of Ecology and Natural Resources
MES	Ministry of Emergency Situations
OJSC	Open Joint-Stock Company
UNDP	United Nations Development Program

1 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.

Azerbaijan faces two distinct flood types: the mountainous regions with steep and narrow valleys are subject to flash flood events with intensive flow, fast rising and falling hydrographs. The lowlands, however, are prone to long lasting floods inundating large areas with insufficient drainage hampered due to the flat terrain. Azerbaijan is surrounded by high mountains. The Greater Caucasus stretches along the border to Russia in the north and north-west and the Lesser Caucasus builds the south-west border covering the area of Nagorno-Karabagh. Flash floods, mudflows, landslides and avalanches are the typical hazards in the mountains, while riverine flood events affect the low-lying land up to the shoreline of the Caspian Sea. Climate change contributes adversely due to rising temperatures making permafrost at high altitudes unfreeze and causing irregular rainfall patterns, more landslides, mudflows and flash floods.

The riverine floods in the plain pose a serios risk to the agricultural sector. However, riverine floods allow enough time for preparations and forecasting is achievable with a good observation network, the utilisation of remote sensing information and operational hydrological models with early warning systems.

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

2 RIVERINE FLOODS AND FLASH FLOODS

2.1 Flash floods and mudflows

Flash floods 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. D is more or less restricted to the valleys surrounded by very high mountains.

Flash flood events occur in Azerbaijan in the Greater and Lesser Caucasus, which is a tectonically and seismically active region. The difference in altitude from the Caspian Sea level (-28 m) to the Greater Caucasus (> 4,000 m) give birth to different climate zones, of which the rugged terrain of the mountains faces regular torrential rain and extreme snow melt events. Although less populated than the low-lying land and plains that form the rest of the country, floods in the mountainous areas cause an average loss of approximately 18 million USD a year, of which 80 % occurs in the Sheki-Zagatala region, where rural and urban development is comparatively higher than in other mountainous regions. The location of the Sheki-Zagatala is depicted in Error: Reference source not found.

Flash floods events in Azerbaijan between 2000 and 2010 were documented through the National Hydrometeorology Department of the Republic of Azerbaijan and the Ministry of Emergency Situations.

Table 1: Flash flood induced incidents in Azerbaijan 2000 – 2010 (Hasan Zade, 2019)

Date	Region	River	Impact
22.04.2000	Nehram	-	Agricultural areas, settlements, 5 buildings destroyed
21.09.2000	Shahbuz	Kukuchay	Settlements and infrastructure affected
27.08.2002	Shaki	Kishchay	Water supply infrastructure damaged, 4 buildings destroyed
19.07.2003	Balakan	Mazımchay	Urban water supply infrastructure damaged, several settlements flooded
10.07.2004	Shaki	Kishchay	Water supply damaged, 5 buildings destroyed
10.07.2004	Balakan	Mazımchay	Farms and settlements affected, one bridge collapsed
07.09.2004	Zagatala	Talachay	Unknown number of Livestock died, 8 buildings destroyed
06.06.2005	Shaki	Shinchay	Urban areas flooded
23.05.2006	Shaki	Kungutchay	2 fatalities, 3 houses destroyed.
01.11.2007	Aghsu	Aghsuchay	5 houses in the village of Kelabayli, 4 in Beyimli village, 1 in Gursulu village destroyed
2008	Dashkasan	-	One fatality, 3 buildings destroyed, urban areas flooded
2008	Xachmaz	Gudyalchay, Alpanchay, Garabashchay	One fatality, 24 buildings destroyed
16.06.2008	Zagatala	-	Urban areas in Gazangul and Micgar villages damaged.
21.07.2008	Shaki	Kishchay	15 livestock lost, 34 buildings destroyed
21.08.2009	Shaki	Kishchay	Settlements damaged, one bridge collapsed
2009	Guba	Shabranchay	Administrative-territorial unit in Chichi and Zeyva villages destroyed, livestock killed, 5 bridges destroyed
06.08.2009	Tovuz	-	9 buildins were destroyed
24.04.2010	Balakan	Balakanchay, Mazımchay,	Settlements flooded

Date	Region	River	Impact
		Katekhchay	
25.04.2010	Tartar	Tartarchay	12 buildings destroyed
03.04.2010	Zagatala	Garachay	Chobankol village partly flooded
17.05.2010	Dashkasan	Shamkirchay	Settlements in Dashkasan, Khoshbulag, Amirvar, Gushchu, Zeylik , partly flooded and infrastructure damaged.
2010	Tovuz	Zayamchay	Agricultural areas destroyed, flood response and emergency response measures not effectively implemented
29.05.2010	Gakh	Gapichay	50 people injured, 50 buildings damaged
16.05.2010	Ismailli	Goychay,Ahohchay	Mudflows occurred in Ashugbayramli, Kalinchaq, Isitisu, Chaygovushan, 22 buildings flooded, agricultural land destroyed
18.05.2010	Shaki	Garasuchay, Boyukgobu	Bash Zeyzid and Varazat villages completely flooded, one bridge destroyed
15.07.2010	Shaki	Gurcanachay	Power and gas supply damaged, urban areas flooded
11.09.2010	Astara	Astarachay	Rudekaran village flooded, roads and evacuation routes blocked
11.09.2010	Lankaran	Lankaranchay	Tangar, Upper Nyuddi and Asha villages flooded, one bridge destroyed, livestock killed

The flash flood prone areas coincide with the area with highest runoff.

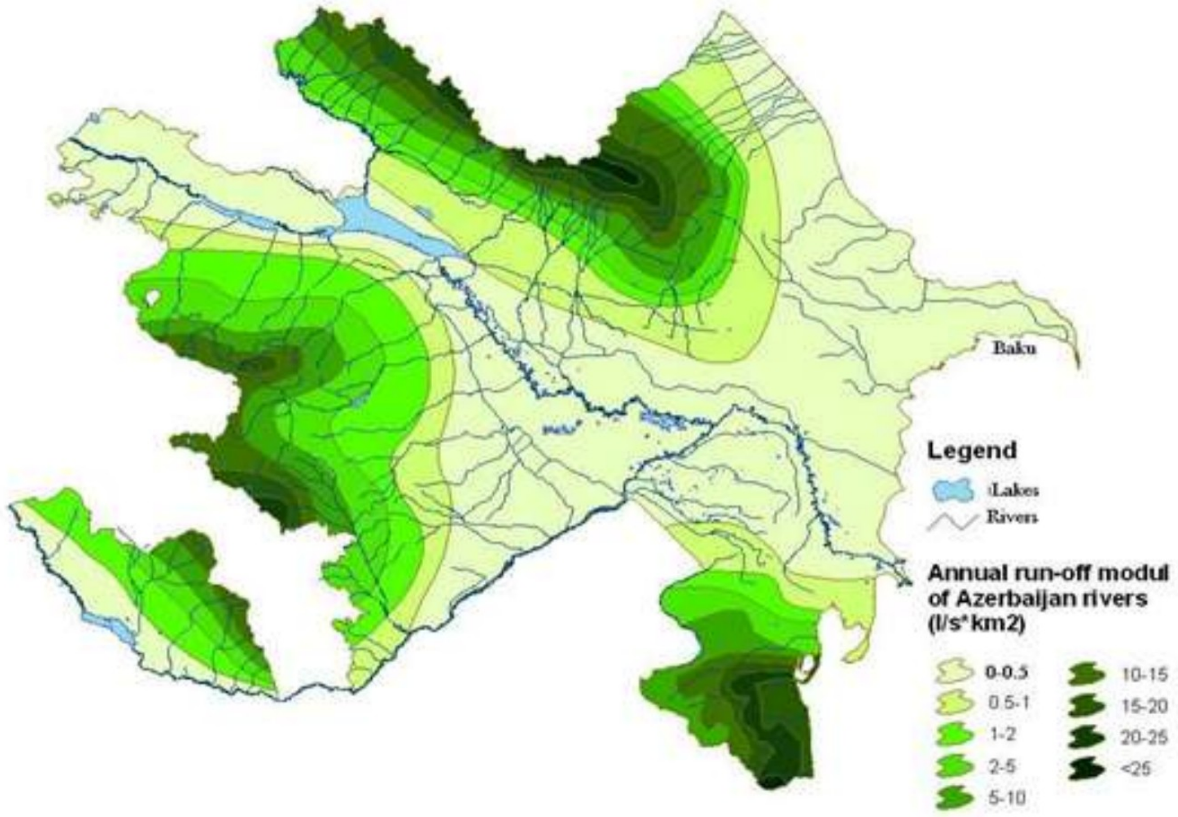


Figure 1: Runoff map of Azerbaijan (Verdiyev, 2012)

2.2 Fluvial or riverine floods

Fluvial or riverine flooding requires excessive rainfall over an extended period of time to form discharge, which exceeds the capacity of a river bed. Riverine flooding is more attributable to the low-lying land and plains in Azerbaijan where braided rivers with low gradients and hampered drainage overflow their banks and flood adjacent plains. The flood plains of Kura and Aras River are prone to this kind of hazard. Events are characterized by large flood volumes with a slow onset compared to flash floods. Generally, the combination of snow in the headwater areas, warm temperatures and lasting rain in the headwater areas is mainly responsible for this hazard type. Riverine flooding cannot be avoided and will occur more or less regularly. It is a mistake to believe that 100% flood protection is possible, but there is a chance to mitigate impacts by integrating flood risk into urban/land use planning in conjunction with state-of-the-art design of flood mitigation measures, sound ecosystems, good reservoir operation, well-functioning hydrological observation network and ready-to-use emergency preparedness plans.

The typical season for flood events is between April to October when snow melt from the mountains occurs and coincides with high water in the Kura and/or Aras River.

At lower reaches of the Kura and Aras rivers, the river bed is located mostly above surrounding areas. Accumulation of sediment has reduced cross-sections and water transport capacity has decreased over the years with the consequence of higher water levels.

Information about floods in the Kura and Aras rivers date back to the 19th century. Devastating flood are reported for 1829, 1850, 1868, 1896 for the Kura River and 1868, 1879, 1885, 1896 for the Aras River. In the 20th century, flow records indicate disastrous floods of the Kura in 1915, 1916, 1928, 1936, 1942, 1944, 1946, 1952 and in the Aras River in 1936, 1938, 1946, 1951, 1963, 1968, 1969. During the catastrophic floods of 1858 and 1896 the Aras River changed its bed.

Between 1900 and 1953, flood events took place almost every year at the lower reaches of the Kura and Aras rivers. In the wake of the construction of Mingachevir and Shamkir water reservoirs and the Aras Dam, the number of flood disasters dropped sharply after 1953. However, flood events that took place in 2003, 2006 and 2010 showed a larger scale and caused major economic losses.

It is reported that economic damages due to floods have increased in recent years. A number of root causes might be responsible:

- Flood plain encroachment
  urban and agricultural activities might have increased and use areas prone to flooding
- River maintenance
  as indicated above, transport capacity is less than it was before, giving rise to higher water levels
- Design code for flood protection measures
  could be a hydrological problem such as the underestimation of peak flow rates or the selected return intervals for design is too low when designing flood protection measures like levees

These man-made root causes are overlaid by climate change induced problems such as higher rainfall intensities, reduction of water storage in glaciers due to higher temperatures, to mention two aspects.

3 CURRENT PRACTICE IN FLOOD RISK MANAGEMENT

3.1 The major governmental bodies with respect to flood risk management

The mainly responsible governmental bodies related to flood risk management are:

- Ministry of Ecology and Natural Resources (MENR)
- Amelioration and Water Management Open Joint-Stock Company (AWM OJSC)
- Ministry of Emergency Situations (MES)
- Azerbaijan National Academy of Sciences (ANAS)

MENR and AWM are mainly responsible for the preparation, planning and implementation of measures. They are also obliged to run and maintain a hydrological monitoring network. ANAS is the body providing scientific background and conducts fundamental research with respect to hydro-meteorology and water resources. MES is the entity for emergency response and coordination during emergencies.

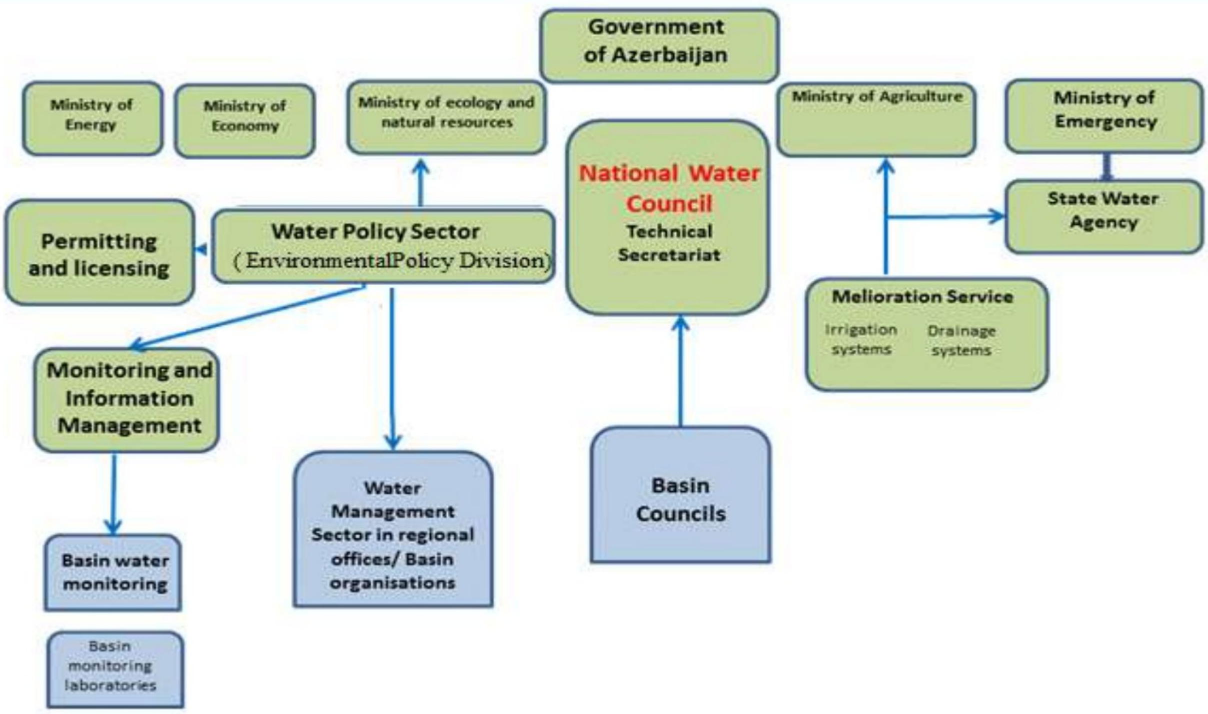


Figure 2: Institutional settings with respect to the water sector in Azerbaijan, source: (Abdulhasanov & Efimova, 2018).

3.2 Flood risk management strategy

Azerbaijan presented its national water strategy during an workshop of the EU Water Initiative 2012 (Verdiyev, 2012) and in 2018 during the 7th meeting of the steering committee of the national policy dialogue in the water sector of Azerbaijan (Abdulhasanov & Efimova, 2018).

Flood risk management is summarized as the following, adopted from (Verdiyev, 2012) and confirmed in (Hasan Zade, 2019):

Design and Planning:

- Prepare and implement flood and other water- induced disaster management policy and plan

- Undertake hydrological modelling and flood risk mapping of the most crucial river systems
- Conduct risk/vulnerability mapping and zoning
- Determine possible methods of flood protection and select appropriate sites for disaster prevention actions
- Implement disaster reduction/mitigation measures. Construct needed protection infrastructure
- Implement a legislation on land use and construction that prevents planning and construction of settlements in flood risk areas

Monitoring:

- Install automatic stage recorders at strategic sites on flood-prone areas to record flood levels
- Estimate flood sizes, in particular peak floods

Operation and Preparedness

- Strengthen institutional set-up and capacity
- Carry out periodic safety checks, at least once in three years, on existing water systems
- Establish safety regulations for major water structures
- Strengthen the disaster networking and information system
- Establish disaster relief and rehabilitation systems
- Ensure appropriate and timely maintenance of flood control structures

(Abdulhasanov & Efimova, 2018) mentions an institutional reform as part of the national water strategy that will also impact on flood risk management. This reform follows the river basin approach and aims to adopt principles of the EU WFD and EU FD. The water sector is subdivided in a national level and a basin level with different task.

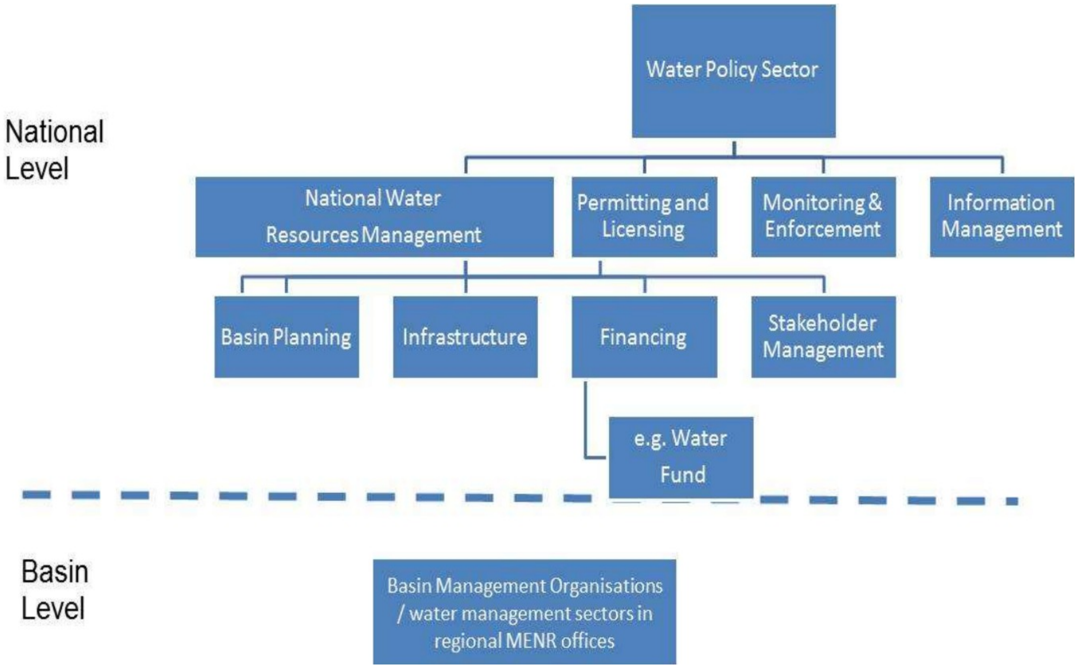


Figure 3: Water policy sector reform, source (Abdulhasanov & Efimova, 2018)

The main body that acts at both levels is MENR with the headquarter in Baku and regional offices in the basins.

According to (Abdulhasanov & Efimova, 2018), river basin districts and sub-basins will be formed as shown in Figure 4 and Table 2.

Table 2: Basin and sub-basin districts according to (Abdulhasanov & Efimova, 2018)

Area	**Basin districts**	International river basin	Sub basin
{km²]			
13375	Northern-Eastern Slope Greater Caucasus	Samur (Russia)	
3515	Lankaran	Astara (Iran)	Caspian Sea
44865	Lower Kura-Araz	Araz (Iran, Armenia)	Kura (Caspian Sea)
19345	Kura Upper Mingechavir Reservoir	Kura (Georgia) Khrami (Georgia) Qabirr (Georgia) Jogazchay (Armenia) Agstafachay (Armenia) Akhinjachay (Armenia) Arpachay (Armenia)	Mingecharvir Reservoir
5500	Araz-Nakhchivan	Araz (Turkey, Iran, Armenia)	Araz

Area	**Sub basins**	Basin district number	International river basin	Sub basin
km²				
7125	Guba-Khachmaz	1	Samur (Russia)	
6250	Absheron	1		Caspian Sea
16820	Shirvan	4		Caspian Sea
11795	Kura-Araz confluence	4		Kura
3515	Lankaran	2	Astara (Iran)	Caspian Sea
7610	Lower Araz basin	4	Araz (Iran, Armenia) Okhchuchay (Armenia) Bargushad (Armenia)	Araz (Kura)
8640	Lower Kura (Left tributaries)	4		Kura
13100	Ganja-Gazakh (Central Kura)	3	Kura (Georgia) Khrami (Georgia) Qabirr (Georgia) Jogazchay (Armenia) Agstafachay (Armenia) Akhinjachay (Armenia) Tovuzchay (Armenia)	Kura
6245	Ganikh (AZ section)	3	Ganikh (Georgia)	Ganikh (Kura)
5500	Nakchivan	5	Araz (Turkey, Iran, Armenia) Arpachay (Armenia)	Araz (Kura)

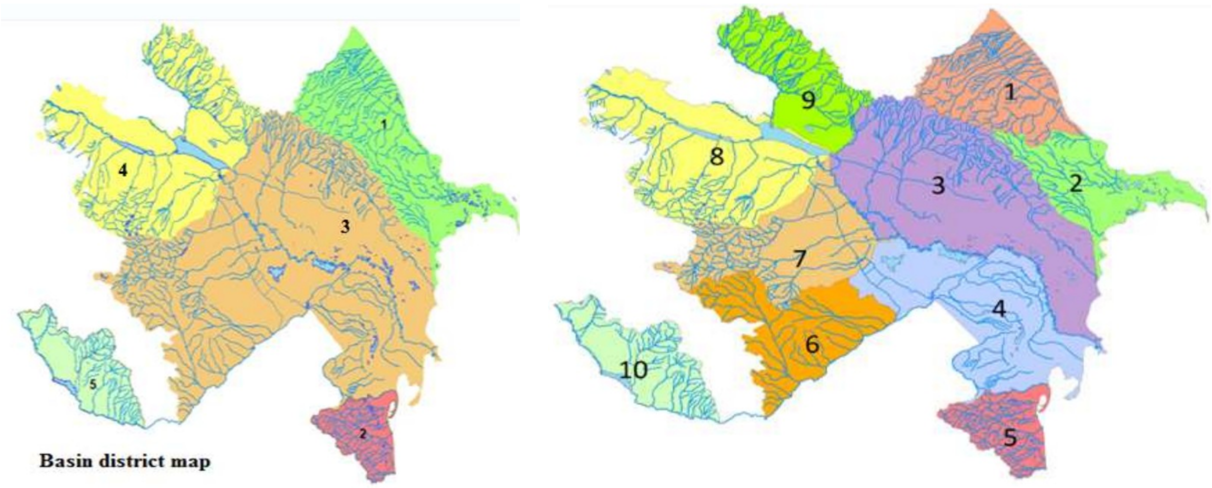


Figure 4: River basin districts and sub-basins, source (Abdulhasanov & Efimova, 2018)

Currently, Azerbaijan is administratively subdivided into so-called economic regions. The economic regions and the sub-basins partly match.

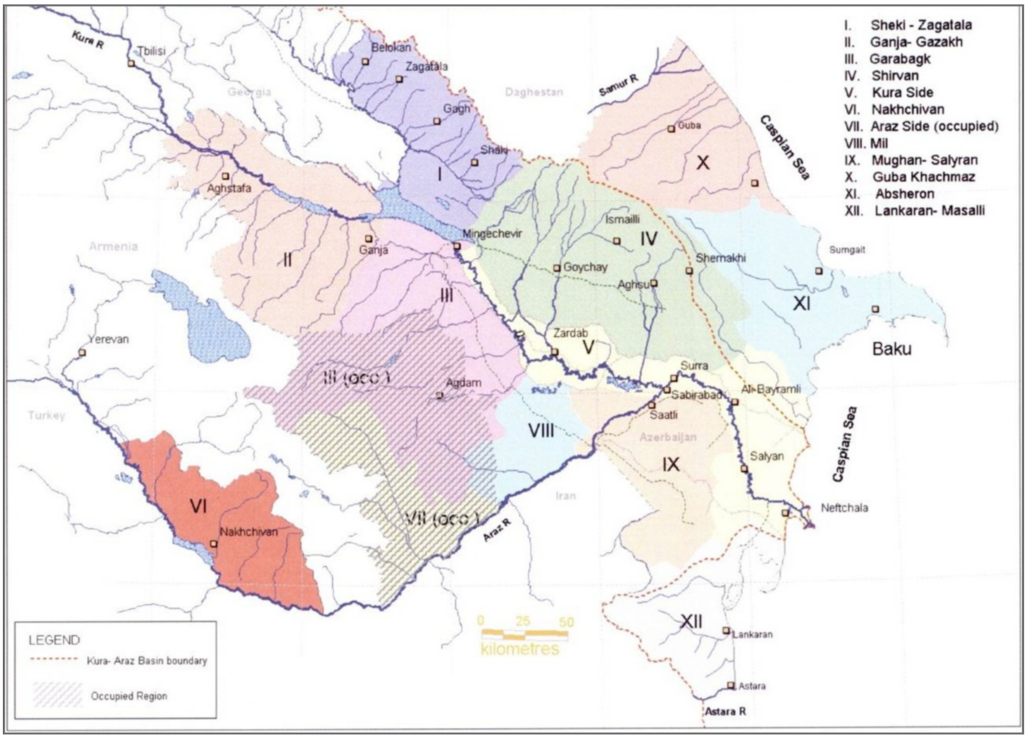


Figure 5: Economic regions in Azerbaijan, from (Hasan Zade, 2019)

The national water strategy as well as flood risk management are in a process of development and not yet implemented. It still lacks a legislative framework. The challenge is the objective to achieve a comprehensive approach, in which natural resources in general and socio-economic development programmes are linked into one territorial development strategy (Abdulhasanov & Efimova, 2018).

3.3 Ongoing activities

The European Water Initiative Plus for Eastern Partnership is one programme with a timeframe 2016 to 2020 that is currently undertaken. The focus is on the whole water sector and not specifically on flood risk management.

Past events have led to various studies on flood and flood risk mitigation. Among these studies is the re-analysis of the severe flood event in 2010 affecting the city of Salyan. The river bed rose by 2.3 m in Yevlakh and 2.0 m in Salyan as a result of sedimentation. As a consequence, the flow capacity is reduced and water levels are higher, which is responsible for bank overflow. It was concluded that the meanders lead to an increased rate of sediment deposition in the meandering river sections of the Kura river and that such meanders can cause erosion. It was further concluded that straightening the river could be one possible solution for more flood protection.

It is true that meanders decelerate flow velocity through longer flow paths and that the gradient is lower. However, straightening the river is no solution as it does not address the root causes of the flood problem of Salyan. With or without meanders, the problem of backwater caused by the Caspian Sea level still remains the same and flow from upstream must be accommodated. The situation can only be contained by a set of engineered and nature-based solutions in combination with land use planning as it is mentioned in the flood risk management strategy (Verdiyev, 2012). An example is provided in Section 4.

Figure 6: Salyan and the meandering Kura River (source: Google Earth)

Other initiavites were launched by the Ministry of Emergency Situations (MES) and the Ministry of Environment and Natural Resources (MENR) in cooperation with Azerbaijan Amelioration and Water Management" OJSC. The focus was mainly on monitoring and operation procedures like:

- flood control operations at large water infrastructures
- warning procedures in mountainous regions
- land use regulation iin mountainous regions

Aforementioned initiative included the generation of hazard maps and hazard risk maps in some focal areas. The attempt was made to classify residential areas according to their exposure to hazards:

- less exposed residential areas;
- average exposed residential areas;
- most exposed residential areas.

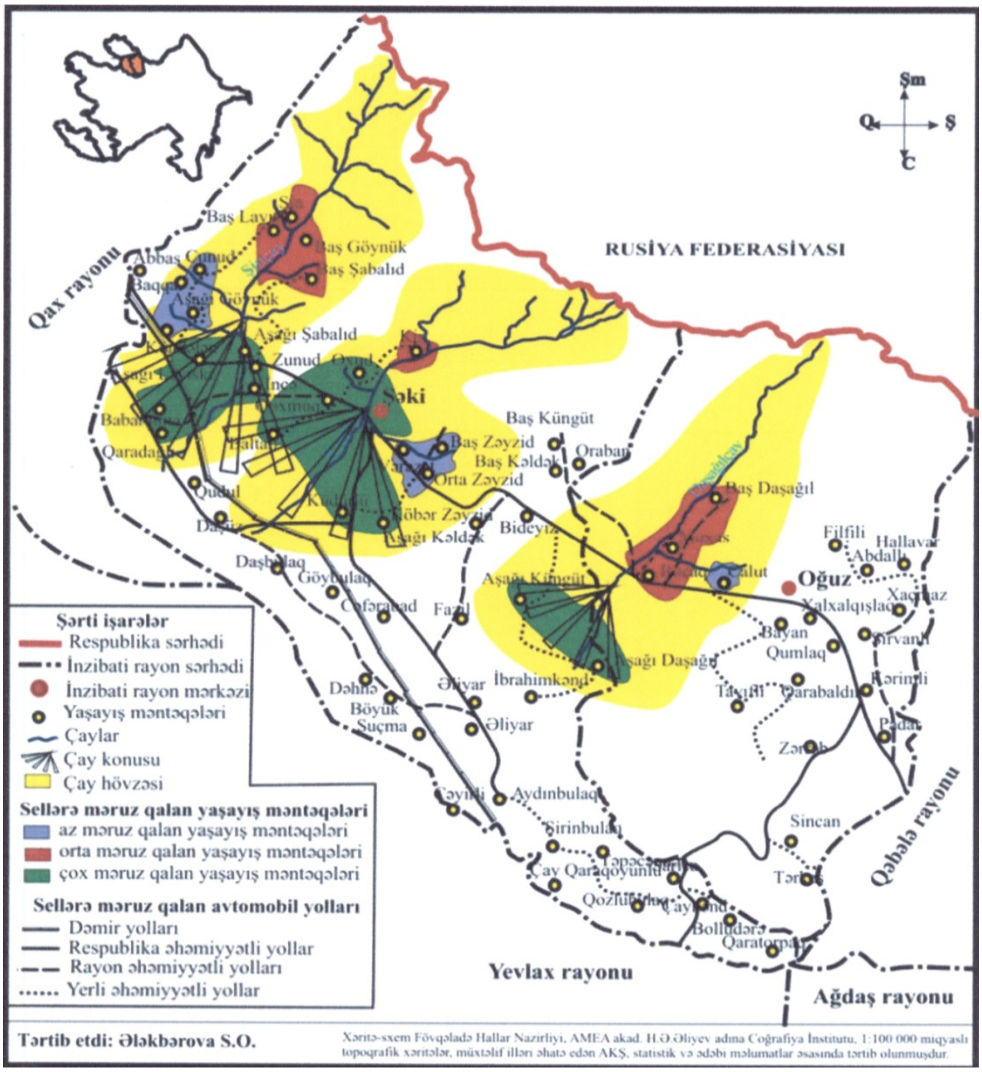


Figure 7: Hazard map with zones of exposure on residential areas and transportation, example from the southern slope of the Greater Caucasus (Hasan Zade, 2019)

4 SUGGESTIONS FOR INTEGRATED FLOOD MANAGEMENT

4.1 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

In Azerbaijan, there is a need to address two distinct flood management concepts, one for flash flood prone mountainous regions and one for the lowlands and plains.

4.1.1 The mountainous region

Major components favouring runoff and thus flood and flash flood formation are steep slopes, poor vegetation cover, less permeable and shallow soils, instability of unfreezing icr and snow 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 land use/agricultural planning ignoring natural hazards. In addition, climate change increases the number of intensive rainfall events and thus exacerbate flash floods, erosion, landslides and mudflows.

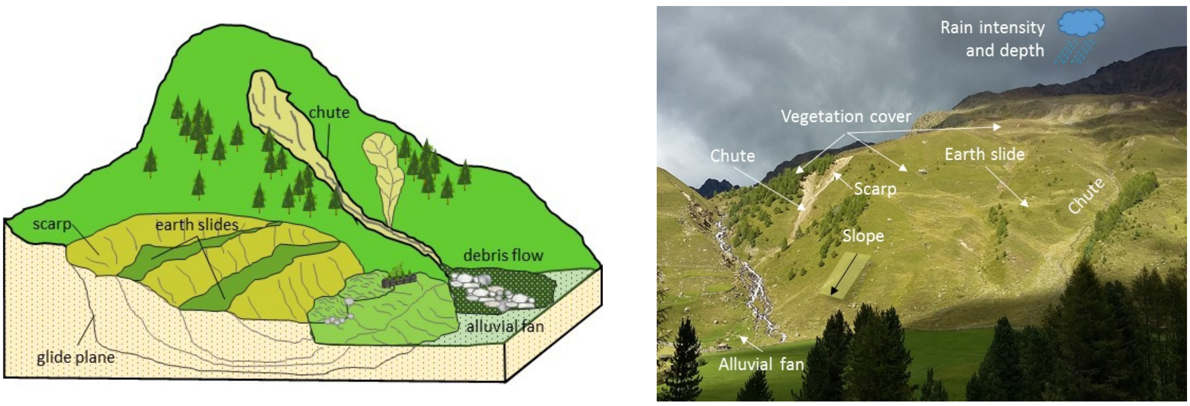


Figure 8: Hydrological features associated with floods, erosion, landslides and mudflows

The question is to what extent is it possible to alleviate 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 as it is already mentioned in the publication (Verdiyev, 2012):

- 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 engineered 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.

4.1.2 The plain and low lying areas

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.

4.2 Types of water related 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).

4.3 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.

4.4 Adaptation of hydraulic approaches

4.4.1 Flash floods and mudflows

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 3: 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).

4.4.2 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.

As a rule of thumb, the mountainous areas can be modelled with a 1D approach, while the plains and the Kura and Araz River require a 2D model in Azerbaijan.

4.4.3 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 manmade, 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.

4.5 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. Figure 7 shows an example of a hazard risk map derived from MENR for an area in the Greater Caucasus. 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.

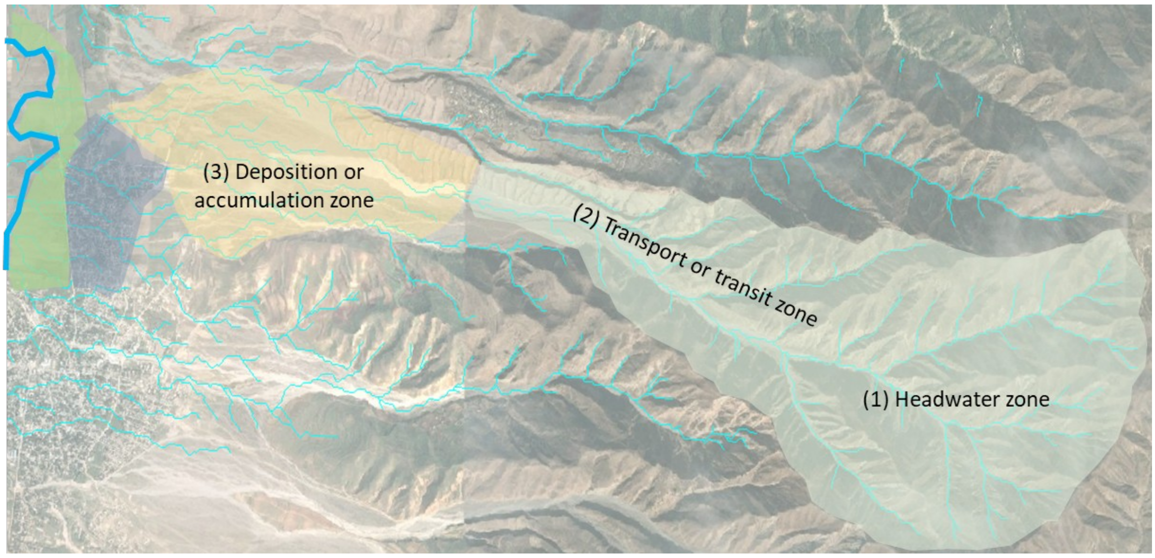


Figure 9: Different zones for flash flood and mudflow analysis

The colour in Figure 10 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)

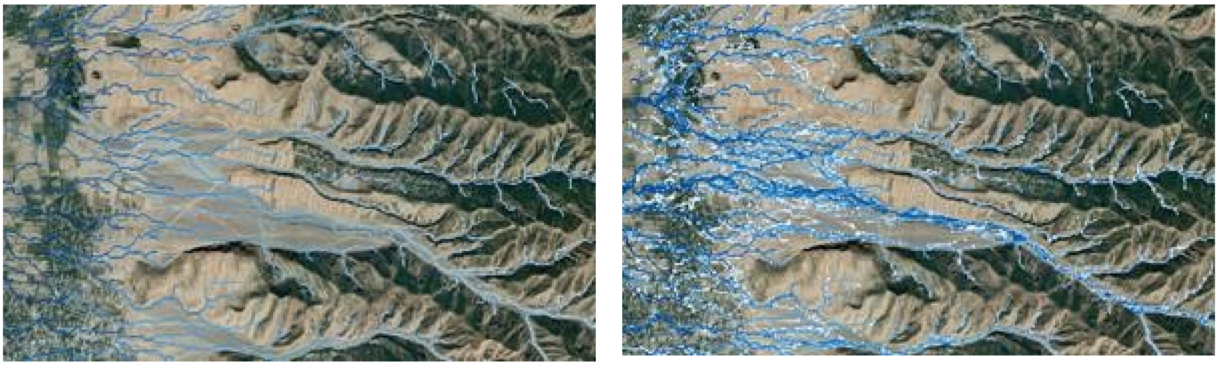


Figure 10: GIS-based flash flood and mudflow trajectory analysis (Lohr, 2018)

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.

4.6 Integration of Mingachevir Reservoir in flood management and emergency preparedness

The Mingachevir Reservoir is the most important flood mitigation structure in Azerbaijan. This is obvious and clearly indicated in (Hasan Zade, 2019). Even though the reservoir is of national interest in terms of flood management, it seems as if no assessment was carried out regarding its flood mitigation potential during extreme hydrological events. This statement is based on the fact that (Hasan Zade, 2019) provides a table with flood information and analysis for main rivers in Azerbaijan but no figures for releases associated with return periods are given for the Mingachevir Reservoir.

The probabilistic assessment of inflow and releases of the Mingachevir Reservoir is mandatory for flood management plans in the downstream section of the Kura River and must precede all flood modelling and flood mapping actions further downstream. This is an extremely important information and helps flood managers and water resources engineers

a) to operate the dam in an optimal way during extreme flood events
b) to derive meaningful flood hazard and flood risk maps downstream
c) to design proper flood protection structures downstream
d) to link inflow and water level of the dam with emergency preparedness measures downstream

4.7 Flood protection of low-lying ground

Azerbaijan has low lying ground and large plains. These areas face the problem that drainage is hampered and water level in rivers rise due to backwater effects. On top of that, adjacent land is often below the elevation of the river.

Another problem mentioned in (Hasan Zade, 2019) is sedimentation. Sediments reduce the cross sections, raise the river bed and lead to higher water levels. However, this can be countered by regular dredging.

Flood protection of these areas is costly and requires combined measures such as:

- Levees along the river
- Upstream flow retention as much as possible
- Water diversions into polder landscapes
- Flexible gates against rising sea level

Levees should leave enough space to accommodate flood volumes. It is not advisable to erect them directly at the river bank since valuable room for flood retention is lost.

Flow retention upstream is crucial. Retention in the form of polders and natural flood plains is a key asset against flood problems. Natural flood plains should be preserved and polders should be created. to alleviated flood problems downstream. All actions reducing space for retention must not be allowed or requires compensation.

Flexible gates that can be closed when the sea level is high during floods Flexible gates are often used when high tide affects drainage. It is questionable whether this could be a reasonable solution for Azerbaijan.

Water diversion into polder landscapes is an effective way of reducing water levels. It requires space and a technical solution at the diversion point. Weirs with flexible gates can be considered. The problem is often lack of space that can be flooded. This can be achieved when land use planning and the water and agricultural sector work together. It requires strong and foresighted planning.

4.8 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. This indicates that assessments and flood management planning, as it is mostly the case, happens at governmental or district level with low or no involvement of rural communities or villages. Communities and/or rural villages have no 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

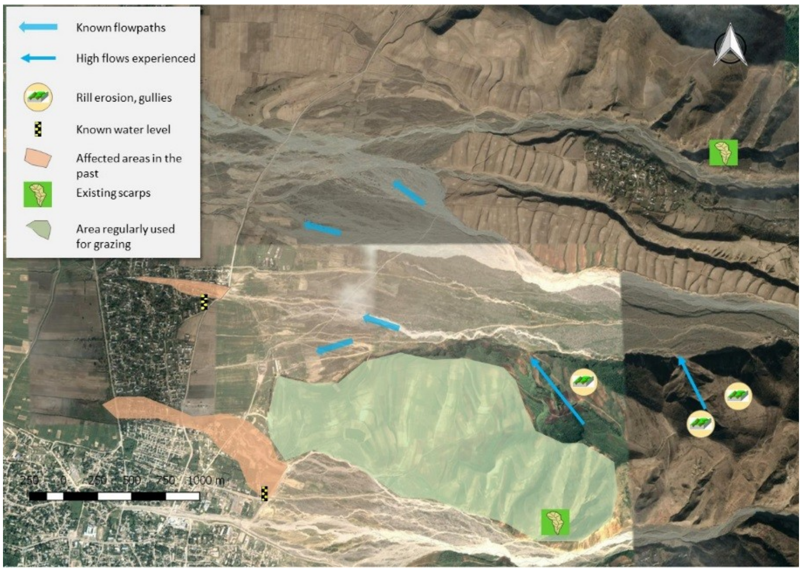


Figure 11: Example of a simple flood inventory map based on knowledge from past events

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.

4.9 Flood risk 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 4.8). 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.

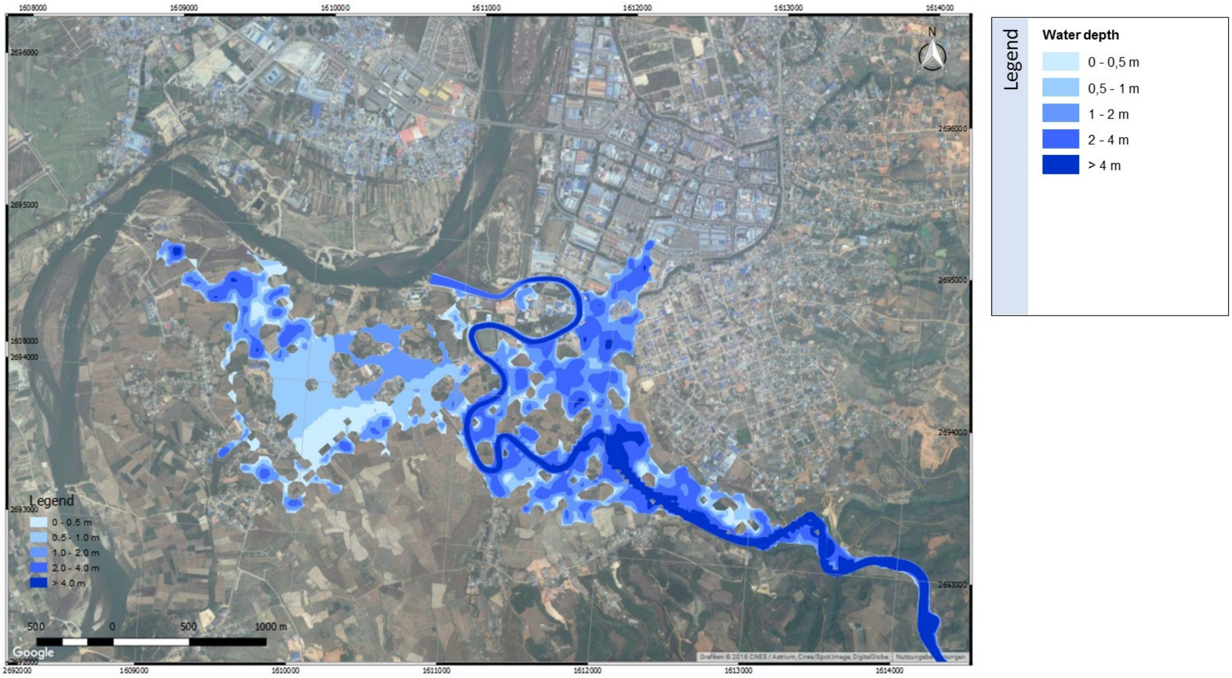


Figure 12: Inundation map with water depth categorised in 5 classes (SYDRO, 2017).

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

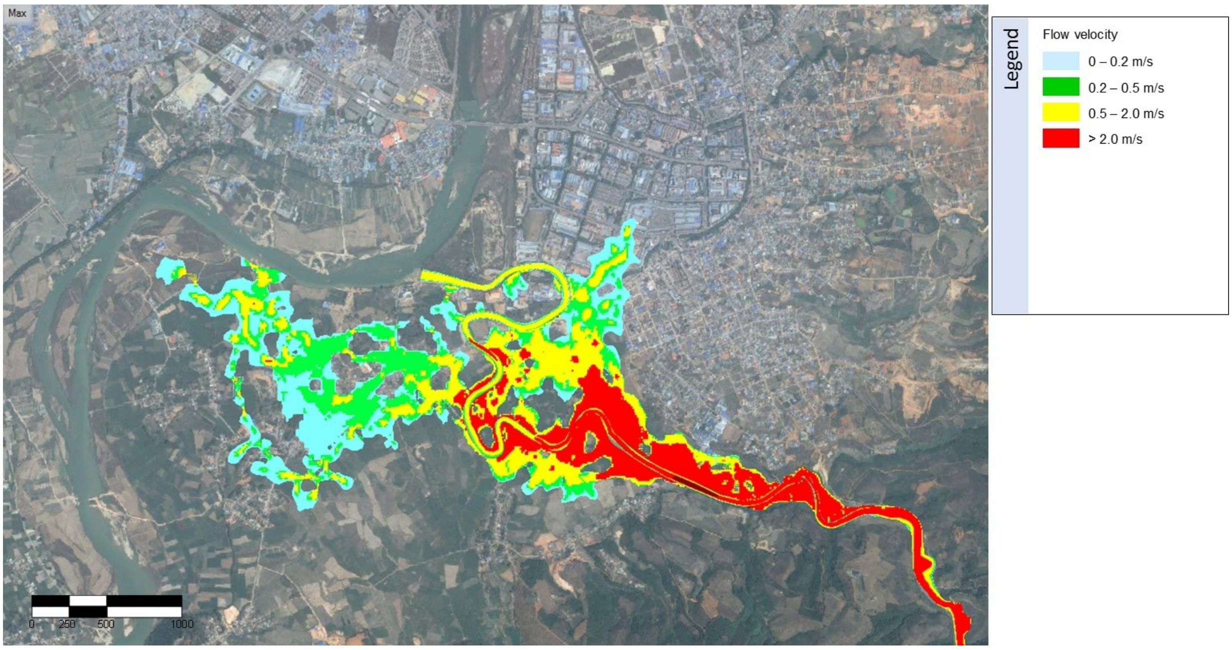


Figure 13: Flow velocity map (SYDRO, 2017)

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.

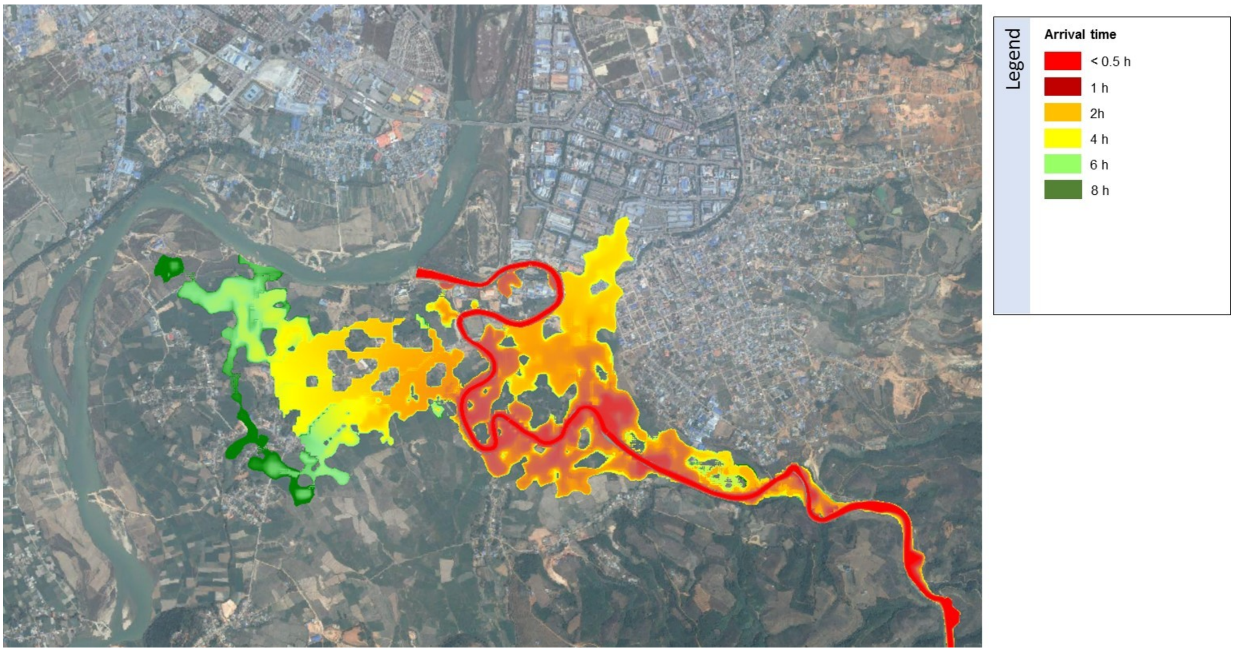


Figure 14: Map of arrival time indicating time for preparation (SYDRO, 2017)

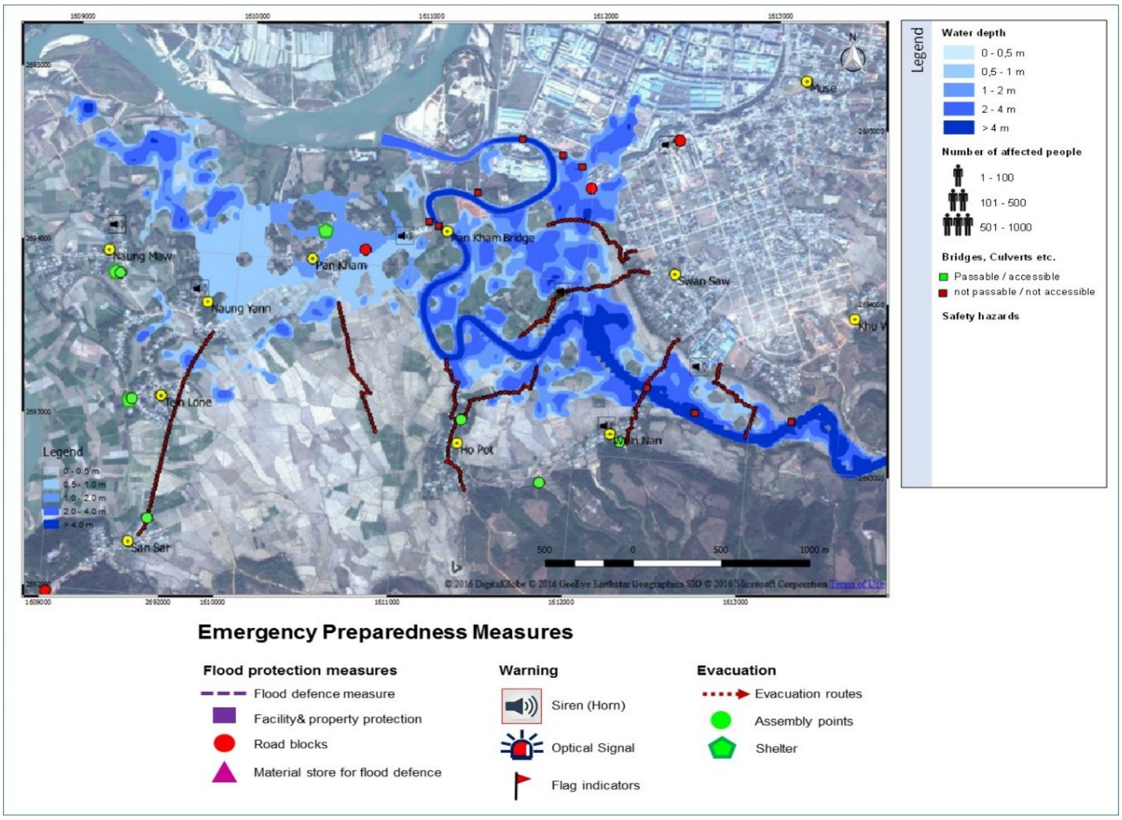
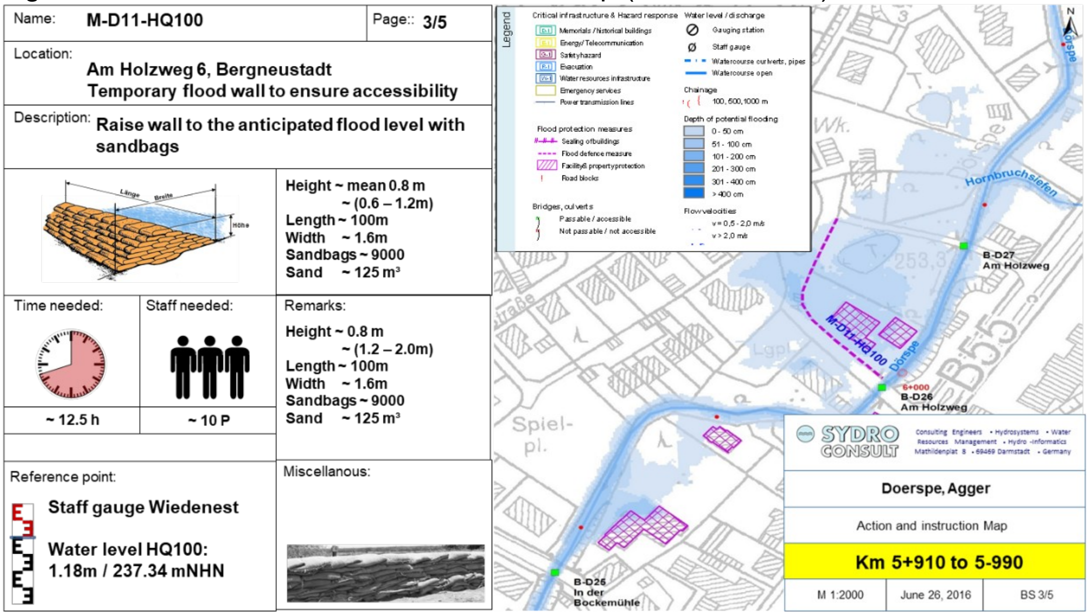


Figure 15: Emergency preparedness map (SYDRO, 2017)

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.

Figure 16: Flood action and instruction map (SYDRO, 2010)



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

4.10 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 17. 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.

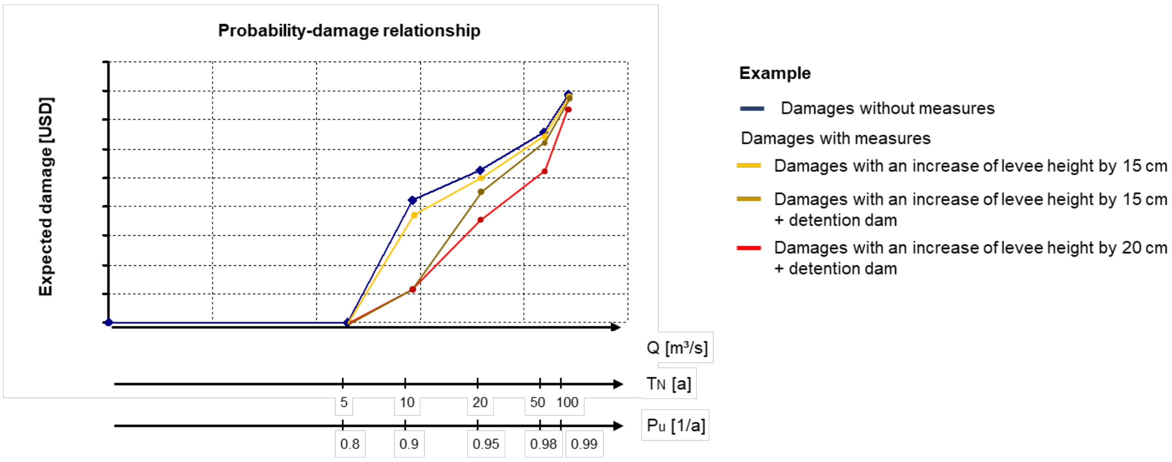


Figure 17: Probability-damage relationship for different scenarios

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 18 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)

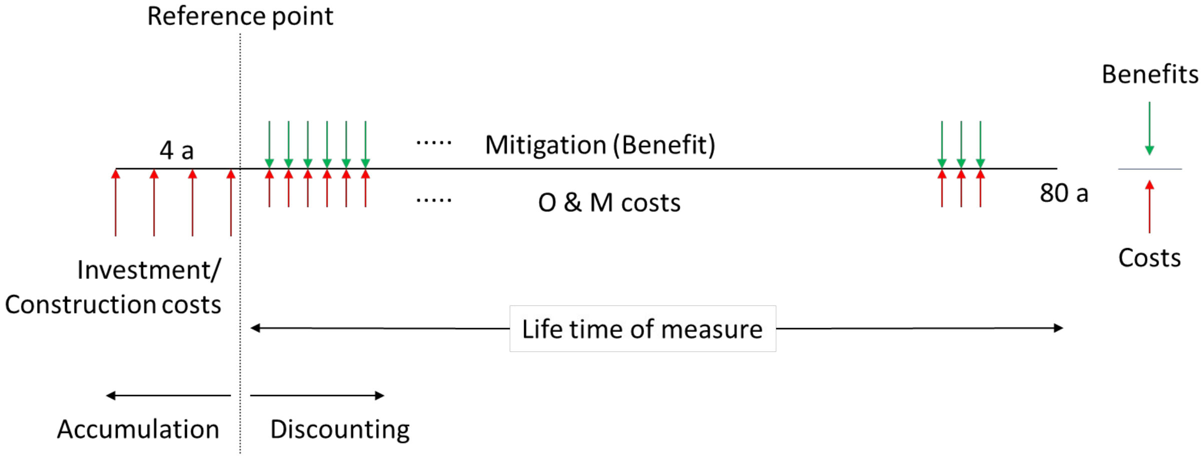


Figure 18: Timeframe and terms of a cost-benefit analysis

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.

4.11 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:

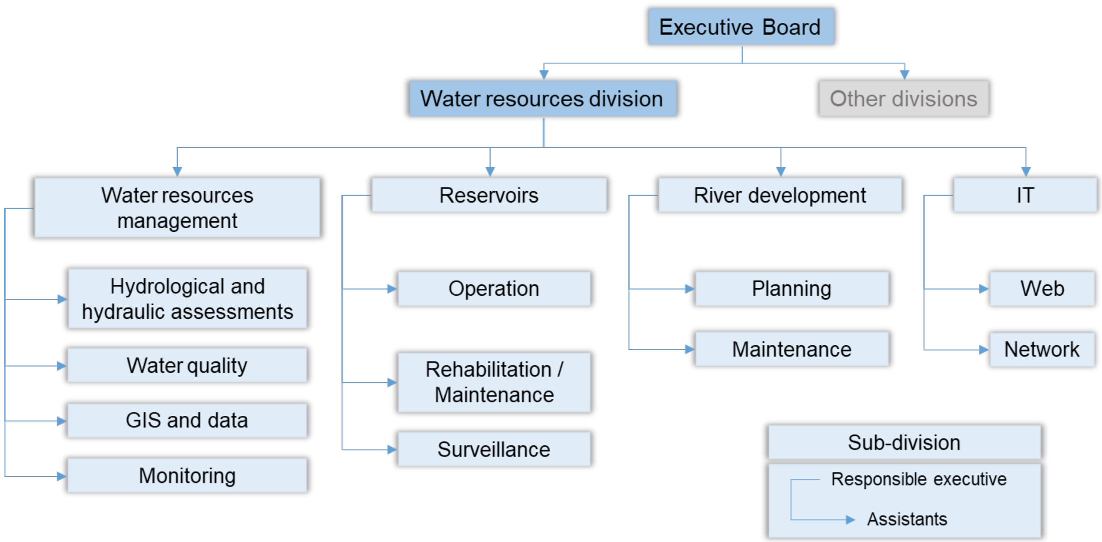


Figure 19: Example of a structure for flood management planning

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

4.12 Legal prerequisites

The responsible entity described in Section 4.11 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.

4.13 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.

4.14 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

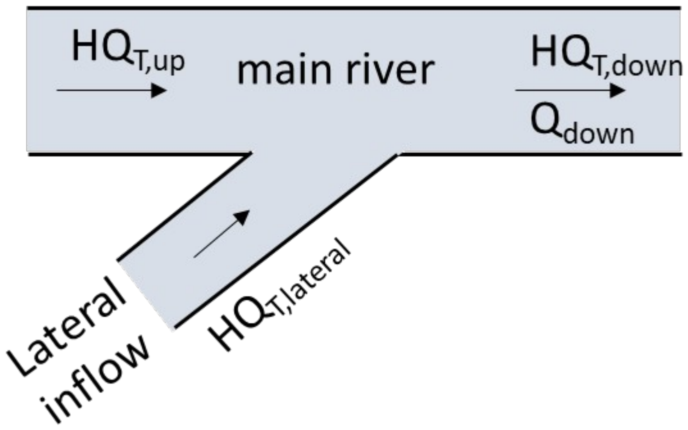
6.5 Information and data access

5 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)

5.1 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).

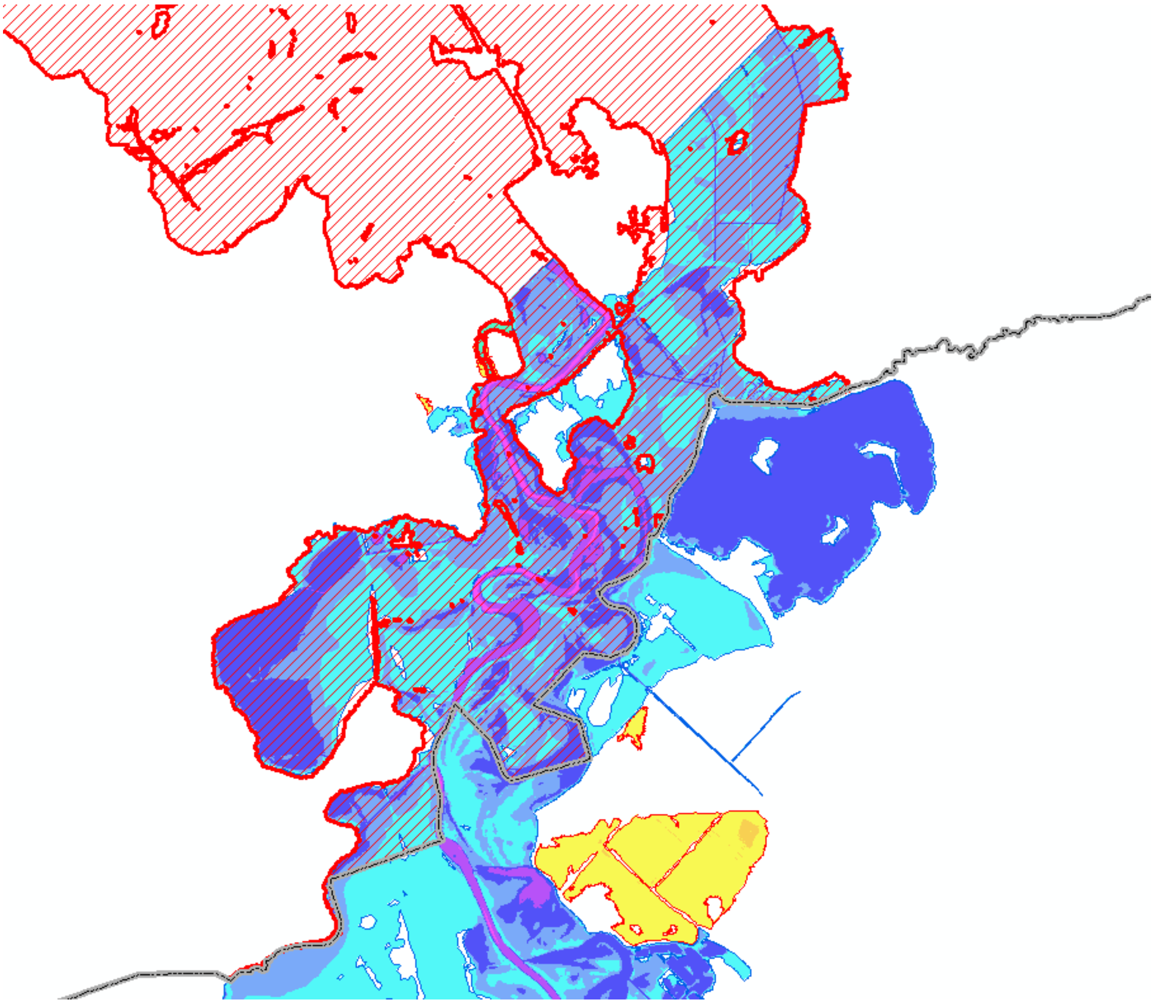
$$Q_{down} = \frac{\ln\left(HQ_{T,lateral}\right)}{\ln\left(HQ_{T,main river}\right)} \cdot HQ_{T,main\ river}$$

More complex approaches require sophisticated multi-variate statistical methods.

5.2 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).

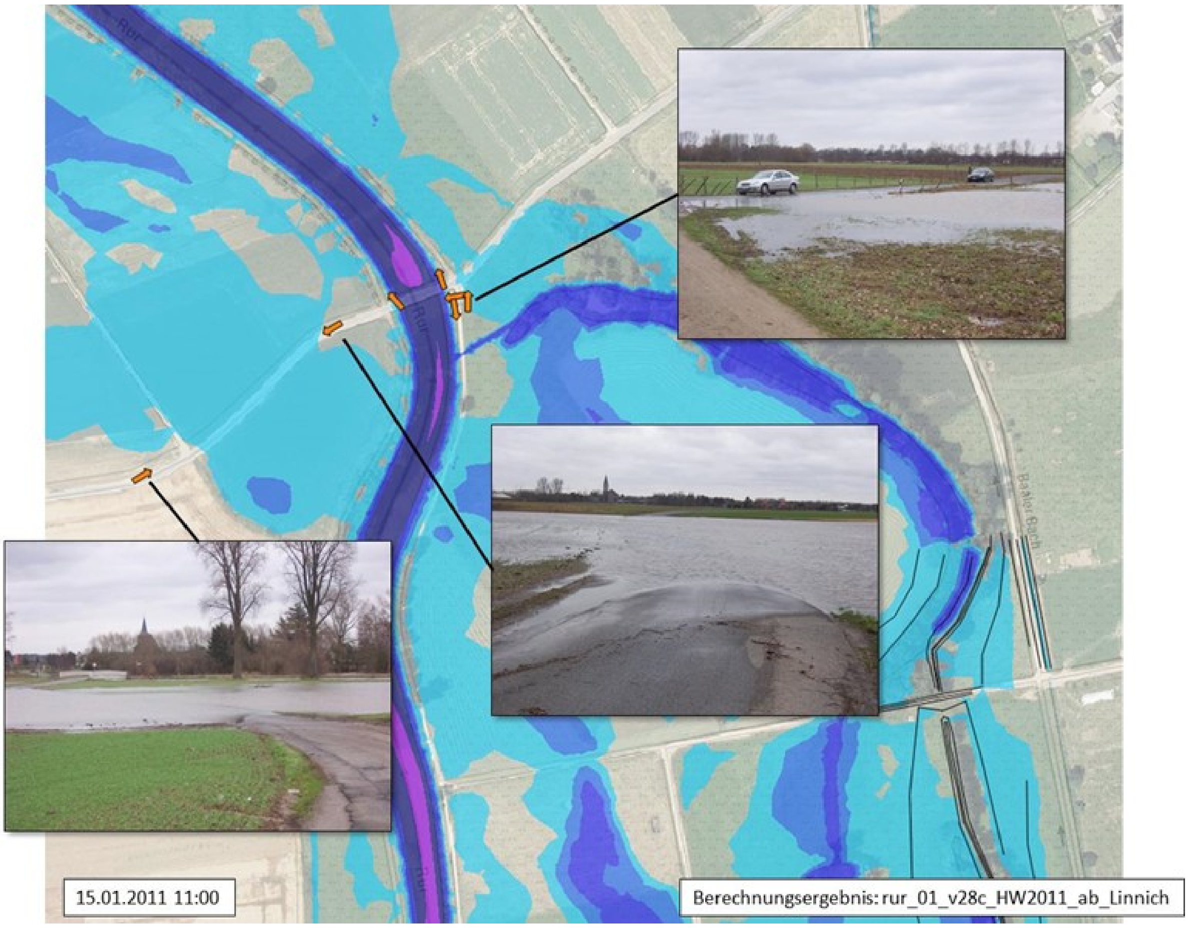


5.3 Details and quality of data

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.

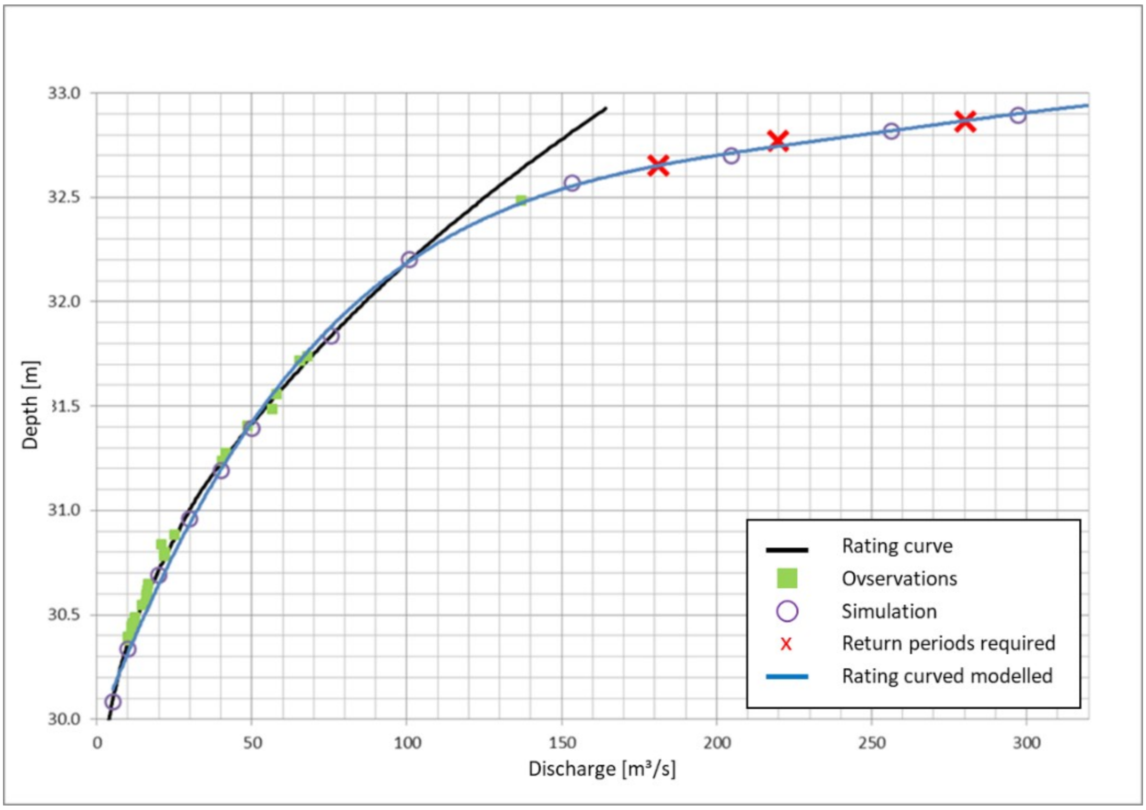
5.4 Match observations with calculations

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.



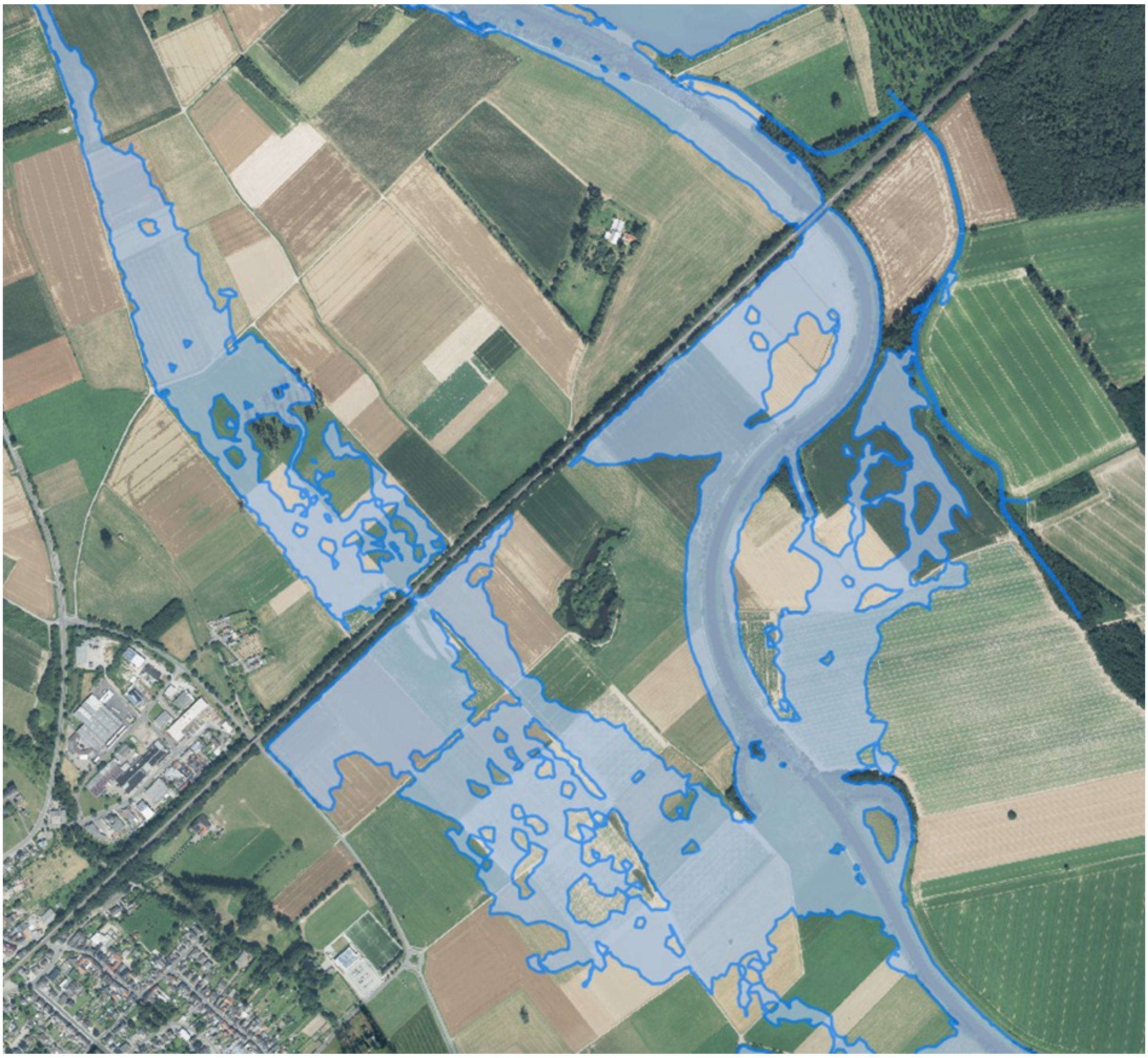
5.5 Errors/uncertainties in rating curves

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.



5.6 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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