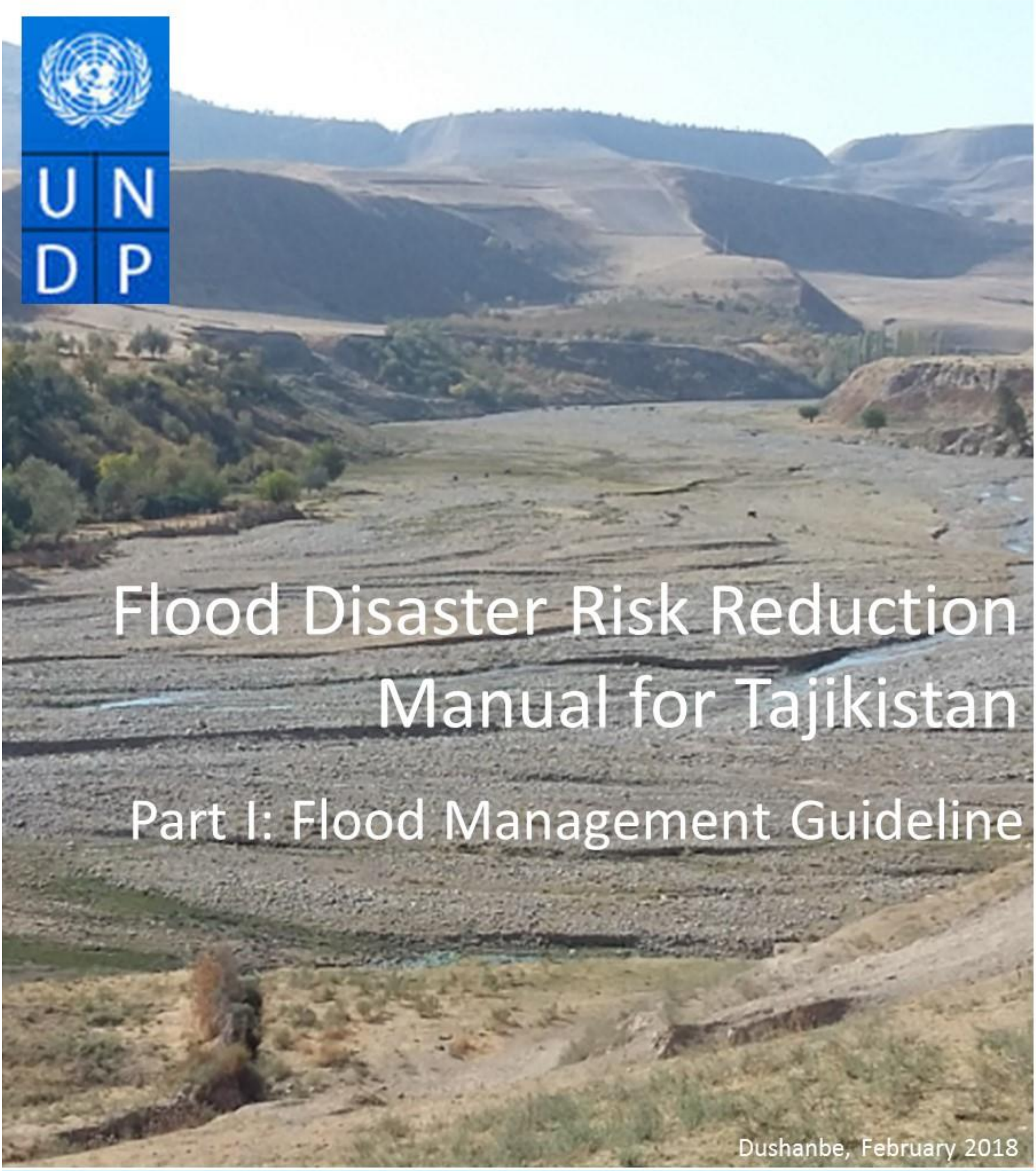


Flood Disaster Risk Reduction Manual for Tajikistan

Part I: Flood Management Guideline

Dushanbe, February 2018

United Nations Development Program of Tajikistan

UNDP Disaster Risk Management Programme

Strengthening Disaster Risk Reduction and Response Capacities

Ecosystem based Disaster Risk Management

Acknowledgements

This document was prepared in order to support the Government of Tajikistan within the framework of the Disaster Risk Management Programme (DRMP) of United Nations Development Programme (UNDP). UNDP assists the country in their effort to conduct a nation-wide risk assessment, selecting and implementing risk reduction measures, improving early warning and disaster management planning, preparedness and response, as well as strengthening capacities of search and rescue teams.

The author wishes to thank the UNDP team in Tajikistan for their support, contribution and commitment. The discussions and meetings in Dushanbe and during the field trips were invaluable for preparing this guideline.

Particular acknowledgements go to Michihiro Tanabe, Ilhom Safarov and Firdavs Faizulloev from UNDP for their dedication in providing the author with information, data and for their assistance in making meetings possible and successful. Mr. Kelly, the Risk Governance Consultant for UNDP in Tajikistan, deserves a big thank you for his contribution regarding the organisational and institutional framework of flood management in the country. Credits belong also to the partners in the project for their help and contribution regarding best practice examples, in particular the people from ACTED, Camp Tabiat, CESVI, German Agro Aid (Welthungerhilfe) and GIZ.

Last but not least, credits belong also to Dr. Michael Bach from SYDRO Consult who supported the author in compiling appropriate hard and soft measures and for sharing his experience in conceptualising flood management with ecosystem-based measures.

March 28, 2018

Dr. Hubert Lohr

Contents

Figures

Tables

Flood Management Guideline Tajikistan

Document Information

Project	Ecosystem based Disaster Risk Management
Project Countries	Tajikistan
Document	Flood Management Guideline Tajikistan
Date	28.03.2018
Consultant	Dr.-Ing. Hubert Lohr
Client	UNDP Tajikistan
Client Representative	Michihiro Tanabe, Firdavs Faizulloev
Financing Organisation	UNDP

1 HOW TO USE THE FLOOD MANAGEMENT GUIDELINE

Tajikistan is a flood prone country in which floods and flood related hazards like landslides and mudflows occur frequently. Both riverine flooding and flash floods hit the country regularly and call for an integrated and holistic approach in which watershed and flood management, environmental safeguard and flood mitigation measures are considered as a unit rather than isolated activities.

Riverine flooding along major streams and in flood plains cause flood problems, which are often of national interest due to the fact that large areas and critical infrastructure are affected. In contrast, smaller tributaries with steep valleys with a mountainous catchment, steep slopes, poor vegetation cover in the headwater area face problems like land degradation due to erosion, flash floods, landslides and mudflows. These events often receive less attention and less support due to their smaller geographical extent. On top of that, lack of data, time and resources come along with unclear steps to be taken regarding flood planning procedures. On the other hand, these phenomena have often very damaging effects.

This document addresses these tributaries and associated flood problems and provides a framework of action in the effort to combat floods.

In the past, flood protection was often solely linked to structured, engineered measures also referred to as grey measures. In recent years, nature-based solutions have gained worldwide interest and have been recognised as low-cost alternatives or complementary measures which, in contrast to grey measures, take effect even in the absence of hazards.

This flood management manual builds on the Flood Green Guide (FGG) developed by the World Wildlife Fund (WWF, 2016) and is streamlined according to the requirements of Tajikistan. It is developed to help flood managers, authorities, communities, engineers and practitioners who are involved in flood management and flood alleviation. In addition, this document tries to consolidate the measures undertaken by various NGOs who have engaged in nature-based solutions in Tajikistan.

This manual is subdivided into three parts.

Part I: Flood Management Guideline (this document)

Part II Hydraulic Calculations with Step-by-Step Example

Part III: Best Management Practice Examples

Part I is the Flood Management Guideline providing a short overview in relation to flooding in Tajikistan. Section 3 is dedicated to data availability. This section is also meant for assisting those who want to make use of publicly available data sources.

Part II is made for those who want to follow the process of assessing rain intensity, flood peaks, flood volume and flow paths analysis and is also equipped with hands-on practice in hydrology and hydraulics, which is useful in the context of floods and designing measures in view of sparse data.

Part III gives an overview about Best Management Practice Examples that have already been implemented in Tajikistan.

This document does neither replace existing regulations and standards nor provide the full set of hydrological, geological, geotechnical, structural and regulatory background required to construct and implement a measure.

2 OVERVIEW OF THE HYDROLOGY AND FLOOD SITUATION IN TAJIKISTAN

Tajikistan covers an area of 141 380 km². The topography contains some low lands in the west and south towards Afghanistan and Uzbekistan and along Syr Darja in the north. The majority of the country, however, are high and rugged mountains rising up to more than 7000 masl (Ismoil Somoni Peak). The capitol is Dushanbe in the west.

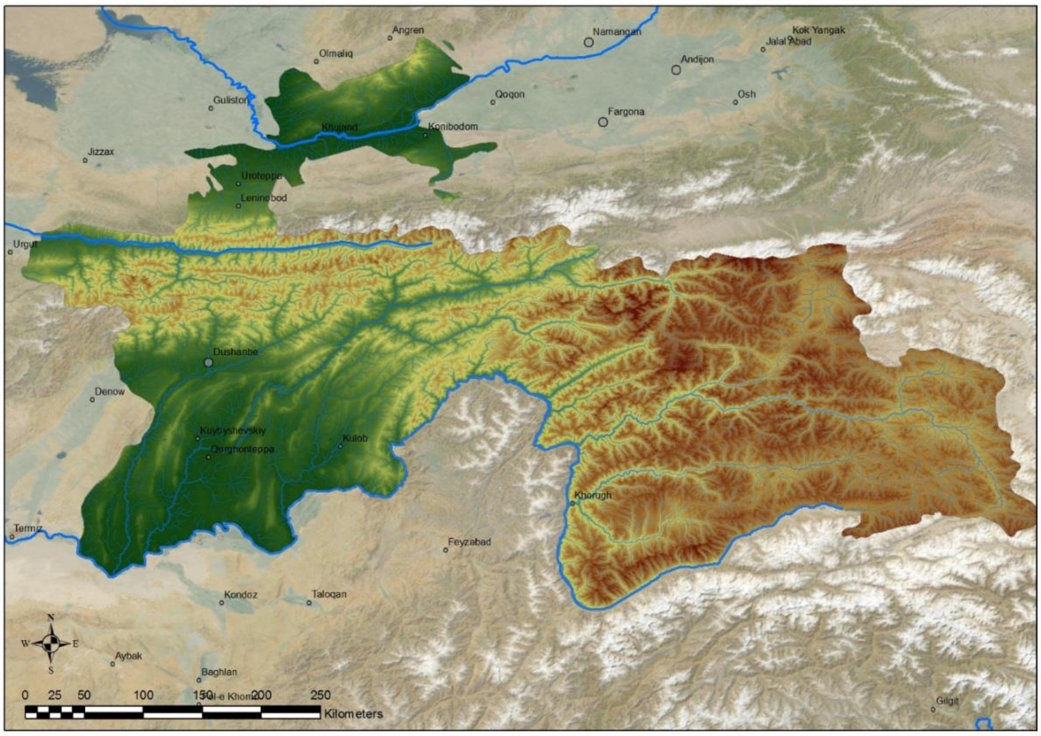


Figure 1: Map of Tajikistan

The border of the country towards south is marked by the Panj River, which is formed by the Bartang and Pamir River. The Zeravshan River, flowing straight from east to west, marks a distinct hydrological feature in the north and needs to be crossed to reach the northern part of Tajikistan. The glaciers in Tajikistan's mountains are the major source of runoff within Tajikistan and for the Aral Sea.

According to FAO (2017), annual precipitation runs up to 690 mm/a, distributed over the month as illustrated in Figure 2

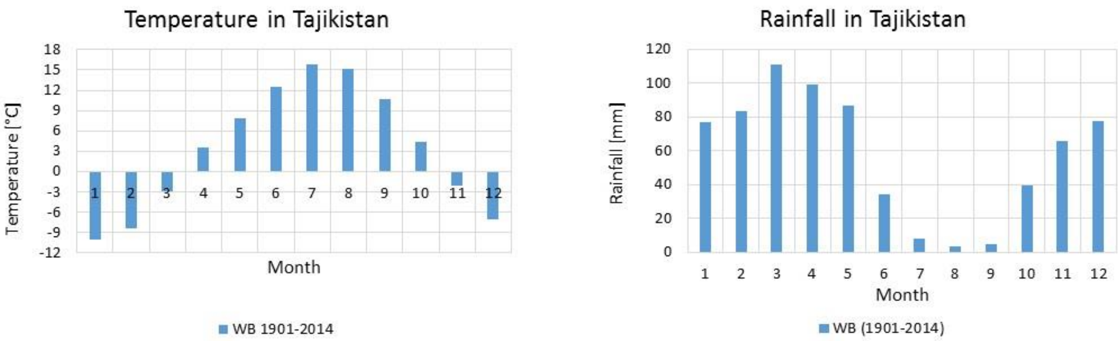


Figure 2: Monthly distribution of temperature and precipitation (World Bank, 2017)

Like many other countries, Tajikistan has a warming tendency regarding the mean temperature January-December with the previous 19 years all above the long-term average based on 1910-2000.

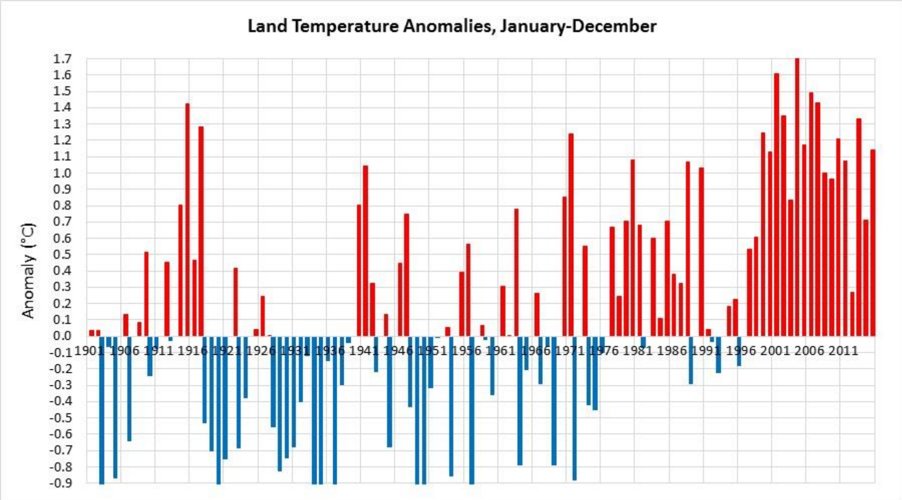


Figure 3: Land temperature anomalies 1910 to 2015, calculated based on World Bank data (World Bank, 2017)

The total amount of surface water produced in the country sums up to 60.5 km³/year, only 6 km³/year infiltrate and recharge groundwater. By transforming the mean annual precipitation to km³/year, the mean annual precipitation-runoff coefficient is very high and amounts to 60%. Mean annual inflow into the country are estimated to 34.2 km³/year and mean annual outflow to 94.7 km³/year. Calculating the long-term annual renewable water resources yields - with groundwater – approximately 22 km³/year. In conclusion, Tajikistan is rich in water resources but has low natural storage potential except for glaciers. If global warming progresses and reduces the glaciers, the immediate runoff will increase and more effort is needed to make use of the water resources. All figures are from (FAO, Aquastat Tajikistan, 2017)

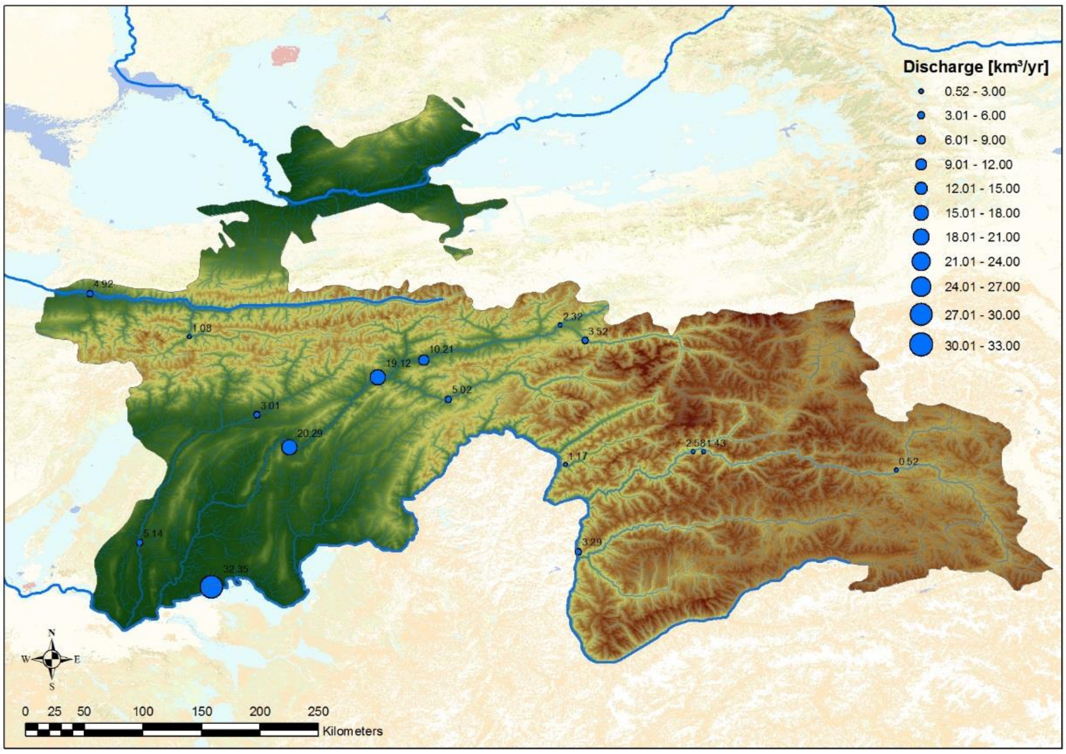


Figure 4: Annual discharge in [km³/yr] at GRDC stations, (GRDC, 2017)

2.1 Flood

Tajikistan is prone to many types of natural hazards which can be directly or indirectly related to flood. Riverine floods occur along larger streams with overbank flow inundating adjacent areas. The duration of flood events depends on the size of the catchment and can range from hours up to a number of days. In Tajikistan, riverine floods occur either in spring following heavy rains or during snowmelt in summer time.

Flash floods originate from high intensity rainfall in narrow valleys and are particularly destructive. There is almost no lead time, especially in steep valleys. Water level can rise within minutes and recede fast. Flash floods have a high energy potential and often carry sediments. Flash floods are extremely difficult to predict. Rain cells are often locally confined and their formation is neither predictable nor traceable with sufficient accuracy. There is a transition from flash flood to mudflows and debris flow and granular flow with increasing sediments load.

According to (ADRC, 2006), the South-eastern slopes of Gissar range, Northern slopes of Turkestan range and Southern slopes of Kuramin range are the areas with greatest flood activity, particularly in the basins of Yakhsu, Varzob, Vakhsh, Zeravshan and Obihingou rivers.

Mudflows are observed frequently in the foothills and mountainous areas of Tajikistan. Apart from torrential rain as root cause, the occurrence of mudflows is also attributable to the damming of watercourses by landslides and glaciers and the accumulation of loose debris on slopes and in the channels of watercourses.

The major mudflows that occurred in Tajikistan were: Garm district the (villages Yaldamich and Navdi) in 1969 and 1998; Pendzhikent in (Shing Jamoat), Tavildara (Langar), Nurek (Navdekh) in 1998 (ADRC, 2006).

The major reason of avalanches in Tajikistan is fresh snow formation. Large amounts of fresh snow not yet consolidated, are likely to be set in motion. In addition, the interface between fresh and old snow is rather unstable and tends to create sliding planes. Most avalanches are observed in February and March (ADRC, 2006).

The following map indicates the most dangerous hydro-geological processes (floods and mudflows, landslides, rockfalls and avalanches) registered around the country.

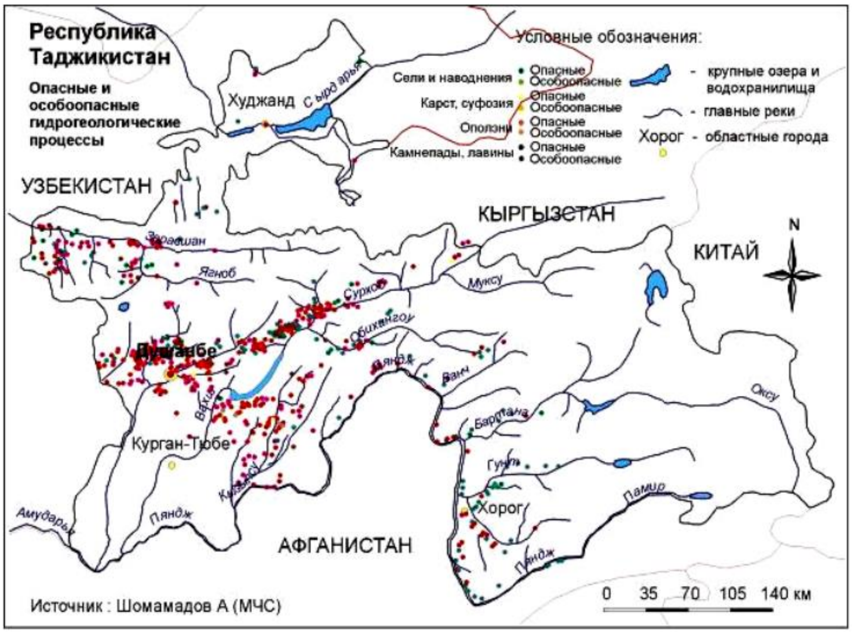


Figure 5: Occurrence of hydro-geological incidents in the country (source: (ADRC, 2006))

2.2 Flood risk

UNEP has established a Global Data Risk Platform (UNEP, 2013) covering the whole world and providing risk zones of inundation for different return periods. Figure 6 shows an extract of Tajikistan with a 100 year return period risk zone of inundation.

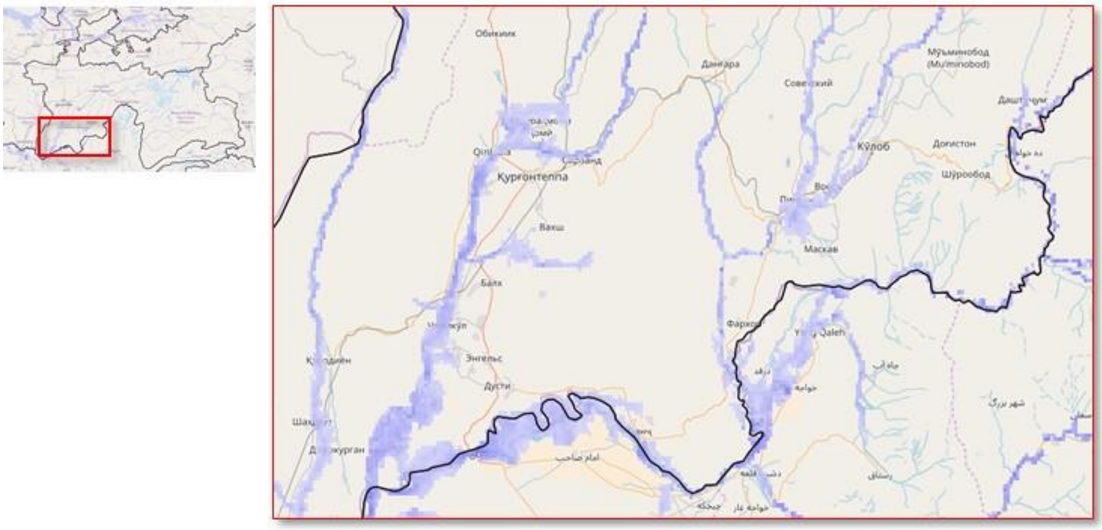


Figure 6: Estimate of 100 year flood return period, extract from the map of Tajikistan from Global Data Risk Platform (UNEP, 2013)

An estimate of landslide risk provides Figure 7, also derived from (UNEP, 2013).

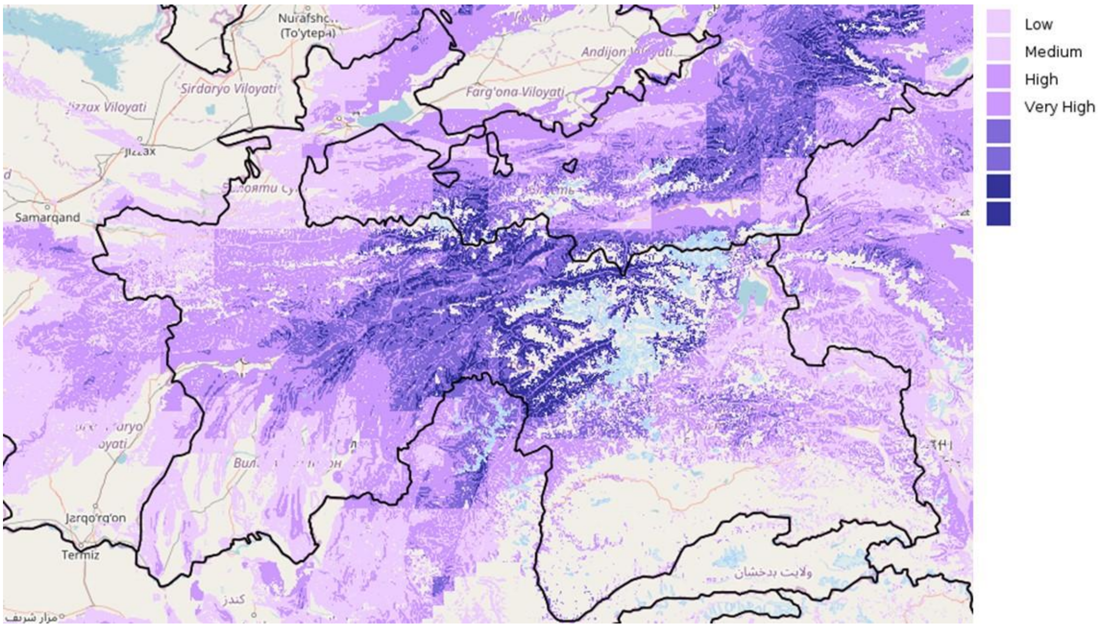


Figure 7: Estimate of landslide risk in Tajikistan (UNEP, 2013)

Tajikistan has a number of large rivers and countless small tributaries and streams. Since large scale interventions to cope with floods are tackled at the national level with support of development banks, flood problems at smaller tributaries and water courses, especially flash flood and mudflows prone valleys perpendicular to rivers, obtain less support. This is the typical line of work of NGOs and international development organisations (see Part III).

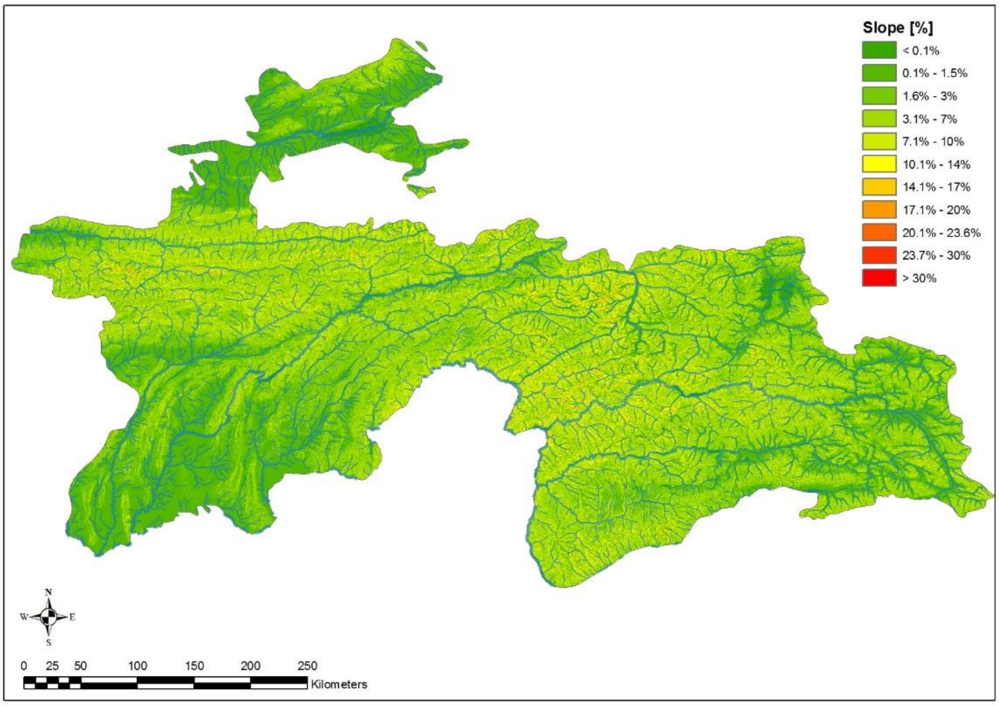


Figure 8: River network and slopes derived from SRTM 90

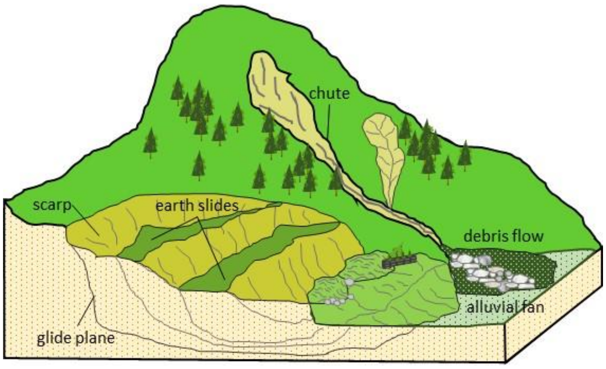
The river network map illustrates the countless number of small catchments and valleys.

Major components which favour runoff and thus flood formation in a terrain like Tajikistan can be summarized as follows:

- Steep slopes

- Poor vegetation cover
- Less permeable and shallow soils

These factors together with unfavourable geological conditions like glide planes pave the way for natural hazards like floods, landslides and mudflows. These hazards are heavily fostered 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 very intensive rainfall events and thus exacerbate flash floods, erosion, landslides and mudflows.



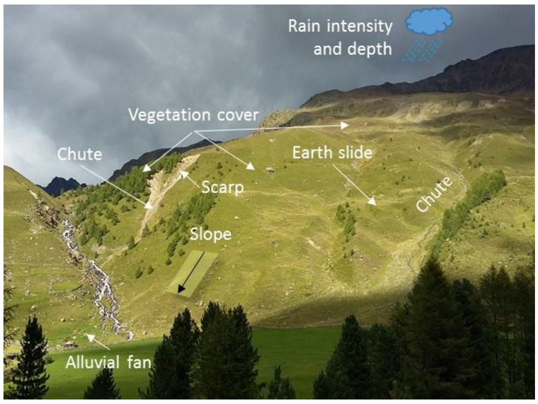


Figure 9: Hydrological features associated with floods, erosion, landslides and mudflows

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

- Design
- Monitoring
- Operation
- Preparedness

It is unrealistic to believe that a 100% flood protection is achievable and to associate flood protection only with traditionally engineered hard measures. Ecosystem-based solutions have gained wide interest due to low costs for implementation, their adaptive character and the fact that they take effect even in the absence of hazards.

3 DATA AND DATA SOURCES

This chapter aims at providing information about data and data sources which are required during flood management planning and for designing measures. Different departments and entities in the country are responsible for monitoring and offer data. On top of that, a vast amount of good information can be found for free in the internet and helps in the attempt to make flood management more efficient. The data mentioned are used in Part II of the Flood Management Guide.

3.1 Official data and data sources

Regarding hydro-meteorological data, there is one focal point for data acquisition in the country which is the State Agency for Hydrometeorology of the Republic of Tajikistan (www.meteo.tj)

The State Agency for Hydrometeorology provides public services in the area of hydrometeorology. The Agency has the following functions:

- take part in the implementation of the common national policy in the fields of hydrometeorology and pollution monitoring
- produces statistical reports at national level in the area of hydrometeorology and provides the data to upper authorities
- in accordance with the established procedure, coordinates the establishment and maintenance of the system of integrated environmental monitoring
- fulfils national obligations in the area of hydrometeorology

In particular, two agencies are mainly responsible for monitoring, data collection, data processing and data provision. Regarding data provision, they work on demand that means that requests, usually in writing, must be submitted to the agencies in order to receive data. Fees are charged for obtaining data depending on the number of data points requested (stand January 2018).

Agency of Hydro-Meteorology – Hydrological Department

The Hydrological Department is tasked with flow observation and record keeping and runs an observation network of 96 hydroposts of which 85 are in operation. All stations keep records of water level. Discharge is calculated at about half of the stations by means of stage-discharge curves. Continuous flow and water level records are available from 1930 to 1990, gaps exist as of 1990. Data are transmitted to the Department in analogue form. Real-time or near real-time information of the stations is not obtainable. Requests concerning individual hydroposts must be submitted in writing. Apart from time series, the department provides also statistical analysis like frequency analysis.

Agency of Hydro-Meteorology – Meteorological Department

The Meteorological Department collects, archives and evaluates meteorological data. There are 54 meteorological stations in the country monitoring temperature, rain, humidity and snow depth. The records are transmitted to the Department in analogue form and are digitised in the Department. Monitoring is intensified during March to August. Apart from time series, rain depth classifications with respect to flooding can be obtained on request, specified for stations or areas.

3.2 Data and data sources from the internet

3.2.1 GIS

A prerequisite to work with digital data is a Geographical Information System (GIS). Nowadays, it is common practice to use a GIS. An excellent GIS system is QGIS which is free of charge and supported by a huge user community. More information about QGIS and download can be found here: https://www.qgis.org/en/site/

3.2.2 Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) is indispensable for working on flood management and related topics. Usually, a DEM comes as a regular raster of cells. Each grid cell represents the mean elevation of the topography underneath the cell. A DEM is characterised by its resolution that is the extent of each grid cell. The smaller the cells are, the better is the representation of the actual topography.

Thanks to satellite technology, the whole world is covered with a DEM on a 90x90 m and since 2014 on a 30x30 m basis. The Shuttle Radar Topography Mission (SRTM) of NASA has prepared the data and made it available for free. Please visit https://www2.jpl.nasa.gov/srtm/ to learn more about the SRTM mission.

Data can be retrieved from various sources. The Earth Explorer from the U.S. Geological Survey (USGS) provides an internet portal from which the SRTM data can be downloaded. The internet address is: https://earthexplorer.usgs.gov/

Download requires registration and allows the selection of an area. The 90m SRTM is indicated as 3-arc second and the 30m SRTM as 1-arc second data.

3.2.3 Climate

Information about climate is essential for flood management. Precipitation is the driver for runoff and estimates about rainfall depth and intensities associated with return periods constitute the basis for almost all calculations with regard to discharge and design floods. Weather stations are scattered throughout Tajikistan and the spatial coverage is not well developed. Time series of precipitation from ground stations often have significant gaps and the temporal resolution is mostly daily values.

The values from Khaburabad can be downloaded up to 1991 here: https://geographic.org/global_weather/tajikistan/khaburabad_853.html

Globally available data sources for precipitation from the internet stem from satellite estimates. They can be used to back data from ground stations or, in the absence of any ground stations, they are the only source available. However, satellite based estimates of precipitation incorporate a lot of uncertainty and require ground truthing with observations from ground stations.

The main data sources are:

TRMM	Tropical Rainfall Measuring Mission (TRMM), was a joint mission of NASA and the Japan Aerospace Exploration Agency. It was launched in 1997 to study rainfall for weather and climate research. After over 17 years of productive data gathering, the instruments on TRMM were turned off on April 8, 2015. For seamless work with TRMM, data are still generated until 2018. https://pmm.nasa.gov/trmm https://pmm.nasa.gov/data-access/downloads/trmm
GPM	The Global Precipitation Measurement (GPM) mission is an international network of satellites that provide the next-generation global observations of rain and snow. Through improved measurements of precipitation globally, the GPM mission is helping, among others, to improve forecasting of extreme events that cause natural hazards and disasters, and extend current capabilities in using accurate and timely information of precipitation to directly benefit society. https://pmm.nasa.gov/GPM

Downscaled climate scenarios	The NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The CMIP5 GCM runs were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections for RCP 4.5 and RCP 8.5 from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5. Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100. The spatial resolution of the dataset is 0.25 degrees (~25 km x 25 km). The NEX-GDDP dataset is provided to assist the science community in conducting studies of climate change impacts at local to regional scales, and to enhance public understanding of possible future global climate patterns at the spatial scale of individual towns, cities, and watersheds. https://cds.nccs.nasa.gov/nex-gddp/
Climate Forecast System Reanalysis (CFSR) climate data	The National Centres for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over this period. The current CFSR will be extended as an operational, real time product into the future. The website allows you to download daily CFSR data (precipitation, wind, relative humidity and solar) in CSV or SWAT file format for a given location and time period. https://globalweather.tamu.edu/

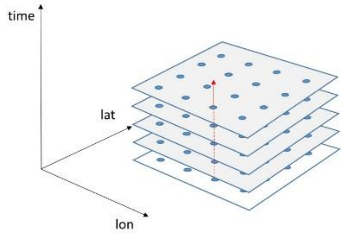
An example application of TRMM data with a 3-hour resolution is explained below.

1. **Download** all 3hr TRMM files beginning from 1998 for your project area.
2. **Extract** all values from all grid point from all downloaded files and sort them according to the date. Depending on the size of your area, the result is a number of time series of rainfall with 3 hr temporal resolution.
3. **Assign** each time series to the best and most reliable nearby ground station.
4. **Aggregate** 3 hr TRMM values to daily values for preparing bias correction.
5. **Screen out** outliers from the aggregated TRMM values within the daily time series which are not sensible.
6. **Conduct bias correction** for all time series based on the daily values. There are a number of methodologies for bias correction. The one shown below is quantile mapping.
7. **Scale** the original 3 hr TRMM time series with the bias corrected 1 day TRMM data. In doing so, total rainfall depth of each day follows the bias correction but the inner-daily distribution is preserved.

Download files

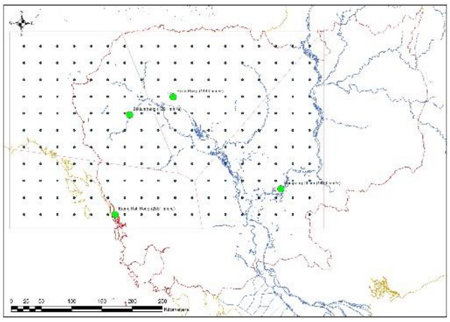
The link is given above.

Extracting values



TRMM files come with latitude and longitudes. Each value from a grid cell must be extracted and appended to a time series along the time axis and for corresponding lat/lon coordinates.

Assigning grid cells to ground stations



For reasons of simplification, Thiessen polygons can be used to assign a grid cell to a ground station
(Example left shows the Tonle Sap Region in Cambodia)

Aggregation

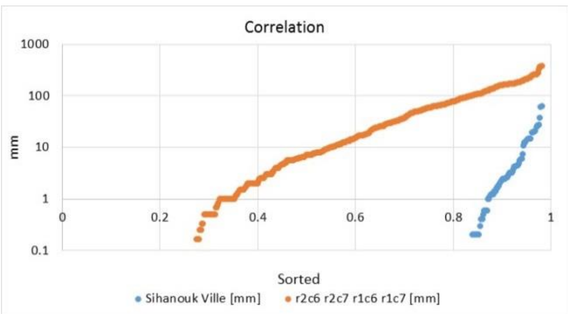
The time series with a 3 hourly resolution must be aggregated to daily values by preserving the total daily rainfall depth.

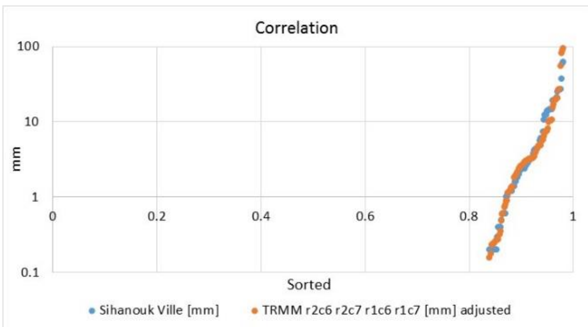
Screening out of outliers

Identification of outliers is necessary to correct the time series from erroneous values. It is a good idea to identify maximum daily rainfall from various ground stations, to sort them and to set a threshold as maximum daily precipitation in accordance with the observed values.

Conducting bias correction

Ground stations (blue) and TRMM 1d values (orange) must be sorted. TRMM values are scaled to match the values from ground stations based on their corresponding probability of exceedance. The left image shows TRMM values prior to bias correction, the right image after bias correction. No precipitation occurs for more than 80 percent of the time at the ground station. This is why the blue line starts at approximately 0.82. In contrast, TRMM only shows for around 30% of the time no precipitation and lies considerably above the observed values. After bias correction the range of TRMM is adjusted to the range of the ground stations. It must be noted, despite the adjustment of the range, the approach still keeps TRMM records that can go beyond the observed range.





Scaling

Scaling of the 3h original TRMM data with corresponding bias corrected daily TRMM values adjust them to match the bias correction but preserves the resolution of 3 hours.

3.2.4 Land use

Land use information are necessary to obtain runoff coefficients and are required by hydrological or hydraulic models. Land use information stem from satellite observations and have astonishing spatial resolutions. Land use also covers ice and snow.

ESA	The European Space Agency (ESA) offers a wide array of data. The website allows applying filters for searching different topics https://earth.esa.int/web/guest/home
USGS Land Cover Institute	This site is a good starting point to see what is available in terms of land use data. The user can select data for download categorised according to continents. https://landcover.usgs.gov/landcoverdata.php
USGS	0.5 km MODIS-based Global Land Cover Climatology These data describe land cover type and are based on 10 years (2001-2010) of Collection 5.1 MCD12Q1 land cover type data. The map is generated by choosing, for each pixel, the land cover classification with the highest overall confidence from 2001-2010, as described in Broxton et al., 2014. The data has been re-gridded from the MODIS sinusoidal grid to a regular latitude-longitude grid, and the map has 43200x86400 pixels (corresponding to a resolution of 15 arc seconds). https://landcover.usgs.gov/global_climatology.php

The site http://gisgeography.com/free-global-land-cover-land-use-data/ gives a good overview what is available and what data can be expected.

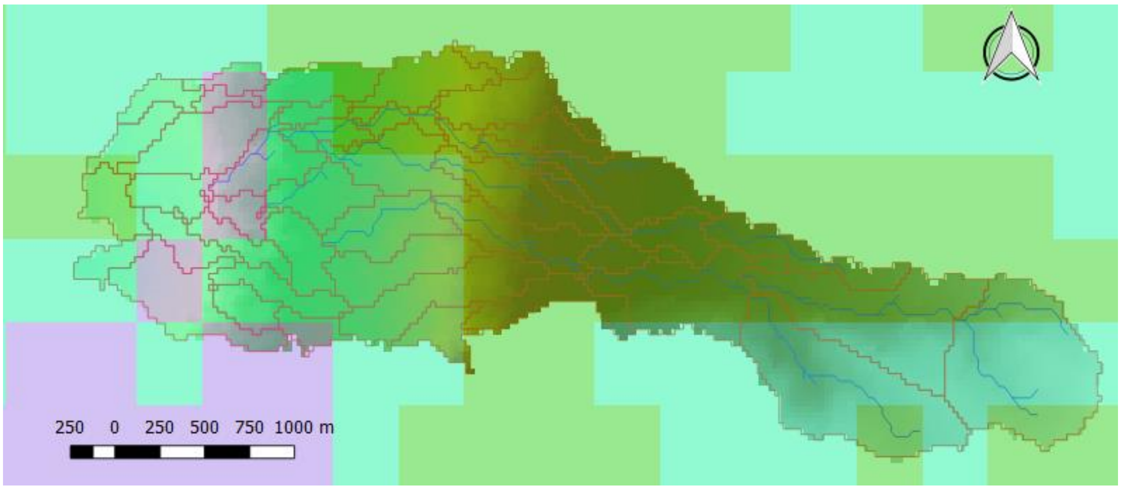


Figure 10: Land use grid from MODIS with 500m resolution

For small catchments, the 0.5 km resolution of MODIS is too coarse. Alternatively, satellite images can be used and classified. The example from above is used to demonstrate the land use grid.

3.2.5 Soil

FAO Soil Portal provides a Harmonized World Soil Database in a 30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981). The resulting raster database consists of 21600 rows and 43200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). (Source: http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/)

However, the resolution does not suffice the needs for small basins. As such, soil data must be collected locally or estimated based on experience supported by agricultural expertise.

3.2.6 Satellite images

The usefulness of satellite images is obvious as they come usually very up to date and own high spatial resolution. In order to use them in a GIS application, the must be processed.

ESA Sentinel mission	https://scihub.copernicus.eu/dhus/#/home is the Sentinels Scientific Data Hub is the official download headquarters for the European Space Agency’s Sentinel satellite data. ESA’s sentinel satellites a worthy alternative to Landsat. This page tells how to download sentinel satellite data. http://gisgeography.com/how-to-download-sentinel-satellite-data/

The site http://gisgeography.com/free-satellite-imagery-data-list/ gives a good overview what data is available and how to access them.

Once satellite images are downloaded, a next step to be taken is Image classification, unless the already classified sources are considered (see 3.2.4). Image classification is the process of assigning land cover classes to pixels, for example, into forest, urban, agriculture and other classes.

The site http://gisgeography.com/free-global-land-cover-land-use-data/ gives a good overview of image classification.

QGIS can be extended with plugins. There is a huge set of freely available plugins for several purposes. Image classification is supported by a plugin available from here https://plugins.qgis.org/plugins/SemiAutomaticClassificationPlugin/ or here https://fromgistors.blogspot.com/p/semi-automatic-classification-plugin.html.

3.2.7 Estimating erosion

Data sources relevant for estimating erosion are:

LUCAS Topsoil	https://esdac.jrc.ec.europa.eu/content/lucas-2009-topsoil-data
European Soil Database	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data
Lucas Earth Observations	https://www.eea.europa.eu/data-and-maps/data/external/lucas-earth-observations-2012
Rainfall Erosivity Database at European Scale (REDES)	https://esdac.jrc.ec.europa.eu/content/rainfall-erosivity-database-european-scale-redes-product-high-temporal-resolution-rainfall
CORINE Land Cover 2006	http://land.copernicus.eu/pan-european/corine-land-cover
COPERNICUS Remote Sensing	http://www.copernicus.eu/
EUROSTAT (statistics on Crops, Tillage, Plant residues, cover crops)	http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_tillage_practices
Good Agricultural Environmental Condition (GAEC)	https://www.gov.uk/guidance/standards-of-good-agricultural-and-environmental-condition

These sources can provide additional information in view of the lack regarding detailed data for Tajikistan.

3.3 How to determine flow for an ungauged location

Obtaining discharge at an ungauged location is usually done by means of a hydrological model. As models are currently not available other, simpler approaches must be used. A prerequisite to estimate flow without a model is the knowledge of discharge at a site with similar watershed characteristics. The following assumptions of the method are:

- Runoff characteristic of the ungauged site is assumed to be equal or at least similar to the site where flow records are available
- Significant regulated or retaining water infrastructure affecting the flow is not in place

The approach suggested without a model is referred to as the Area Proportion Method. A gauged catchment with similar watershed characteristics is used to derive flow information for the ungauged catchment. The discharge at the desired site is computed by using the formula:

$$Q_{ungauged} = Q_{gauzged} \cdot \frac{Area_{ungauged}[km^2]}{Area_{gauged}[km^2]}$$

Other methods for peak flow estimation or annual flow estimation may exist or have been derived for some areas in Tajikistan. It is recommended to approach the Agency of Hydro-Meteorology, Dushanbe, to inquire whether better methods are at hand for the specific area of concern.

3.4 Be your own data manager

Usually, information and data about flood events are not sufficiently available, especially small tributaries lack reliable information. It is a good idea to engage voluntarily in making observations and to learn and understand the hydrological behaviour of a catchment area. Therefore, this guideline wants to encourage readers to become a volunteer and active observer of hydro-meteorological parameters. Thus, making notes about hydro-meteorology in a structured way raises awareness about natural processes and at the same time, might help engineers, communities, agencies and flood managers in their effort to improve data gaps.

Nowadays, conducting observations is rather easy with mobile phones equipped with cameras, GPS and all sorts of more or less useful apps. Although observations, which are encouraged here, may not correspond to the standards of the World Meteorological Organisation, they can still provide valuable information and shed light on hydro-meteorological behaviour of areas which remain completely unobserved otherwise.

Precipitation:

An instruction about rainfall measurements are given in (FAO, 1989). However, even without using a rain gauge, making notes about rainfall with explanations about intensity is a valuable contribution. An example table for simple rainfall observations is given below:

Table 1: Example for making rainfall observations

Rainfall		Remarks	Location	Observer	Rainfall depth
Begin	End				
14 March 2018 07:30	14 Mach 2018 12:00	High intensity rain between 10:00 and 10:30, low intensity during the rest of the time	Coordinates of location, for example from mobile phone's GPS	Name, mobile phone number and address of observer	Estimated: not more than 8 litre/m² (if an estimate can be given)

Snow:

Measurement of snow is as important as rainfall in Tajikistan. The simplest way of measuring snow is by using a white board with a ruler. The board should be equipped with flags so that it is easy to find it after snowfall. White colours are better than dark to avoid melting because dark colours absorb more radiation. Once the snow is on the board, a ruler can be used (the longer the better) to obtain the snow depth. The board should be sited away from buildings or other objects as they are warmer and can cause snow drift.

source: https://www.theweathernetwork.com/us/news/articles/measuring-snowfall-is-not-as-simple-as-it-may-seem/75819

It is obvious that this method yields only the snow depth which does not correspond with the water equivalent of snow. To obtain the water equivalent, snow must be melted and the resulting amount of water recorded. Observations once a day are considered as sufficient.

Table 2: Example for making snow observations

Reading	Remarks	Location	Observer	Snow depth	Photo
14 March 2018 08:52	Still snowing, temperature < 0°C	Coordinates of location, for example from mobile phone's GPS	Name, mobile phone number and address of observer	Figure in mm	Photo from the site with the board

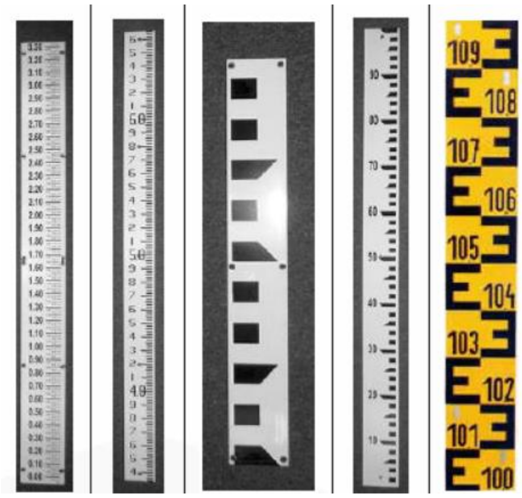
Water level:

Observations of water levels are helpful to link rainfall to flow or when the extent of flooding and affected areas is of interest. Water level recording requires a reference point which is ideally an immobile, solid structure at a water body or river bank that is not subject to change, for example a pillar of a bridge, a rock, a solid building, etc.

A staff gauge is usually used to record water levels. A staff gauge is a long ruler placed in a water body that is used to measure water surface elevation or just to determine the rise/fall of the water surface over time. The staff gauge can be mounted or, if no material is available, painted to a solid structure.

Picture: (USACE, 2016)

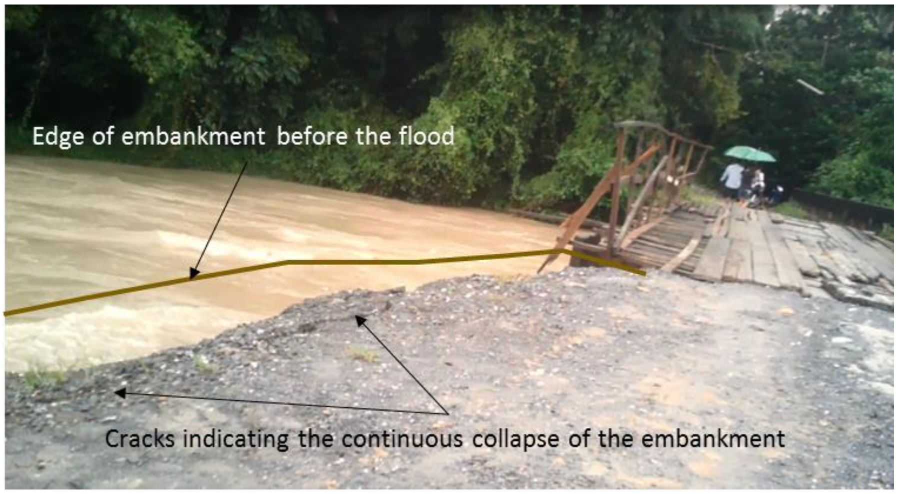
Staff gauge at the Mbuluzi River, Swaziland



The photo shows some types of number plates that can be used for staff gauges. If no number plates are available, a simple staff gauge can be made using lath and a marker. Using a tape measure, draw the scale and numbers on the lath.

Picture: (USACE, 2016)

Siting the staff gauge is important so that it is ideally not overtopped during a flood event, not affected by backwater and still accessible to make readings. An observer should never risk to get caught in a dangerous situation while conducting readings. Especially during flood events with fast flowing water and unstable river banks, it is not advisable to stay too close to the river banks. To make readings from the distance, the numbers and markers should be large enough and coloured. Use the zoom function of a mobile phone's camera.



South Thailand, 2013

Using a pillar of a bridge for a staff gauge is only meaningful when the place from which the staff gauge is visible remains stable and accessible during a flood event. The picture above shows the situation where the embankment was washed away step by step and became inaccessible to visit the pillar with the staff gauge underneath the bridge.

Table 3: Example for making water level observations

Reading	Remarks	Location	Observer	Water level	Photo
14 March 2018 08:52	Water level still rising, approx. 5 cm within 2 minutes	Coordinates of location, for example from mobile phone's GPS	Name, mobile phone number and address of observer	Figure	Photo from the site with the staff gauge

Keeping the records

Information gathered can be kept locally or further distributed by means of social media. A new way of flood monitoring supported by social media is crowd sourcing. Crowd sourcing came into being due to the advent of social media where available news feeds are continuously scanned in real time on the internet with regard to certain topics to monitor and aggregate flood news.

The freely accessible Europe Media Monitor (EMM) is a fully automatic system that analyses both traditional and social media. It gathers and aggregates about 300,000 news articles per day from news portals world-wide in up to 70 languages.

EMM is the news gathering engine behind a number of applications, including the Global Disaster Alert and Coordination System (GDACS). EMM monitors the live web, i.e. the part of the web that has ever changing content, such as news sites, discussion sites and publications. It was developed and is maintained and run by the European Commission's Joint Research Centre (JRC).

http://emm.newsbrief.eu/emmMap/?type=category&language=&category=Flooding).

Global Flood News monitors mainstream and social media specifically in regard to floods. It also performs crowd sourcing for flood related information and flood detection. Global Flood News works closely with the Global Flood Awareness System (GloFAS), who are also working on a prototype for social media analysis for flood events.

http://www.globalfloodsystem.com

Both platforms offer Russian as language and explain how to upload reports with detailed information including photos.

3.5 Reliability of data

Data always contain uncertainties and even the best observations are never 100% accurate. Accuracy of rainfall measurement is mainly affected by wind, by the height of the gauge and exposure. Wind and exposure errors can be very large, even more than 50 percent. The catch of rainfall is a function of the height of the gauge, the more open the location the greater will be the difference in catch with height (FAO, 1989). Discharge measurements are not accurate either and ± 20 to 50% are a common range of accuracy.

The fact that data are never constitutes a 100% representation of the reality must be kept in mind when data are used in formulas and results are interpreted. This means that it is wise to conduct a sensitivity analysis and check what if when figures would be higher or lower. This is why in most flood design procedures a safety margin should be applied in order to be on the safe side.

The following list sorts items according to their expected uncertainty and calculation methods. Items at the bottom of the list are more error prone and formulas are less reliable.

- Precipitation
- Discharge
- Snow
- Sediment transport
- Erosion

4 COURSE OF ACTION FOR PLANNING MEASURES

This flood management guideline builds on the Flood Green Guide (FGG) developed by (WWF, 2016) and adjusts it according to the requirements of Tajikistan. The WWF FGG framework provides 5 stages for the development of flood management and the selection of flood mitigation measures. The five stages taken from (WWF, 2016) are:

1. Preliminary analysis and assessment
2. Method identification
3. Method selection and design
4. Operation and monitoring
5. Project evaluation

The five stages can be translated into the following course of action.

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 derived. 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 combine mitigation measures are realised. Based on the type of the measure, the implementation of measures can range from building concrete protection infrastructure to policy changes or stakeholder training courses. In all cases, it includes emergency planning and the maintenance 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.

The course of action can be illustrated according to the Federal Office for the Environment (FOEN), Swiss Confederation (FOEN, 2016).

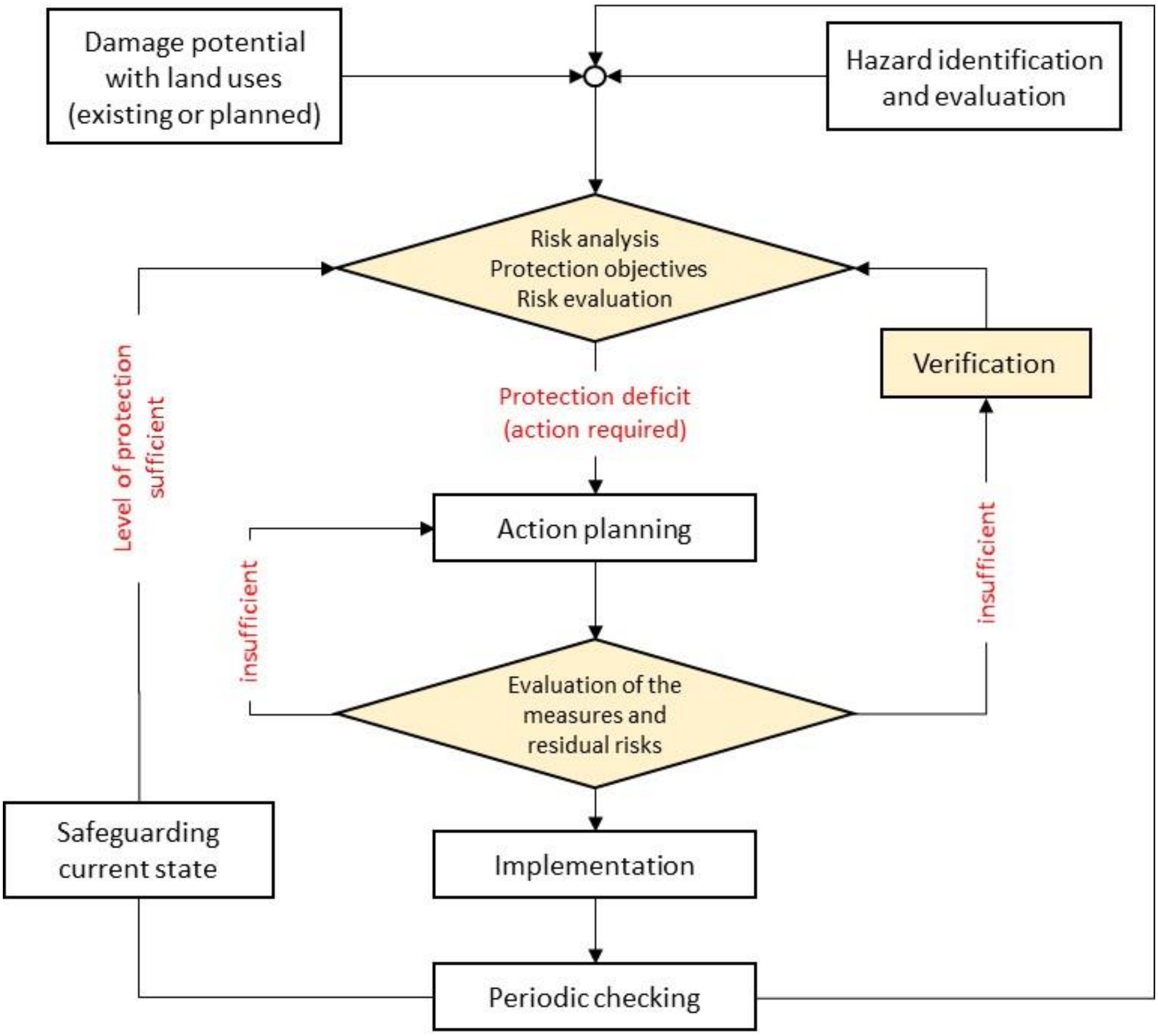


Figure 11: Action planning procedure (adopted from (FOEN, 2016)

4.1 Hazard identification

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 WWF Flood Green Guide (FGG) defines different flood hazard types

- Riverine/fluvial flooding
- Flash flooding
- Areal flooding
- Mudflow/Debris flow
- Rain on ice flooding
- Lake level flooding
- Coastal flooding
- Storm surge
- Tsunami flooding
- Urban flooding
- High groundwater

Not all flood hazard types defined in the Flood Green Guide are relevant or of major importance for Tajikistan. Consequently, this guideline focuses on selected hazards. Riverine flooding and areal flooding is a relevant hazard risk in Tajikistan. However, its management requires integrated planning and measures on very large/nationwide spatial scale and thus will not be covered in the guideline.

Given the topography and hydrology of Tajikistan, special emphasis will be put on torrential hazards. (Llano, 1993) gives a more detailed typology of torrential hazards, which would fall into the FGG-types of flash flooding, mudflow/debris flow and rain on ice flooding:

- Landslides
- Gully formation
- Torrential mudflows
- River flooding
- Other periodic events, e.g. avalanches

The occurrence of different flood hazard types is closely linked to catchment characteristics, mainly its topography, land use/land cover and prevailing hydrologic boundary conditions. In essence, catchments with steep slopes and heavy rainfall are particularly prone for torrential hazards. The WWF Flood Green Guide gives general definitions and summaries of important processes and potential damages for major torrential flood hazards (WWF, 2016):

- Flash floods are normally local events. Normally, small to medium areas are affected. The flow is characterized by a very fast onset and a short duration but high flow volumes. Hydrological 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 reason 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 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 travel 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 high 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).

4.2 Torrent classification

For risk assessment and risk classification of watersheds, a methods is presented based on the approach of (Dvořák & Novák, 1994). The method evaluates the characteristics of a stream with regard to its proneness for torrential flows and torrential flood hazards. Land use, stream density, topography, soil characteristics in combination with the current status of a watershed regarding erosion are input from which a GIS based analysis can be carried out.

Škopek (1982, 1987, cited from (Dvořák & Novák, 1994)) proposed a "watershed torrent coefficient" K_b to distinguish torrential water bodies from other streams and rivers, Equation 1 is derived from the Gavrilovich-formula (Gavrilovich 1972, cited from (Gavrilovic, Stefanovic, Milovanovic, Cotric, & Milojevic, 2008)), an erosion potential estimation method (Dragičević, Karleuša, & Ožanić, 2017).

$$K_b = \frac{H \cdot O \cdot V_S \cdot P \cdot E \cdot \sqrt{S+1}}{L \cdot \sqrt{S_Z + 1}}$$ *Equation 1*

where	Kb	=	Watershed torrent coefficient [-]
	H	=	Density of hydrographic network [km · km^{-2}]
	O	=	Length of the watershed line [km]
	V_S	=	Mean altitude difference [km]
	P	=	Coefficient of the mean permeability of the soils
	E	=	Coefficient of the watershed's propensity for erosion
	S	=	Watershed area [km²]
	L	=	Length of the main stream [km]
	S_Z	=	Area of the afforested part of the watershed [km²]

The density of the hydrographic network is calculated with Equation 2.

$$H = \frac{L + \sum L_i}{S}$$ *Equation 2*

where	H	=	Density of hydrographic network [km / km^2]
	L	=	Length of the main stream [km]
	L_i	=	Length of the separate tributaries [km]
	S	=	Watershed area [km²]

The formula for the mean altitude difference with regard to the whole catchment (or the sub catchment for which the torrent coefficient is calculated for) is given in Equation 3

$$V_S = V_P - V_U$$ *Equation 3*

where	V_S	=	Mean altitude difference [km]
	V_P	=	Average altitude (above sea level) of the catchment [km]
	V_U	=	Altitude (above sea level) of the river mouth (or the location for which the torrent coefficient is calculated for) [km]

The average altitude of the catchment is calculated by Equation 4.

$$V_P = \frac{\sum S_i \cdot h_i}{S}$$ *Equation 4*

where	V_P	=	Average altitude of the catchment [km]
	S_i	=	Area of watershed between two neighbouring contour lines [km²]
	h_i	=	Mean altitude between two neighbouring contour lines [km]
	S	=	Watershed area [km²]

The forested area S_Z of the catchment can be taken from land use information directly. However, as S_Z is an indication for the protection of bare ground by vegetation cover, the forested area S_Z can be calculated with Equation 5 for catchments with a sparser forestation. By using Equation 5 for the calculation of S_Z, cover of soils by forests and permanent grassland is accounted for.

$$S_Z = 0.6\, S_F + 0.8\, S_G + 1.0\, S_B \qquad \text{Equation 5}$$

where S_Z = Forested catchment area [km²]

S_F = Afforested part of catchment [km²]

S_G = Grassland (meadows, pasture) covered watershed [km²]P

S_B = Part of catchment with predominant arable land or bare soils [km²]

The coefficient P describing the mean permeability of the soils of the watershed considered can be taken from Table 4. Estimates for the coefficient of the watershed's susceptibility for erosion can be taken from Table 5, where visible erosion characteristics of a catchment are described and linked to respective values for the coefficient describing the erosion tendency of the catchment.

Table 4: Coefficients of mean soil permeability of the catchment (P) for different types of soil (Dvořák & Novák, 1994)

Degree of soil permeability	Type of soil	P
Totally impervious	Rocks Heavy clayey soil	1.00
Impervious	Clayey soil	0.90
	Peat Swamps	0.80
Not very permeable	Clay loam Grey forest podzol	0.70
	Loam to clay loam	0.65
Permeable	Loamy soil Limy chernozem	0.60
	Loamy sand	0.55
	Loamy sand to sandy loam	0,50
Very permeable	Sandy soils Sands Gravels	0.45

Table 5: Coefficient E of a watershed's tendency for erosion (Dvořák & Novák, 1994)

Intensity of erosion in the catchment and stream channel	E
Whole watershed affected by all types of erosion, stream channel devastated by both lengthwise and crosswise erosion, rough sediment continuously removed, transported	1.0

and deposited. Exposed soil surface without sufficient vegetation cover prevails in the whole watershed. The slopes have a gradient of more than 50%.	
Up to 80% of the watershed area is affected by rill and gully erosion. Transport and accumulation of rough sediment prevail in the stream channel.	0.9
Up to 50% of the area of the watershed is affected by furrow, rill and gully erosion. The gradient of the slopes is above 30%. There is significant transport and intensive accumulation of coarse sediment in the stream channel.	0.8
Furrow and rill erosion types prevail in the watershed. The slope gradient is above 20%. Gravel and cobbles are transported in the stream channel.	0.7
Sheet erosion and sporadically also rill erosion, prevail in the watershed. There is significant crosswise and lengthwise erosion in the channel, with transport of gravel.	0.6
Sheet erosion affects up to 50% of the watershed, furrow erosion becomes rill erosion, and gravel is transported and accumulated in the channel. The slopes in the watershed have gradients of up to 20%.	0.5
25 - 30% of the watershed area is affected by sheet erosion, furrow erosion occurs in some places. There are sites of movement of finer sediment - this sediment is transported and deposited in the stream channel. The gradient of the slopes is 10- 15%. The vegetation cover is disturbed - forests are affected by industrial emissions.	0.4
About 20% of the watershed area is affected by sheet erosion, in some places by furrow erosion. There are distinct signs of the topsoil's being washed away. Fine sediment is transported in the channel of the stream.	0.3
The whole watershed is free of distinct signs of erosion. There is a large proportion of farmed land in the watershed. Sediment largely develops through erosion in the stream channel. The slopes have gradients of up to 20%.	0.2
Whole watershed free of visible signs of erosion. Forest covers a prevailing part of the area and has a good species and age structure. The remaining area is perennial grassland. The channel of the water course is stabilized in both direction and gradient.	0.1 - 0.0

Combining the different factors representing catchment topography, stream network, soil, erosion tendency, land use, soil cover leads to the "torrent coefficient" K_b, which can be grouped into five different categories describing the torrential characteristics of the water course/catchment assessed. The classification given in Table 6 range from water courses of non-torrential nature (category I) water courses with very strong torrent characteristics (category V). A flood risk protection scheme naturally should take into account these different categories to prioritize mitigation measures. This could encompass the understanding that technical flood hazard protection may be impossible for torrential water courses with very/extremely strong torrent characteristics and thus, human settlements should be forbidden totally in its affected area. As the damage potential is higher the bigger the torrent coefficient K_b gets, mitigation measures can be prioritized for catchments/areas with water courses of strong torrent characteristics and subsequently expanded to catchments with water courses of less strong torrent characteristics.

Table 6: Classification of streams regarding their torrentiality (Dvořák & Novák, 1994)

K_b	Category	Characteristics of the water course

< 0.1	I	Water course of non-torrential nature
0.1 – 0.4	II	Torrent with a low intensity of erosion
0.4 – 0.7	III	Torrent with medium strong torrent characteristics
0.7 – 1.0	IV	Torrent with strong torrent characteristics
> 1.0	V	Torrent with very strong torrent characteristics

Similar methods for accessing the torrential nature of catchments or its erosion proneness are published.

(Gavrilovic, Stefanovic, Milovanovic, Cotric, & Milojevic, 2008) developed a torrent classification as base of a management strategy of erosive prone regions which is an evolution of the torrent classification of the Škopek-formula presented here. Based on the torrent classification the required scope of erosion-control measures are derived.

A general review of the Gavrilović method (erosion potential method) and its modification was performed by (Dragičević, Karleuša, & Ožanić, 2016). They present a good overview of the original method, its different modifications (e.g. for estimating the torrential potential of catchments and streams), its possible application in geographic information systems, and its worldwide application. Following, (Dragičević, Karleuša, & Ožanić, 2017) performed a sensitivity analysis of the erosion potential method (Gavrilović method). They found that the most sensitive parameters for the Gavrilović method are the soil erodibility coefficient and the soil protection coefficient.

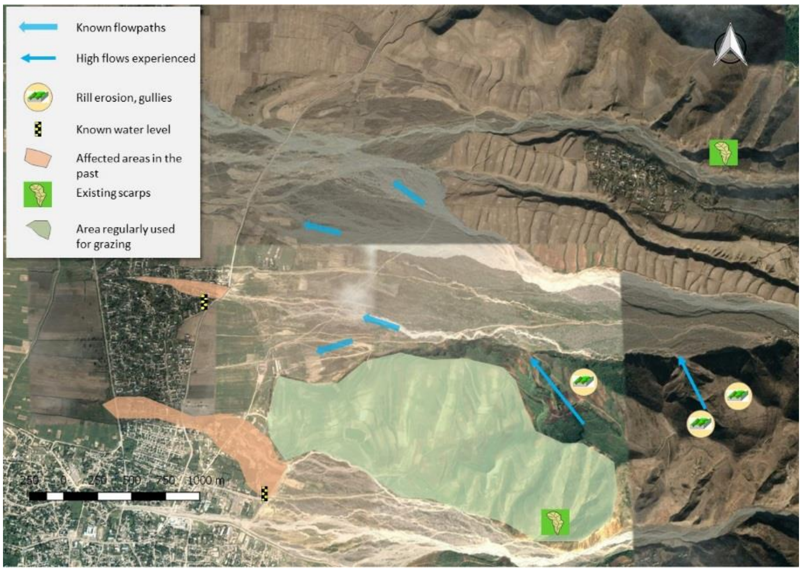
4.3 Risk assessment

The process of assessing the risk is the first task to be done. It is paramount to assess the magnitude and extent of flood hazards, to identify locations where the hazards would strike and what kind of countermeasures can be done. The risk assessment should also identify which factors favour hazards, for example poor watershed management with high runoff rates and erosion. By adopting the approach given in (WWF, 2016), risk assessment consists of five topics.

Inventory of past flood events

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

- Type of floods that have occurred in the past including spatial and temporal extent frequency, month, duration
- Draw their 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 the map
- Indicate major flood formation areas in the map



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 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 to support the investigation.

Figure 12: Example of a simple flood inventory map based on knowledge from past events

Factors contributing to flooding

Factors contributing to flooding need to be listed and drawn on a map. In a second step they can be classified as anthropogenic (as a result of human action) or natural.

Damage incurred or expected

The locations affected should be indicated on a map and damages listed with as much detail as possible. Valuing damage in monetary terms is preferred. 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, apply the damage inventory 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 13. 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.

In rural areas, it is often the best solution in terms of cost-effectiveness 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, e.g. a 100 year flood or more, in high risk areas –

unfortunately large rural areas in Tajikistan are high risk areas – 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.

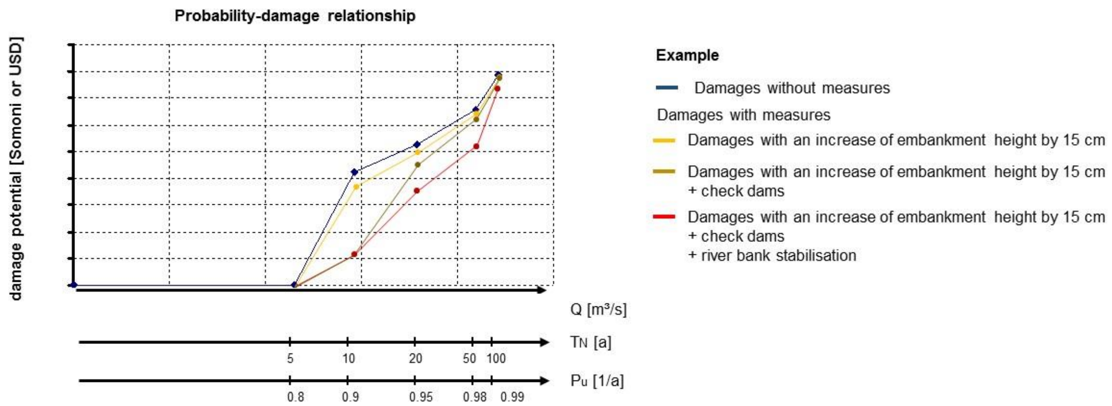


Figure 13: Probability-damage relationship for different measure

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

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, etc. These groups should be marked on the map and special attention should be paid while dealing with flood management and planning measures.

Capacities to respond to flooding

Capacity is the ability to resist or respond to damage caused by flooding. Vulnerable groups and institutions are in the focus here. Vulnerable groups ofen lack sufficient means to cope with floods and thus need support to strengthen their capacities. This must be taken into account while flood management is developed and measures are planned.

Communities and institutions are commonly seen as the authority who takes 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, planning measures and
- institutional development determining clear roles and responsibilities, capacticy development, financing mechanisms and an appropriate regulatory framework

4.4 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 flood modelling. Different types of flood maps should be developed to support the selection process of proper measures but also to account for emergency preparedness. Four maps are shown with different information.

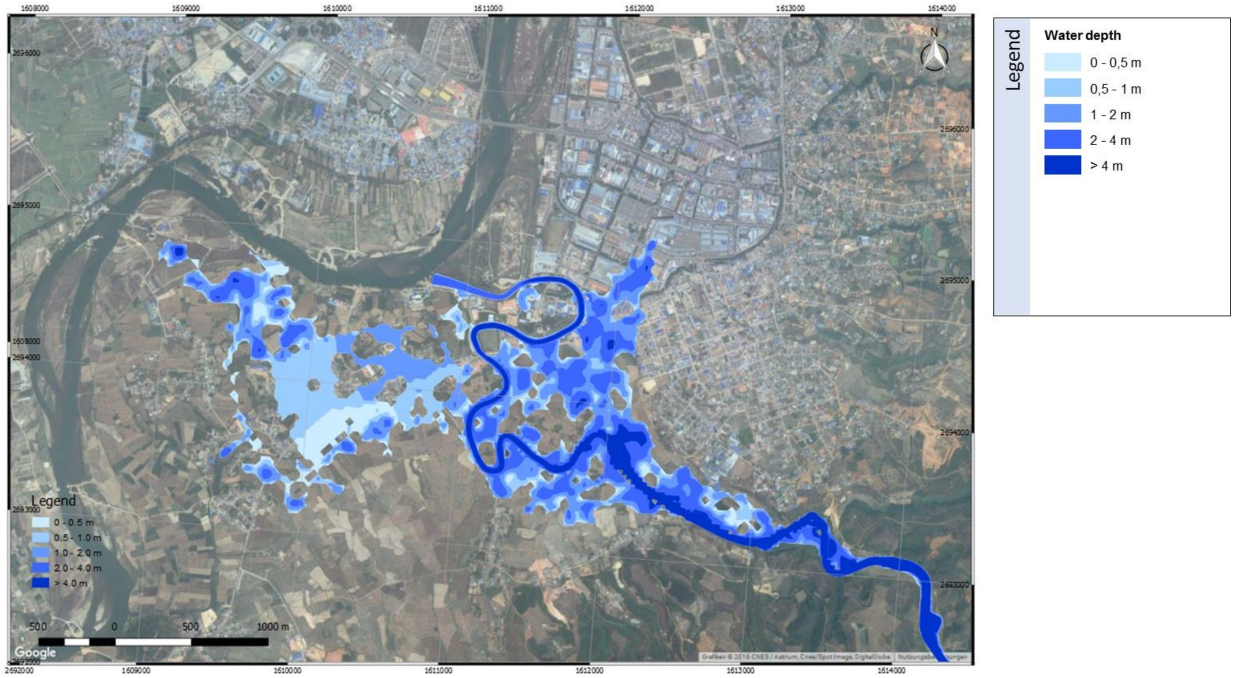


Figure 14: Inundation map with water depth categorised in 5 classes.

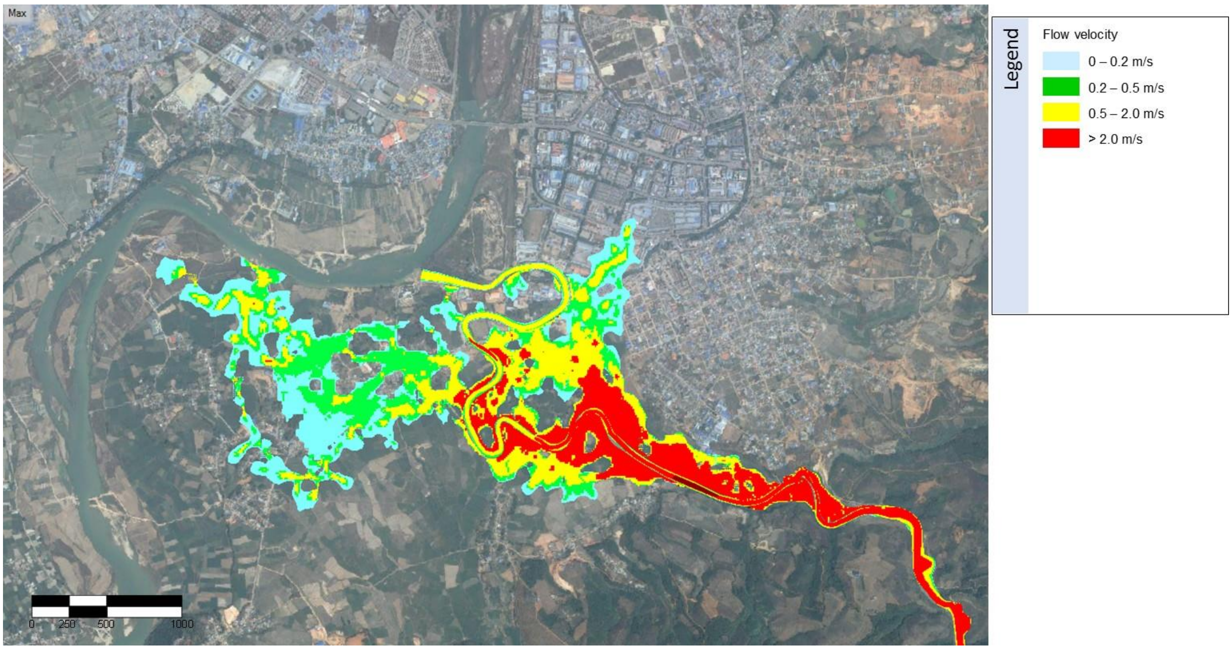


Figure 15: Flow velocity map indicating the risk to be washed away

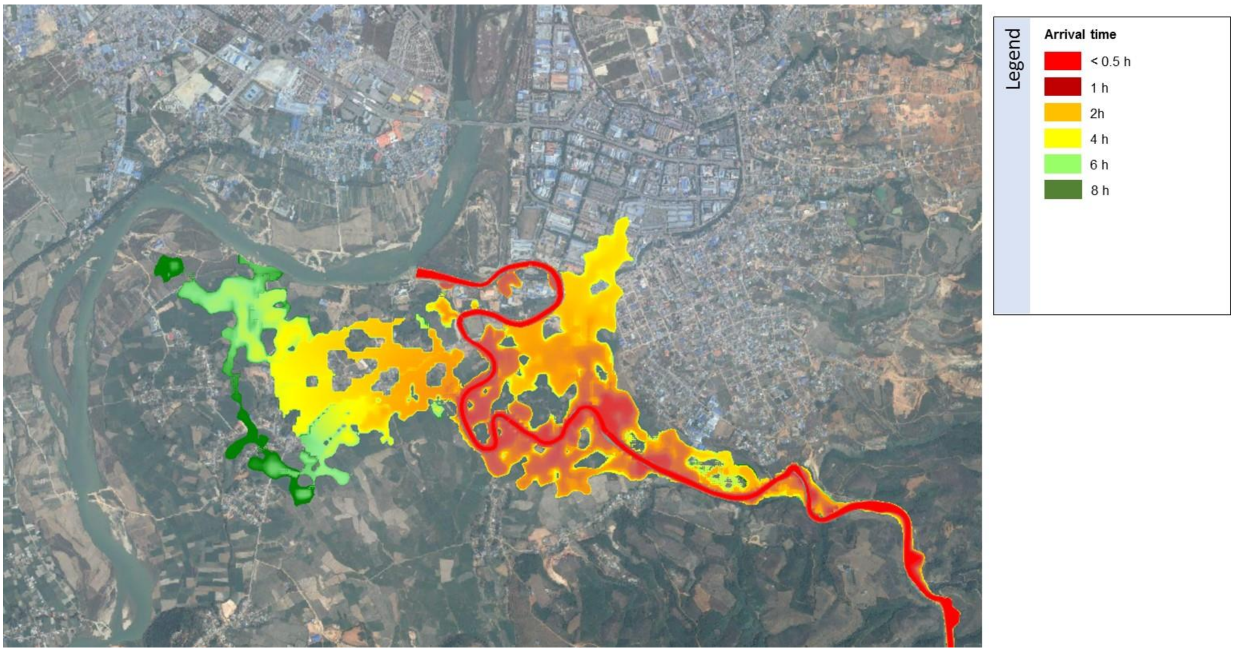


Figure 16: Arrival time map indicating time for preparation

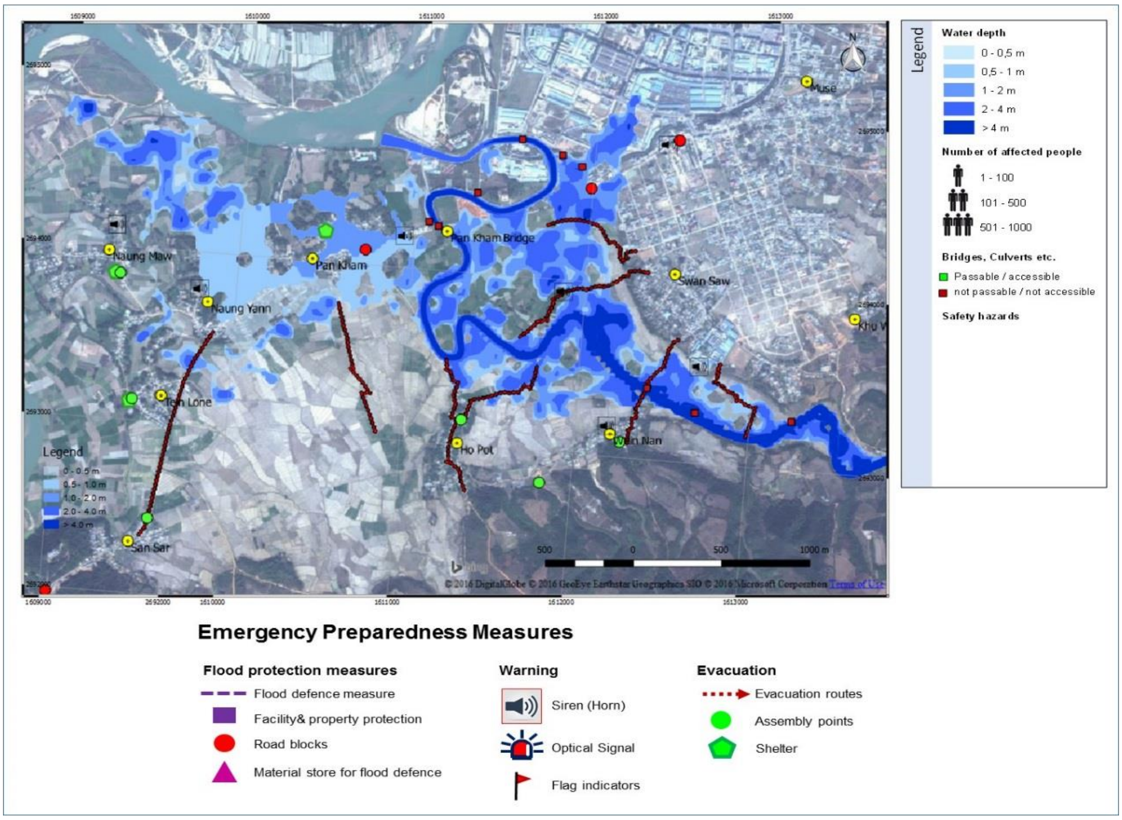


Figure 17: Flood action and emergency preparedness map (SYDRO, 2017)

Requirements for flood mapping are:

- Suitable digital elevation model
- Hydrological modelling for deriving flow
- 1D or better 2D hydraulic modelling for deriving flood extent
- GIS tool to prepare the maps

The data sources and proper tools for developing flood maps are given in Part II and Section 3.2.

4.5 Design flood

A level of protection must be determined and agreed on to identify whether or not intervention is required. The level of protection is either compulsory by law or should be determined in a joint decision-making process including all affected stakeholders. The level of protection usually defines a certain probability of occurrence expressed as rate of flow or water level and measures are designed to contain flood events up to this level. The level of protection is not a physical process but more a political decision. Demanding a high level of protection, e.g. HQ100 – a flood event that occurs statistically once in hundred years, will imply very high costs for implementation. Therefore, it is recommended that selecting design discharge fulfils the five criteria given in Section 4.3. A suggestion for levels of protection for differently used areas is given by (Dvořák & Novák, 1994).

Table 7: Level of protection (design floods), adopted from (Dvořák & Novák, 1994)

Level of protection	Values at risk	Design discharge for channel capacity
1	Compact built-up urban area, larger housing estates, larger villages, industrial plants, important linear structures running parallel (highways, railways, etc.), protected monuments	$Q_{50} – Q_{100}$
2	Smaller villages, groups of houses, sporadically built up valleys (distance between homes not less than 100 m), roads of local importance, forest haulage roads, dumps, recreational resorts, fields of endangered by gullying	$Q_{20} – Q_{50}$
3	Outside built up areas – intensive agricultural protection, skidding and other forest roads	$Q_5 – Q_{20}$
4	Outside built up areas – meadows, production forests, irrigation and drainage facilities	$Q_5 – Q_{10}$

4.6 Selection of measures

As mentioned in the introduction of this document, this manual focuses on smaller watersheds with mostly hilly or mountainous topography. Streams in these watersheds own a high seasonality and heavy rainfall and/or snowmelt give often rise to gully formation, torrential mudflows, river flooding, landslides and other periodic events. This is why torrent control and streambed stabilisation, among others, is considered essential.

Although every watershed is different, there are some similar characteristics. In general, mountain watershed can be divided into three sections:

1. The **Headwater area** or **collection area** is characterised by steep slopes and is the origin of fast flowing runoff and origin of sediment transport (erosion, landslides, rock fall, etc.). Water and sediments are collected within the headwater area and concentrated into the transport reaches.
2. A **transport reach** (which is not always found in torrential catchments) concentrates water and sediments from the collection area. Depending on the gradient, transport reaches in torrential watersheds are mostly erosive and further material (sediments, material from the stream bed and stream banks are) is accumulated.
3. With the reduction of slopes, the **alluvial cone** or **debris cone** is formed, also called **deposition area**. The flow exits the confined channel reaches, widens, slows down and loses part of its energy. Velocity and transport capacity of the flow decrease and the eroded material from the headwater area and the transport reaches is deposited again. Watercourses in a deposition area often change due to sedimentation along the river bed and banks.

Different hazards for areas with anthropogenic land use may result from the different processes in the three sections (Rimböck, Höhne, Mayer, & Wolter-Krautblatter, 2015):

- Displacement of sediments on hill slides may lead to rock falls destroying houses or infrastructure or block roads and other pathways. Landslides may lead to the slipping of houses and/or other infrastructure.
- Erosion may expose fundaments, undermine protection walls and result in further landslides and/or a total displacement of stream stretches.
- The transport of water and debris may damage houses and infrastructure through impact load or water damage.
- Deposition may block bottlenecks, leading to flooding, the covering of huge areas with debris and/or a displacement of stream stretches.

Summarizing, the typical form of a torrential catchment resembles an hourglass. Material is collected in the headwater area like in a funnel, transported through the transport reaches and deposited in the deposition area again. After the deposition of sediments and debris, the water follows the natural topography.

Measures can generally be subdivided into groups depending on the purpose and according to their location within a watershed.

- Stopping erosion in the headwater area and foster ecosystems in order to alleviate the development of floods of torrential nature
- Stabilization of the channel and the retention of debris in the transport reach
- Retaining watercourses sediments in dedicated areas to hinder an uncontrolled expansion
- Facilitating flow through urban areas by maintaining urban drainage capacities
- Framing flood plain and land use management to foster flood resilience and safeguard ecosystems

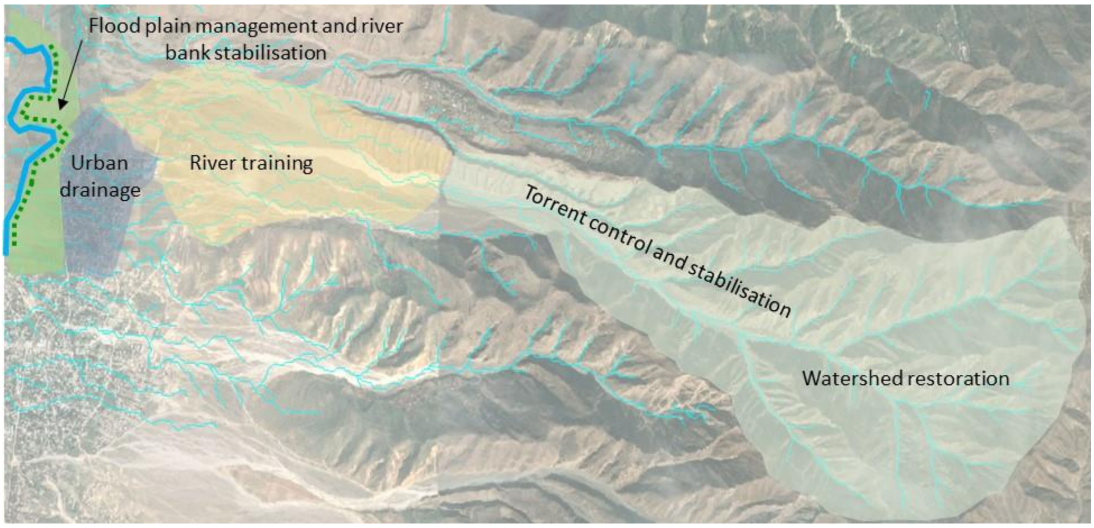


Figure 18: Watershed characterisation regarding potential interventions

Accordingly, the three main strategic pillars for intervention are:

- Watershed management / watershed rehabilitation
- Structural measures
- Non-structural measures

Flash flood mitigation in the upstream part of a catchment aims at reducing the occurrence of flash floods and focuses on reducing slope instability, reducing the amount and velocity of runoff and preventing erosion. In the downstream areas, the focus is on mitigating the effects and impact of any flash flood that occurs. River training refers to the structural measures which are taken to improve a watercourse and its banks. River training is an important component in the prevention and mitigation of flash floods and general flood control, as well as in other activities such as ensuring safe passage of a flood under a bridge. For flash flood mitigation, the main aim is to control the water discharge regime in the watercourse by limiting its dynamic energy, thereby controlling the morphological evolution of the river training measures also reduces sediment transportation and thus minimise bed and bank erosion (*ICIMOD, 2012*).

Even though according to (WWF, 2016), soft or green measures should be given preference to the application of hard structural measures, it should be noted, that the damage potential of torrential flood hazards is high and difficult to contain by purely applying soft measures. In fact, it is most likely that a combination of measures may lead to the most sustainable flood risk management.

The process of selecting measures is supported by the following table, which links objectives with tasks to be achieved and measures.

Table 8: Selection of measures adopted from (Jakob & Hungr, 2005), (WWF, 2016)

Objective	Task	Measure
Disposition management		
Decrease runoff	Decrease peak discharge	Forestry management/Reforestation landscaping, terracing Watershed management, Harvesting control Road building control Swales and infiltration devices Diversion of runoff to other catchments
Decrease erosion	Decrease surface erosion due to overland flow	Forestry measures landscaping, terracing Soil bioengineering/Soil conservation measures Watershed management/Watershed restoration Drainage/Engineered drainage systems/ Swales and infiltration devices Debris clean out
	Increase slope stability	Forestry measures Soil bioengineering Terrain alteration (grading, scaling) Drainage control/Engineered drainage systems Swales and infiltration devices Stabilization of toe slope (e.g. consolidation, rock buttresses) Stabilization of debris sources
	Decrease vertical and lateral erosion in channel bed	Channel enlargement Channel-bed stabilization Transverse structure (sill, ramp, check dam) Longitudinal construction Groyne and revetment Soil bioengineering/Riparian vegetation restoration
	Decrease water discharge at high erodible channel reach	Diversion of runoff to other catchment Bypass
Event management		
Discharge control	Decrease peak discharge to prevent damage	Water storage/Small dams/Levees Channel enlargement (widening and deepening) Enlargement of cross sections at channel crossing Sacrificial bridges/ Fords Removal of barriers

Objective	Task	Measure
		Clean out of debris Diversion Floodway
Debris control	Transformation process Deposition debris under controlled conditions Debris flow deflection to adjacent areas Organ debris filtration Protection of roads	Debris flow breaker Permanent debris deposition Temporary debris deposition Deflection to area of lower consequence Debris shooting channel Organic debris rake Debris sheds
Preventive		
Reduction of potential loss	Debris flow transport and deposition without damage Local protection of objects (e.g. house, person, traffic rout)	Land-use planning (local, regional) Soil and watershed protection legislation Crop change and alternative land use Restrict use of hazard area Information, Education, Awareness, Preparedness, disaster risk management Specification of construction rules Flood and waterproofing (building regulations) Regular maintenance of protection structures
Event response		
Reduction of potential loss	Debris flow transport and deposition without damage	Flood monitoring and warning system Information/Warning system (before, during, after event) Warning and evacuating of hazardous areas Closing of traffic route Immediate technical assistance
	Upkeep of protective measures	

5 STRUCTURAL AND NON-STRUCTURAL MEASURES

5.1 Watershed management

Watershed restoration is the domain of biological or bioengineering measures on hillsides and along streams in the headwater area. Techniques applied are similar to those used in soil conservation (plant cover and water control). As watershed restoration aims at preventing or reducing runoff, it is the measure which addresses the root cause of flood formation. Whenever possible, any suitable bare, degraded watershed land should be managed to any other form of land use, preferably reforested. Fast growing species, however, are not really advisable since they provide neither effective interception nor soil cover. The hydrological features that should be kept in mind while thinking at watershed management are:

- Interception:
  The vegetation canopy retains raindrops and reduces their size and mechanical strength, thus protecting the soil from erosion caused by rain splash. Interception differs from absorbing a few millimetres of rain by leaves up to more than >10 mm by all year round green conifers.
- Soil stabilisation:
  The dense network of roots physically binds and restrains soil particles in the ground, while the above ground portions filter sediment out of runoff.
- Absorption:
  Roots absorb surface water and underground water thus reducing the saturation level of soil and the concomitant risk of slope failure.
- Infiltration:
  Plants help maintain soil porosity and permeability, thereby increasing retention and delaying the onset of runoff.
- Evapotranspiration:
  Vegetation transpires water absorbed through the roots.
- Surface runoff reduction:
  Plants, in particular the near-ground layer of small plants and shrubs, increase the surface roughness and reduce the velocity of surface runoff

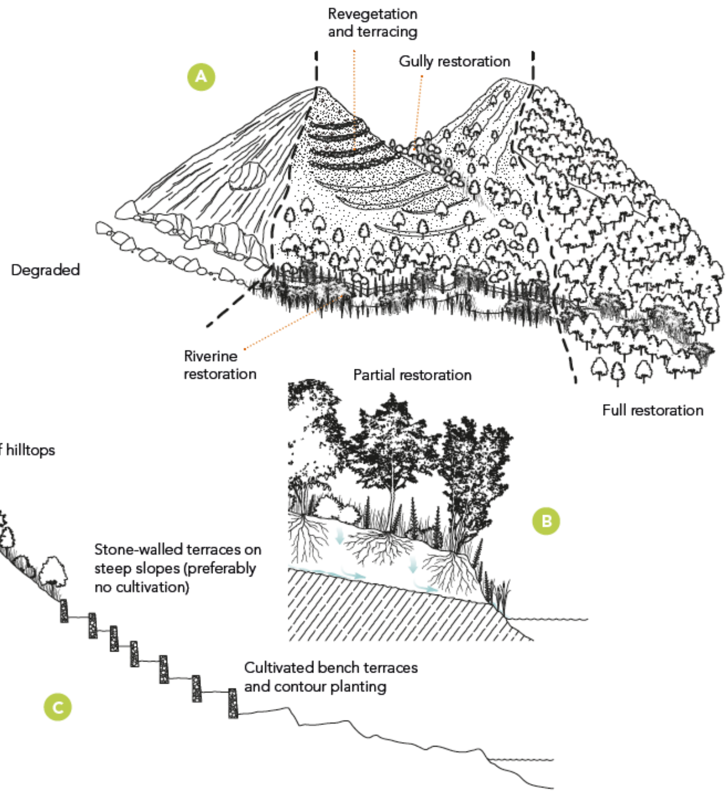
(adopted and modified from (ICIMOD, 2012)*)*

5.1.1 Integrated watershed management

Factsheet: Integrated watershed management	
Main objective(s)	Reduction of protection measures in transport reach and runout zone Restoration/Conservation Reduction of Runoff Reduction of erosion
Type	Active (Structural) Soft (EbA)
Location	Headwater
Scale	Catchment
Description	Integrated watershed management s aims at runoff and erosion reduction. The underlying concept is to reduce high costs for protection measures in the downstream catchment areas by low cost measured in the upper

catchment part. Major components are:

- Revegetation: Restoring natural vegetation, afforestation, protective forests, stand conversation
- Bioengineering: Slope and erosion protection, erosion control structures
- Terracing
- Drainage systems: Drainage of wet areas or hillsides to stabilize ecosystems in order to prevent glide planes and hill slides
- Agricultural measures: Grazing management, replacement of forest pasture



Upper watershed conservation: (A) Techniques applied in different scales and locations in a typical upper watershed landscape, (B) Cross section of a revegetated area, (C) Some low-cost soil conservations measures (WWF, 2016).

Schmittenbach, Austria in 1887 and 1976 after reforestation (Jakob & Hungr, 2005)

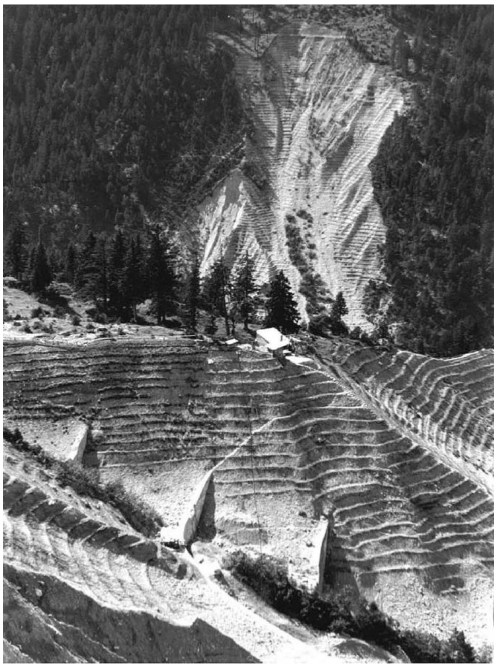
Design criteria	Revegetation should not change the natural habitat, but protect against natural hazards and be managed in a sustainable manner.

	(Extensive) Fertilizer application should be avoided. Failure of erosion control structures, bioengineering features and drainage system may cause safety issues, thus proper design is essential.
Duration until max. effectiveness	Medium/Long
Cost	Low/Medium
Maintenance	Regular control Regular revegetation (if necessary)
Evaluation criteria	Amount of surface runoff reduction Amount of erosion reduction Area reforested, area terraced, area restored with natural ground cover, area with stabilized soils
Notes	Aside from flood protection, all measures with regard to soil conservation and the restoration of natural ecosystems provide synergy effects for the protection of ecosystems, biodiversity and carbon emission reduction
Literature	(WWF, 2016), (Jakob & Hungr, 2005)
Internet:	https://www.wocat.net/ and many others

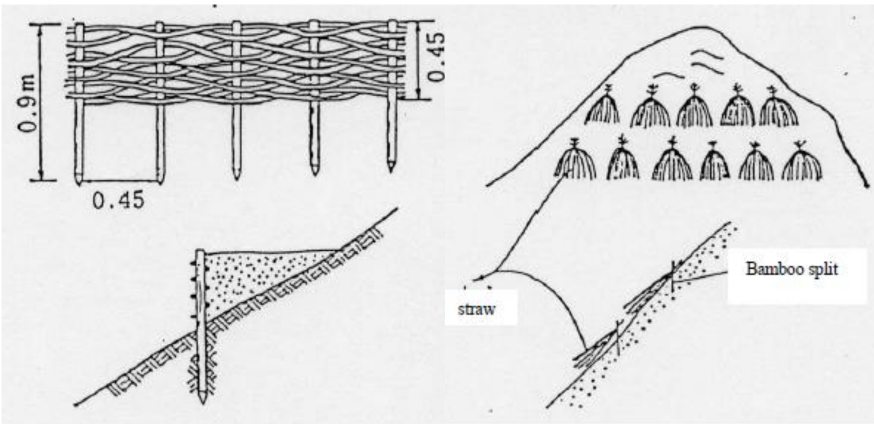
5.1.2 Soil bioengineering

Factsheet: Soil bioengineering	
Main objective	Reduction of protection measures in transport reach and runout zone Reduction of loss of fertile soils Erosion prevention, runoff reduction
Type	Active (Structural) Soft (EbA)
Location	Headwater/ Water body
Scale	Local/Catchment
Description	Soil bioengineering and/or terrain alteration applies live or dead plants to accelerate natural succession, thus stabilising soils and reducing erosion. Respective measures can be applied for: - Slope stabilization - Bank development - Channels, gullies, rivers, streams - Road ditches Longitudinal structures are (Jakob & Hungr, 2005): Tree spurs (rough coniferous trees), branch layering in gullies, vegetated channels, live brush mattresses, living slope grids, different fascines, vegetated revetments of different materials, log brush barrier construction, live pole construction, brunch and brush packing, and double-row palisades. Traverse structures are (Jakob & Hungr, 2005): living groynes, live siltation

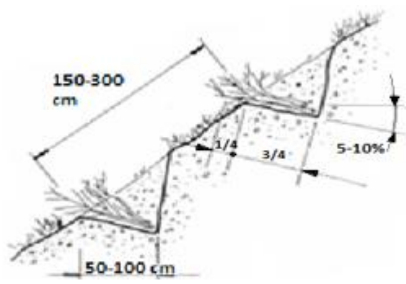
construction, living, combs, brushes and palisade constructions, brush sills, fascine sills, log crib walls, with brush layers, as well as planted gabions and wooden crib dams.



Slope stabilization, Austria (Jakob & Hungr, 2005)

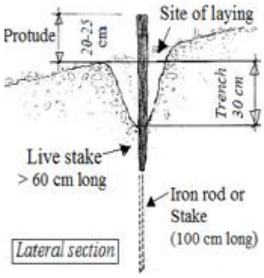


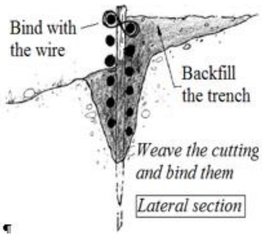
Example erosion prevention measure (STC, 2000) – Wooden post fence (left), Straw covering works (right), many more examples are given in (STC, 2000)



(CESVI, Soil Bioengineering Techniques, Leaflet 2, Brush Layering, 2017)

(CESVI, Soil Bioengineering Techniques, Leaflet 2, Brush Layering, 2017)





(CESVI, Soil Bioengineering Techniques, Leaflet 2, Brush Layering, 2017)
This examples are taken from leaflets prepared by CESVI. They demonstrate already applied soil bio-engineering techniques in Tajikistan.

Design criteria	Combination of surface protection (e.g. seeding) with stabilization structures has proven to be most effective. In water bodies, the applied stabilization structures have to withhold the friction forces during flood events. The longevity of soil bioengineering measures depends on the flood forces still present, thus, they are often combined with hard structural measures.
Duration until max. effectiveness	Medium – Long
Cost	Low – Medium
Maintenance	Regular control
Evaluation criteria	Amount of erosion reduction Area equipped with bioengineering measures Length of bioengineering measures placed Area revegated
Notes	Soil bioengineering measures often also reduce surface runoff and increase groundwater supply/recharge
Literature	(CESVI, 2013), (Jakob & Hungr, 2005), (Llano, 1993), (STC, 2000)

5.1.3 Recommendation

Intensive research in the alpine region has revealed that watershed management through planting and bioengineering measures increase soil stability and resistance against sliding. Tests have shown that plants are able to increase soil mechanical characteristics by their root system by 5°. In other words, the friction angle with plants is 5° higher compared to unvegetated soil (Graf, 2017).

The same research group (Graf, 2017) concludes that with respect to afforestation gaps in a protection forest in direction of the slope should not be longer than 20 (max. 30) meters to protect against avalanches and landslides. The width of a gap in a protection forest, however, is less important. A rich diversity of different trees and age of plants is superior to monoculture with only one type of tree.

Landslide prone areas are particularly susceptible against the application of fertilisers and grazing due to increased nutrients and soil compaction and destruction of the topsoil.

An example is provided regarding terracing (see Part II). The example shows how hydrological analysis can contribute to assess the effectiveness in terms of erosion. Part III provides examples or already conducted interventions in various areas in Tajikistan regarding watershed management.

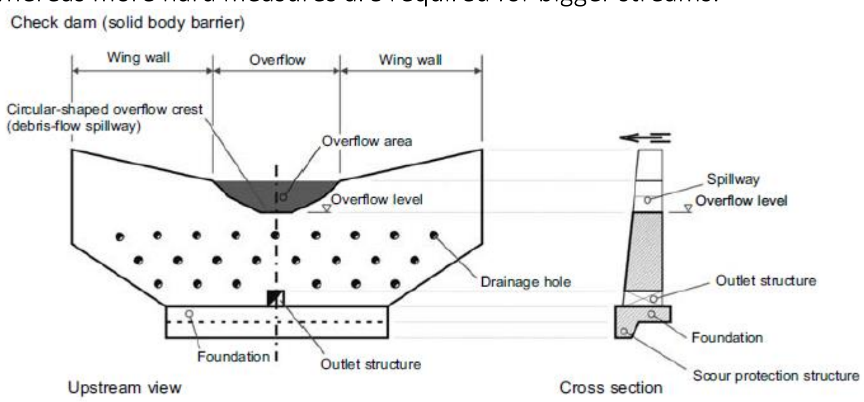
5.2 Measures for torrent control and streambed stabilisation

The aim of torrent control is to develop an equilibrium bed slope in a torrent so that bed erosion and incision is in balance with deposition. Torrential streams develop a high tractive force which exceeds the resistance of particles defined as the critical force at which material starts to move. The tractive fore depends on flow, its specific gravity and the gradient (see Part II). A reduction of the gradient will reduce the tractive force. Any decrease of the specific gravity due to measures retaining sediment upstream, will reduce shear stress. Finally, measures upstream retaining water and reducing peak flows alleviate the tractive force.

Torrent control and streambed stabilisation is the domain of traverse structures. Check dams are the preferred measure. They can be built in various forms either as hard or soft measures. Significant effort is needed to achieve proper design and siting.

5.2.1 Traverse channel protection measures

Traverse channel protection measures	
Main objective(s)	Channel stabilization Erosion control
Type	Active (Structural)’ Soft (EbA) / Hard
Location	Transport reach
Sphere of influence	Local/Catchment
Description	The main function of transverse structures is the reduction of channel gradients. The height and distance between transverse structures is defined by the original channel slope and the desired channel slope for protecting the stream bed which is generally considered as a rule of thumb by 3% ((FAO, Gully Control, 1986). Transverse structures can be built with natural materials for small sized structures in small water bodies (EbA), whereas more hard measures are required for bigger streams.



Sketch of a typical check dam (Jakob & Hungr, 2005)

Transverse toe slope stabilization, Austria (Jakob & Hungr, 2005)

Top: Small wooden check dams, Bottom: Small stone check dams, the right one with a metal gabion mesh (Rimböck, Höhne, Mayer, & Wolter-Krautblatter, 2015)

Design criteria	Transverse structures have to withstand the impact of flood and debris floods, the scouring processes at its lateral abutments, the scouring downstream of the dam and the lateral bypassing of the structure (Jakob & Hungr, 2005). Drainage is important to reduce the static water pressure.
Duration until max. effectiveness	Hard structures – Immediate Soft structures – Medium
Cost	Medium – High
Maintenance	Stability control (hard structures) Check for weathering (soft measures)

	Clean out of debris after events
Evaluation criteria	Reduction of erosion
Notes	-
Literature	(Jakob & Hungr, 2005), (Rimböck, Höhne, Mayer, & Wolter-Krautblatter, 2015), (STC, 2000), (Dvořák & Novák, 1994), (DPHW, 2010)

Three types of check dams are considered in more detail as they will most likely be the favourite options in Tajikistan: Loose stone check dams, boulder check dams and gabion check dams.

Loose stone check dams:

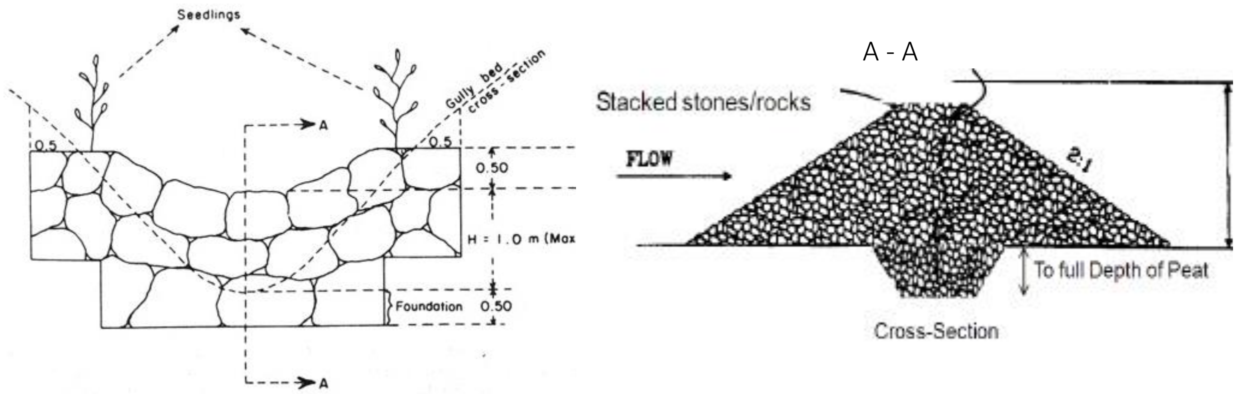


Figure 19: Loose stone check dam (FAO, Gully Control, 1986) and (Seng, 2011).

Loose stone check dams made of relatively small rocks are placed across the gully. They are predominately used to stabilize small gullies with rather small catchment areas (2 ha or less). These dams can be used in all regions, preferably when stones are available at the site.

Specifications according to (FAO, Gully Control, 1986) are:

The maximum effective height of the dam should not exceed 1.0 m and its foundation depth is at least 0.5 m. The thickness of the dam at spillway level is 0.5 to 0.7 m and the inclination of its downstream face is 20 percent (1•1/5 ratio); the thickness of the base is computed accordingly. The upstream face of the dam is generally vertical.

The foundation of the dam is dug so that the length of the foundation will be more than the length of the spillway. The foundation of the wings should be dug in such a manner that the wings will enter at least 50 cm into each side of the gully. The crest and middle part must be constructed with bigger rocks than the rest of the dam.

To avoid scour, the immediate area beneath the downstream face should be lined as well as the wings and abutments.

Boulder check dams:

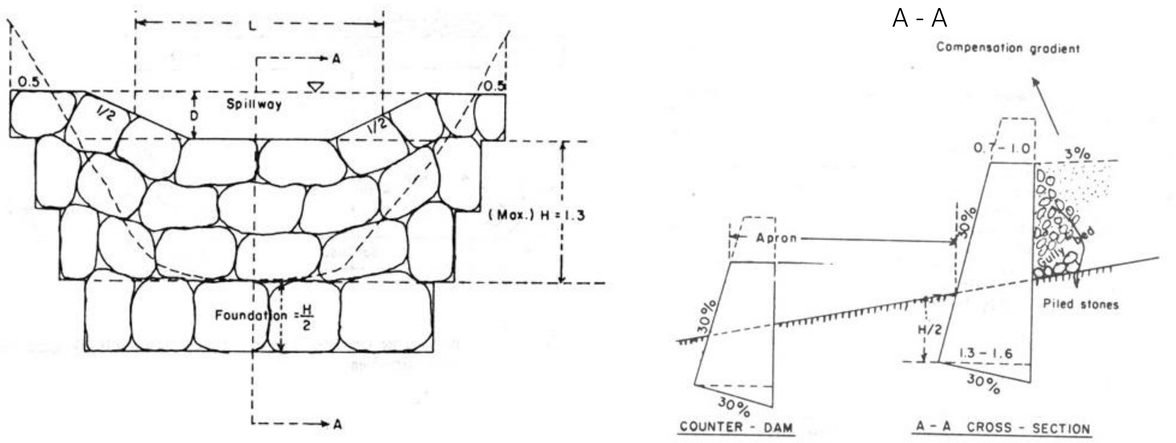


Figure 20: Boulder check dam (FAO, Gully Control, 1986).

Specifications according to (FAO, Gully Control, 1986) are:

Boulder check dams can be used in all regions. The maximum total height of the dam should not exceed 2 m. Foundation depth must be at least half of the effective height. The thickness of the dam at spillway level is 0.7 to 1.0 m and the inclination of its downstream face is 30 percent (1:0.3 ratio); the thickness of the base is calculated accordingly. The upstream face of the dam is usually vertical.

Calculating stability against overturning, collapsing and sliding is not necessary as long as the recommendations above from FAO are met. From the hydraulic viewpoint, the form of the spillway is ideally trapezoidal and formed like a venture channel minimizing hydraulic resistance. This is difficult to achieve with gabions alone but can implemented with stacked stones covered with wire and fixed to the underlying gabions.

Gabion check dam:

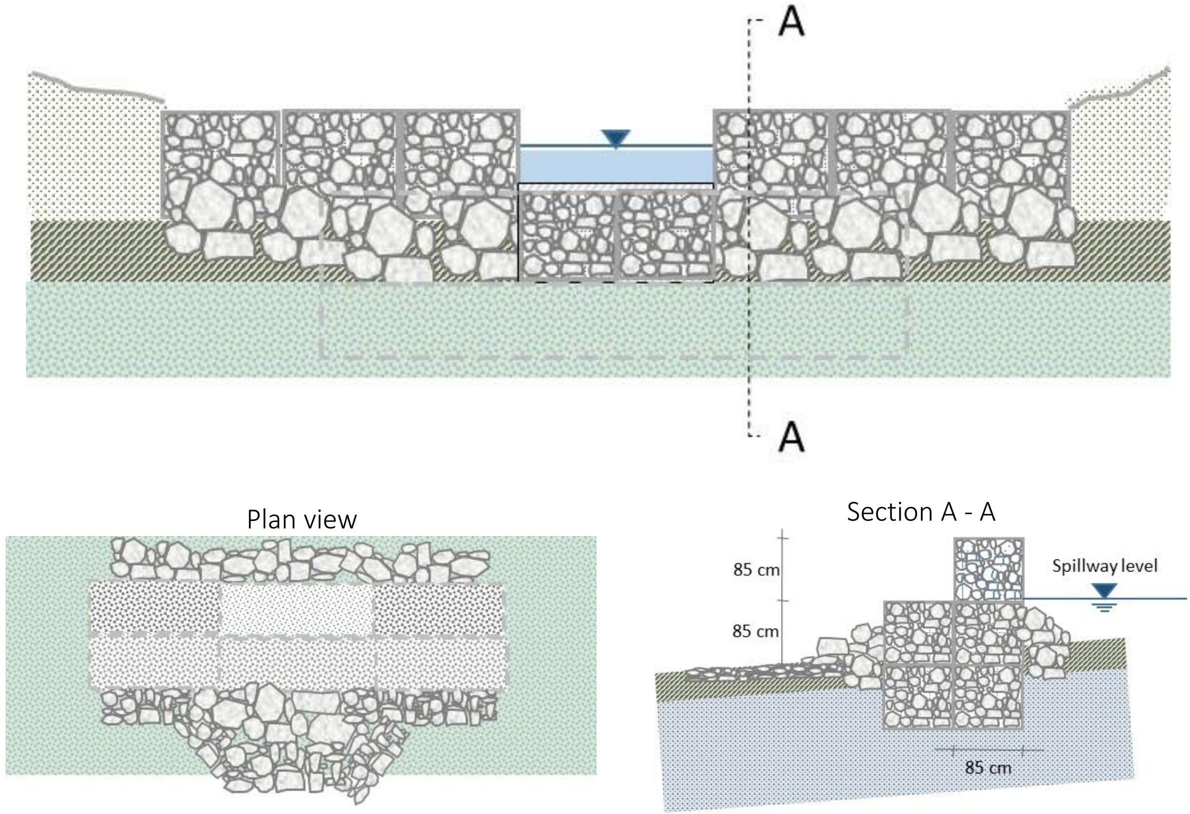
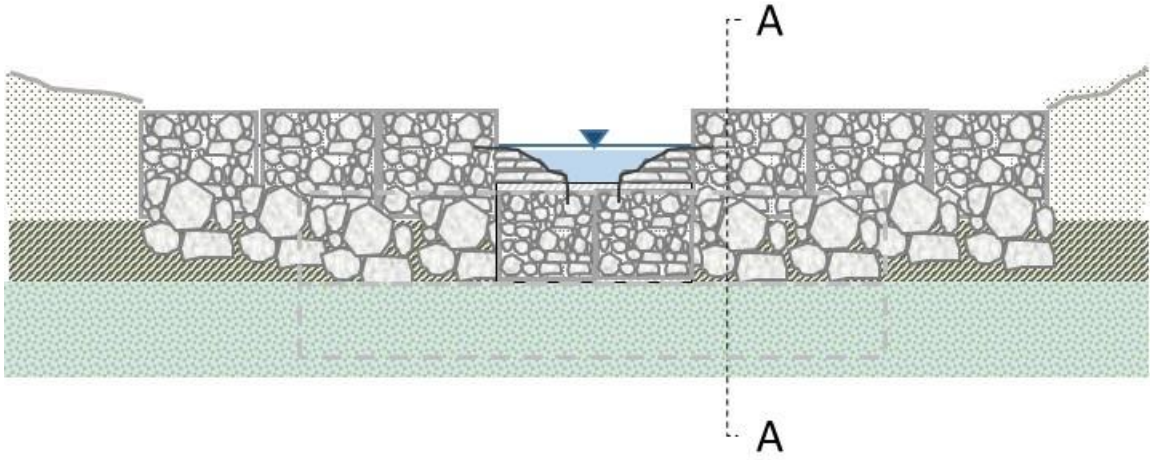


Figure 21: Gabion check dam



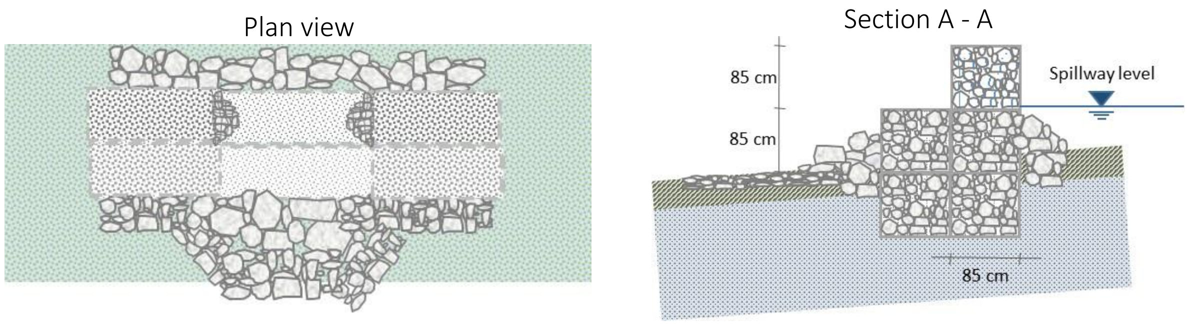


Figure 22: Gabion check dam

Gabions are best used where suitable and enough filling material, ideally in direct vicinity of the site, and enough manpower is available.

Specifications according to (FAO, Gully Control, 1986) and (Llano, 1993) are:

Gabions are suitable for building dams up to 10m high. At first sight, gabions appear as permeable. However, all the gaps between the stones will have filled up with sediment after a few flood events. Using a gabion check dam a long stilling pool with a cutoff wall to prevent undercutting should be considered. The disadvantage is that wires can become oxidized. Therefore, wires used should be galvanized to prevent oxidisation.

Filling the gabion should be as dense as possible, largest stones outside in contact with the mesh, smaller stones inside. Bracing of opposite faces, horizontally and vertically, is required to keep the gabions in shape. If more than one layer comes into use, gabions should be tied so that the whole structure is fixed together and behaves more or less like one monolithic block but still having flexibility. Wings should enter at least 50 cm into each side of the gully.

Stability against sliding, overturning and collapsing is achieved if stabilising forces are larger than destabilising forces.

Stabilising forces	Destabilising forces
• Weight of the structure • Weight of earth above foundation	• Hydrostatic pressure upstream face • Horizontal earth pressure • Uplift (occurs only if the bed material is

	earthen material with porosity; uplift can be neglected in combination with solid rocks as bed material)

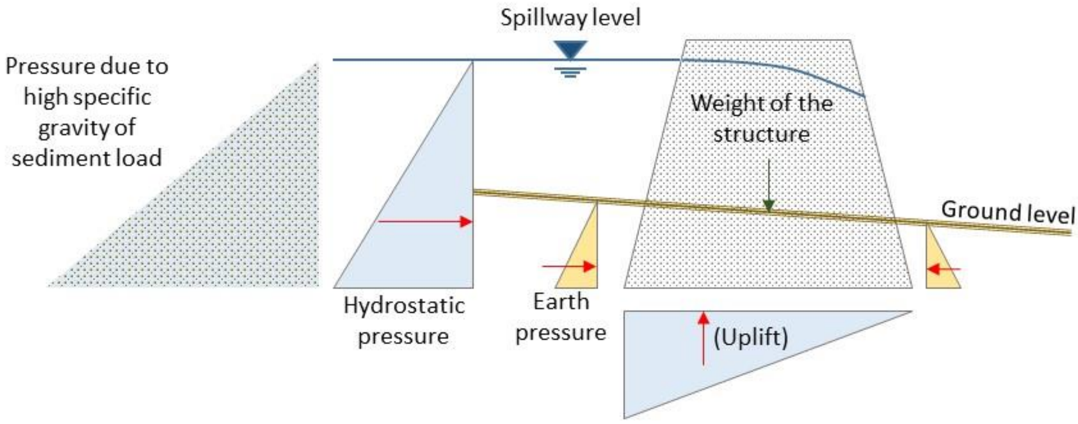


Figure 23: Forces impacting on Gabion check dams, modified according to (Llano, 1993)

Dynamic pressure come on top in fast flowing torrents as water arrives as a jet. However, this is mainly restricted on the crest area (not illustrated in Figure 23).

What must be beard in mind is the effect of mudflows and/or high sediment load in torrents. The semi-liquid material has high specific gravity (≈ 2.5 t/m³), high roughness coefficients and high velocities and exerts immense destructive forces on a traverse structure. When calculating stability, the specific gravity should be adjusted and dynamic pressure applied.

The value of the forces can be estimated by: $F = \gamma \cdot g \cdot H \cdot v^2$
where:

γ:	specific gravity [kg/m³]
g:	gravity [m/s²]
H:	height of structure [m]
v:	flow velocity [m/s]

5.2.2 Longitudinal channel protection measures

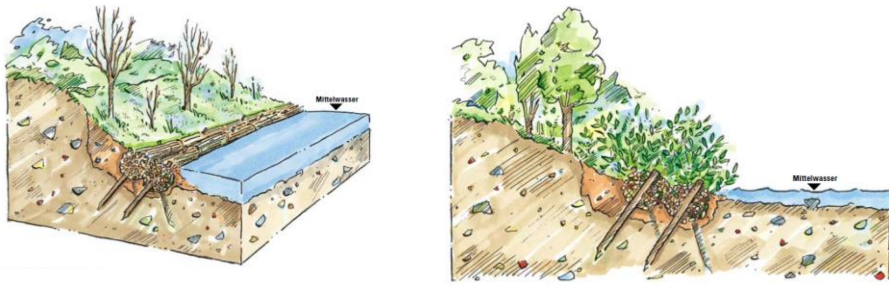
Longitudinal channel protection measures	
Main objective(s)	Channel stabilization, Prevent widening of channels Hill slope toe stabilization
Type	Active (Structural) Soft (EbA) / Hard
Location	Transport reach, deposition area
Sphere of influence	Local/Catchment
Description	Longitudinal structures counteract the lateral erosion, thus stabilizing the respective channel reaches and reducing erosion. In smaller streams, these measures can be built with natural materials (EbA). To withstand the forces

of flood and potential debris floods in bigger water courses or debris-prone torrents, the recommended materials are stone or concrete (Jakob & Hungr, 2005).

Longitudinal toe slope stabilization (Jakob & Hungr, 2005)

Longitudinal protection measures: Concrete wall (left), stone wall (right) (Rimböck, Höhne, Mayer, & Wolter-Krautblatter, 2015)

Embankment stabilization by stem sets (Jany & Geitz, 2013)



Embankment stabilization by fascines (Jany & Geitz, 2013)

Engineer-biological method (tree wall) (Jany & Geitz, 2013)

Design criteria	The bank stabilization method has to withstand the sheer stress of floods and the impacts of debris flows. If structural stability cannot be achieved by gravity of the material alone, anchors can be placed into the banks.
Duration until max. effectiveness	Hard structures – Immediate Soft structures – Medium
Cost	Medium – High
Maintenance	Stability control (hard structures) Check for weathering (soft measures)
Evaluation criteria	Reduction of erosion
Notes	-
Literature	(Jakob & Hungr, 2005), (Rimböck, Höhne, Mayer, & Wolter-Krautblatter, 2015), (Jany & Geitz, 2013), (STC, 2000), (Dvořák & Novák, 1994), (DPHW, 2010)

5.2.3 Debris flow control

In many torrential catchments, the risk for debris flows remains even when applying measures such as integrated watershed management, soil bioengineering and protection of channel erosion is in place.

Thus, explicit debris flow control is necessary. As outlined above, aside from the stabilization and consolidation measures described, the main different principals of debris flood control are:

- Energy dissipation
- Dosing/Filtering
- Retention
- Diversion

Often, a combination of measures is necessary for a maximum of protection. It can be necessary to apply both measures in different torrents and a chain of measures in each torrent to protect one location.

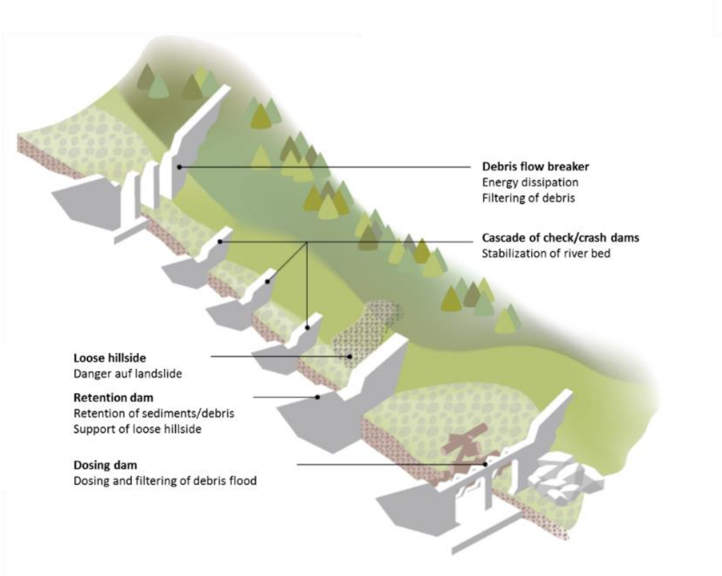


Figure 24: Chain of measure, modified (Rimböck A. , 2015)

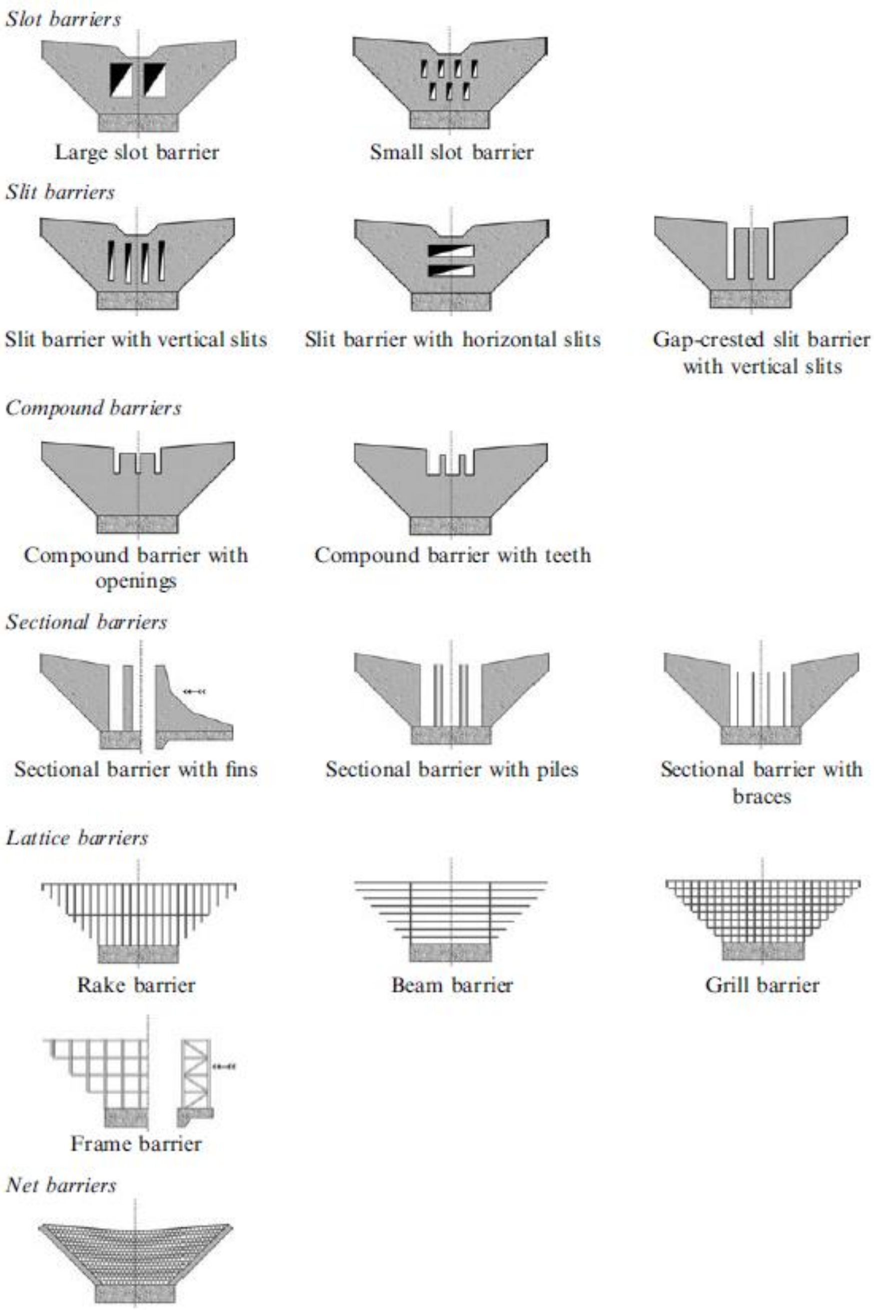
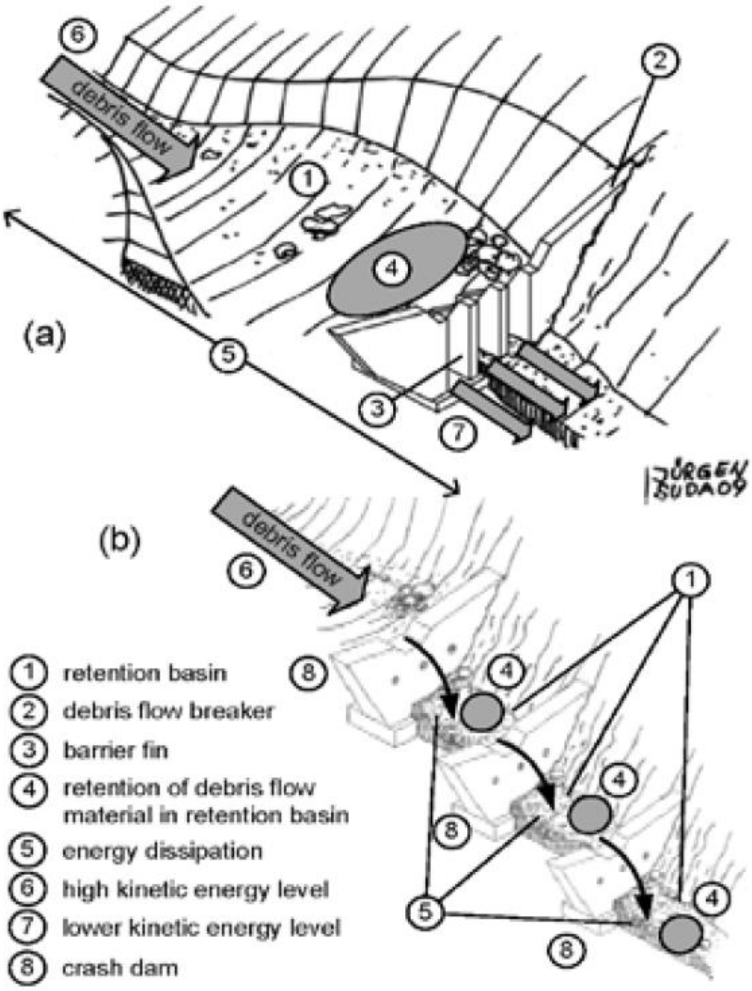


Figure 25: Types of (open) barriers (Jakob & Hungr, 2005)

5.2.4 Debris flow breaker

Debris flow breaker	
Main objective(s)	Energy dissipation
Type	Active (Structural) Hard
Location	Transport reach/ Deposition area
Sphere of influence	Local/Catchment

Description	Debris flow breakers or a cascade of crash dams aim at the dissipation of debris flow energy. The energy dissipation can be reached by breaking the surge front or transforming the displacement process. This can be achieve by directly impacting the flow process by massive structures (debris breaker) or a series of crash dams, where the debris flow loses energy by falling down and within the spilling pool. Debris breaker are normally combined with a retention basin, where a part of the debris flow is deposited. Debris breaker are the uppermost structure in the functional chain of debris flow control structures. Crash dams are generally more suitable for the deposition area/alluvial fan (Mazzorana, et al., 2015).

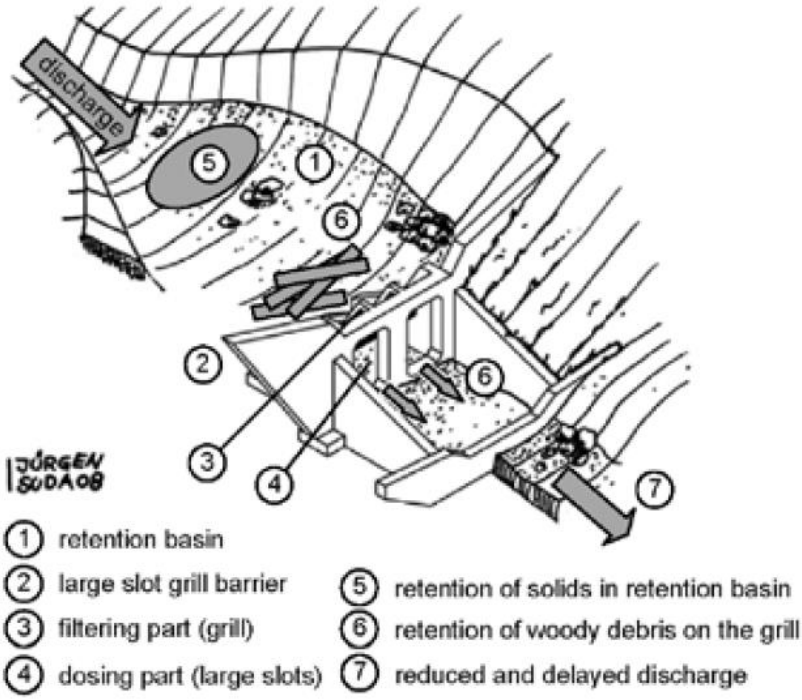


Schematic view of (a) a debris flow breaker for energy dissipation and (b) a cascade of crash dams for transformation of debris flow process (Rudolf-Miklau & Suda, 2011)

	Left: Debris flow breaker – sectional barriers with fins, Right: Cascade of crash dams-compound barrier (Mazzorana, et al., 2015)
Design criteria	Debris breakers need to be built as massive structures, with reinforced concrete. If needed, several consecutive debris breakers can be built. The same holds for a crash dams, where a cascade of dams can be built if necessary to reach the desired energy dissipation.
Duration until max. effectiveness	Immediate
Cost	High
Maintenance	Check for structural stability Clean out of debris after event Repair after event
Evaluation criteria	Retained volume of debris flow. Upholding of structure during events.
Notes	-
Literature	(Mazzorana, et al., 2015), (Rudolf-Miklau & Suda, 2011), (Bergmeister, Suda, Hübl, & Rudolf-Miklau, 2009)

5.2.5 Dosing and filtering dams

Dosing and filtering dams	
Main objective(s)	Dosing Filtering
Type	Active (Structural) Hard
Location	Transport reach
Sphere of influence	Local/Catchment
Description	A dosing structure temporally retains the coarse bedload of a debris peak and spills sediment in a controlled way with decreasing discharge. The filtering aims at a selective retention of coarse solid components, like boulders, large rocks, drift wood, etc., whereas fine grained bedload can pass the filtering structure. The filtering size should be adjusted to solid components that pose great risk for downstream reaches, e.g. by blocking bridges or other bottlenecks. Large slot barriers are normally used for closing and filtering structures. (Mazzorana, et al., 2015)



Schematic view of a large slot grill barrier for dosing and filtering (Rudolf-Miklau & Suda, 2011)

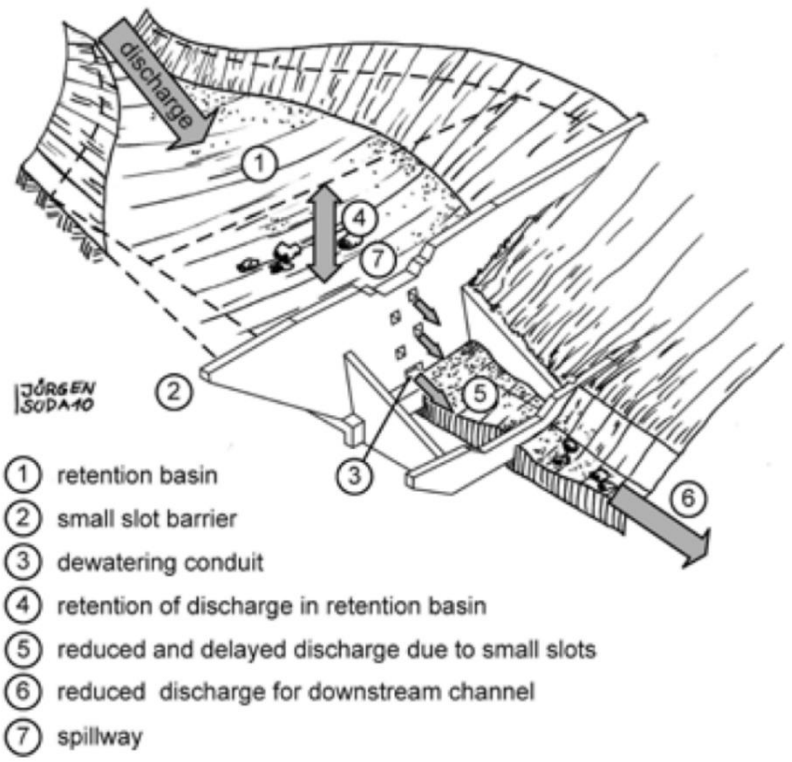
Large sot grill barrier (Mazzorana, et al., 2015)

Design criteria	Dosing and filtering dams need to be built as massive structures, with reinforced concrete.
Duration until max. effectiveness	Immediate
Cost	High
Maintenance	Check for structural stability Clean out of debris after event Repair after event
Evaluation criteria	Retained volume of debris flow.

	Upholding of structure during events.
Notes	-
Literature	(Mazzorana, et al., 2015), (Rudolf-Miklau & Suda, 2011), (Bergmeister, Suda, Hübl, & Rudolf-Miklau, 2009)

5.2.6 Retention Barriers

Retention Barriers	
Main objective(s)	Retention
Type	Active (Structural) Hard
Location	Transport reach/Deposition area
Sphere of influence	Local/Catchment
Description	Retention barriers are applied, if the transport capacity of downstream reaches (e.g. within settlements) is not enough to contain the debris flow. Natural or artificial reservoirs are used to withhold sediments and debris. For retention, small slot barrier types are applied. (Mazzorana, et al., 2015)



Schematic view of a large slot grill barrier for dosing and filtering (Rudolf-Miklau & Suda, 2011)

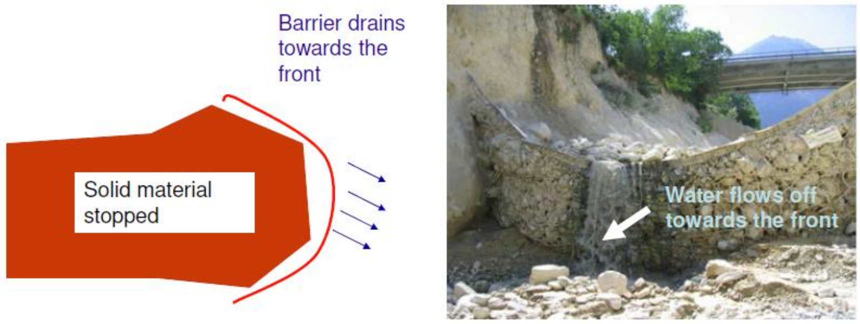
Large sot grill barrier (Mazzorana, et al., 2015)

Design criteria	Dimensioning for transport capacity of downstream reaches
Duration until max. effectiveness	Immediate
Cost	High
Maintenance	Regular excavation of deposited sediments and debris Check for structural stability Clean out of debris after event Repair after event
Evaluation criteria	Retained volume of debris and sediments. Upholding of structure during events.
Notes	Retention barriers are inefficient if directly exposed to debris flow (Mazzorana, et al., 2015)
Literature	(Mazzorana, et al., 2015), (Rudolf-Miklau & Suda, 2011), (Bergmeister, Suda, Hübl, & Rudolf-Miklau, 2009)

5.2.7 Net barrier/flexible barrier (Wendeler, 2016)

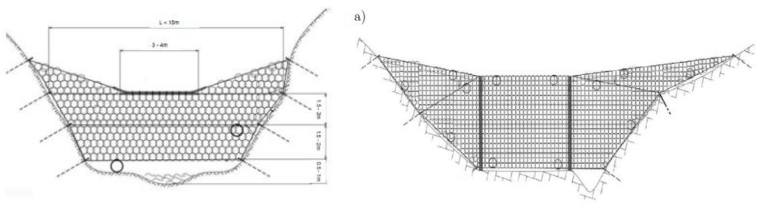
Net barrier/flexible barrier (Wendeler, 2016)	
Main objective(s)	Retention/Filtering
Type	Active (Structural) Hard
Location	Transport reach (Headwater)
Sphere of influence	Catchment
Description	Flexible ring net barriers in debris flow control originate from rock fall barriers, which have been found to also withhold debris flow or landslides now and then. They act similar to debris flow brakes and debris flow screens, removing the water from the debris flow mixture and stopping the solid material. The ring net retains coarse blocks, stones and larger woody debris, whereas dissolved mud can pass with the water. Mesh size and basal opening size determines the size of debris material retained or let trough. If necessary, a secondary mesh can be used to also

retain fine, organic matter.
Depending on the width of a cross section, two construction modes for flexible ring net barriers are applied. Narrow channel spans can be controlled with a ring net spanning from on channel side directly to the opposite site, whereas a system with intermediate posts has to be applied for larger spans.



Principle of drainage and retention or ring net barriers (Wendeler, 2016)

Secondary fine on ring net barrier, retaining a slope-type debris flow and its very small constituents (Wendeler, 2016)

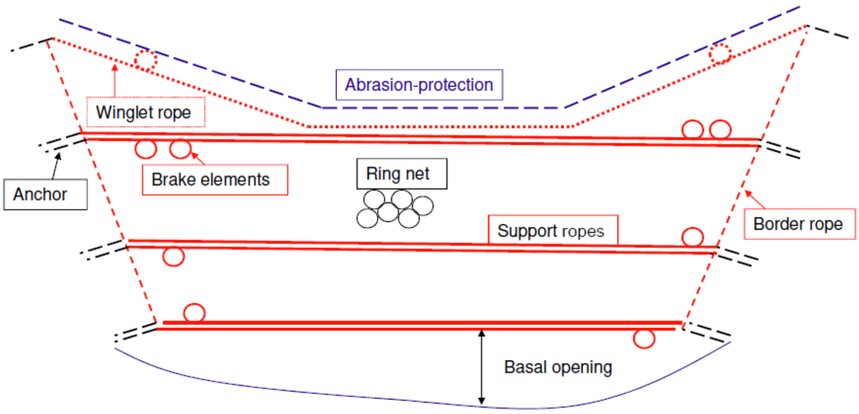


Left: System without posts for narrow spans; Right: System with posts for wide spans (Wendeler, 2016)

Design criteria

Support ropes span from on channel bank to channel bank, usually with one or more brake elements integrated. The winglet rope extends from top anchor to top anchor with winglets on both channel sides. The winglets function is to avoid lateral bank erosion, once the barrier is filled by forcing the main debris flow to the centre of the barrier. Two border ropes from top to bottom anchor mark the lateral ends of the barrier.

	When the barrier is loaded, the ring formed brake element reduce in diameter, became longer and the rope lengths increases respectively. Thus, brake elements dissipate energy of the debris flow, thereby reducing the load of the net barrier construction. Anchoring of net barriers is crucial and, in general, difficult. Often, the substrate cannot bear enough load. In rocky substrates, rock anchors can be drilled. For less solid substrate, self-drilling anchors or drilled rope anchors with casing are usually recommended. Necessary anchor length can reach up to and more than 10 meter. For lower anchors, probable washout of anchor heads should be taken into account when estimating anchor lengths. The ring net consist of interwoven wire rings. The diameter size depends on both the ring net construction and the intended grain size that should be retained by the net. Typical diameter range from 300 to 350 mm, with wire diameters around 3 mm. Once the net barrier is filled up, the remaining debris flow cannot be retained and flows over the net. The load and shear stress of the remaining debris flow would damage the net, thus a robust abrasion protection is added on top of the ring net.



Schematic construction of a flexible debris flow barrier (Wendeler, 2016)

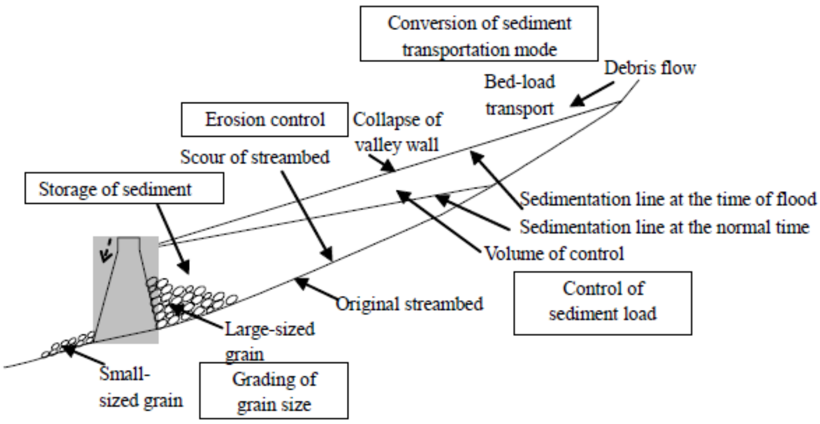
Left: Pulling up of a ring net during installation; Right: Alternative mesh size at Gaviota Pass, Canada (Wendeler, 2016)

Duration until max. effectiveness	Immediate
Cost	Medium
Maintenance	Check for corrosion of ring net Check for stability of anchors Clean out of debris after events

	Reinstallation of ring nets after events
Evaluation criteria	Pull-out test for anchors before installation of the net. Retained volume of debris flow. Upholding of structure during events.
Notes	Net barriers with basal opening allow most aquatic animals to pass through the net without restrictions. Visually, the net structure is more filigree compared to solid wood or concrete barriers, thus the landscape view is affected less.
Literature	(Wendeler, 2016), (Volkwein, Wendeler, & Guasti, 2011), (Fonseca, Quintana, Megal, & Roth, 2007)

5.2.8 Sabo dam (c.f. Retention barriers)

Sabo dam (c.f. Retention barriers)	
Main objective(s)	Retention
Type	Active (Structural) Hard
Location	Headwater, (Transport reach)
Sphere of influence	Catchment
Description	Sabo dams have been developed in Japan. In contrast to aforementioned a Sabo dam aims at fully retaining sediment load.



Various functions of a sabo dam (IDI, 2004)

Gosuke sabo dam, Japan; Left Empty; Right: With trapped sediment (Mizuyama, 2008)

Design criteria	Sabo dams need to be built as massive structures, with reinforced concrete.
Duration until max. effectiveness	Immediate
Cost	High
Maintenance	Regular excavation of deposited sediments and debris Check for structural stability Clean out of debris after event Repair after event
Evaluation criteria	Retained volume of debris and sediments. Upholding of structure during events.
Notes	-
Literature	(Mizuyama, 2008), (IDI, 2004)

5.2.9 Deflection and conduction structures

Deflection and conduction structures	
Main objective(s)	Deflection/Control of debris flow
Type	Active (Structural) Hard
Location	Deposition area, alluvial fan, debris cone
Sphere of influence	Deposition area, alluvial fan, debris cone
Description	Deflection and conduction structures aim at directing the debris flow in a controlled way. The remaining debris flow in the deposition area can be deflected by embankments or controlled by massive walls. If walls are applied, the debris is directed through settlements by so called shooting channels or bypassed around a settlements.

Shooting channel conduction mud flows through a village in Italy. By diverting water into it, the shooting channel can be flushed after events (Unknown, ?)

A debris flow bridge, protecting a road in France (Unknown, ?)

Left: Several conduction dykes in a torrent fan (Bergmeister, Suda, Hübl, & Rudolf-Miklau, 2009)

Design criteria	-
Duration until max. effectiveness	Immediate
Cost	Medium – High
Maintenance	Check for structural stability Repair after event
Evaluation criteria	Transport capacity Deflection success
Notes	-
Literature	(Bergmeister, Suda, Hübl, & Rudolf-Miklau, 2009)

5.3 Land use planning and risk reduction

Factsheet: Land use planning	
Main objective	Reduction of vulnerability Reduction of risk
Type	Passive (Non-Structural)
Location	Settlements/Deposition area/Alluvial fan/Debris Cone
Scale	Local
Description	Flood hazard risk is a combination of potential hazards and exposure to the hazards. Damage of torrential origin is closely linked to settlements, population density, infrastructure and agricultural development. Land use planning aims at providing a framework for designating infrastructure and settlements e.g. a legislative ban for housing in areas

	prone for mudflows. The image below shows appropriate land use within an alluvial fan near Innsbruck, Austria. Residential areas are situated on the left-hand side, whereas only farmland is located within the alluvial fan.  *Appropriate land use of an alluvial fan, Austria (Jakob & Hungr, 2005)*
Design criteria	Risk mapping and accordant legal and administrative procedures for the designation of restricted zones for e.g. housing, roads, etc. In areas with a high impact load of debris flows, development of further settlements and infrastructure should be prohibited. Building regulations in hazardous areas can help reduce damage to buildings and infrastructures.
Duration until max. effectiveness	Short – Long
Cost	-
Maintenance	Observe compliance with legislation
Evaluation criteria	Consistency of actual land use with land use according to legislative restrictions. Risk maps and land use maps coordinated and issued
Notes	-
Literature	(Jakob & Hungr, 2005)

6 REFERENCES

ADRC. (2006). *Tajikistan. Country Report*. Asian Disaster Reduction Center.

Bergmeister, K. S.-M. (2009). *Schutzbauwerke gegen Wildbachgefahren*. Ernst & Sohn, ISBN 978-3-433-02946-9.

Bergmeister, K., Suda, J., Hübl, J., & Rudolf-Miklau, F. (2009, 4). *Schutzbauwerke gegen Wildbachgefahren.* Ernst & Sohn, Verlag für Architektur und technische Wissenschaften GmbH & Co. KG. doi:10.1002/9783433600283

Bertle, F. (1966). *Effect on Snow Compaction on Runoff from Rain on Snow*. U.S. Bureau of Reclamation, Engineering Monograph No. 35.

Bühlmann, E., Wolfgramm, B., Maselli, D., Hurni, H., Sanginov, S., & Liniger, H. (2010). Geographic information system-based decision support for soil conservation planning in Tajikistan. *Soil and Water Conservation Society. Journal of Soil and Water Conservation*, 65(3):151-159.

Caritas. (2006). *Watershed Management Study River Bank Protection Project & Risk Dialogue II.* Caritas Luxembourg.

Caritas. (2012). *Chukurak Watershed Activity Plan.* Carits Switherland.

CESVI. (2013). CESVI, Tajikistan: Natural Resource Management Hand book Soil Bio-Engineering Techniques for Slope protection and stabilisation.

CESVI. (2017). *Soil Bioengineering Techniques, Leaflet 2, Brush Layering*. CESVI, Reduction of Land Degradation and Prevention of Desertification through the Development of Natural Resources Management in Tajikistan.

DPHW. (2010). *Technical Standards And Guidelines For Design Of Flood Control Structures.* Tech. rep., Department Of Public Works And Highways - Japan International Cooperation Agency.

Dragičević, N., Karleuša, B., & Ožanić, N. (2016). A review of the Gavrilović method (Erosion Potential Method) application. *Građevinar*. doi:DOI: 10.14256/JCE.1602.2016

Dragičević, N., Karleuša, B., & Ožanić, N. (2017). Erosion Potential Method (Gavrilović method) sensitivity Analysis. *Soil and Water Research*, 51-59. doi:10.17221/27/2016-SWR

Dvořák, J., & Novák, L. (Eds.). (1994). *Soil Conservation and Silviculture* (Vol. 23). Elsevier. doi:https://doi.org/10.1016/S0166-2481(08)70068-0

FAO. (1986). *Gully Control*. Retrieved from FAO watershed management field manual: http://www.fao.org/docrep/006/ad082e/AD082e00.htm#cont

FAO. (1989). Irrigation Water Management: Irrigation Scheduling - Annex 1: FAO. Retrieved from http://www.fao.org/docrep/t7202e/t7202e00.htm#Contents

FAO. (2017). *Aquastat Tajikistan*. Retrieved from Global Water Information System, Computation of long-term annual renewable water resources (RWR) by country (in km³/year, average). : http://www.fao.org/nr/water/aquastat/main/index.stm

FAO. (2017, 12 1). *Watershed management field manual: Slope treatment measures and practices*. Retrieved from FAO Corporate Document Repository (Forestry Department): http://www.fao.org/docrep/006/ad083e/AD083e00.htm#cont

FOEN. (2016). *Protection against Mass Movement Hazards - Guideline for the integrated hazard management of landslides, rockfall and hillslope debris flows.* Tech. rep., Federal Office for the Environment, Bern.

Fonseca, R. L., Quintana, C. R., Megal, L. L., & Roth, A. (2007, 6). Protection systems against debris flows. *Safety and Security Engineering {II}.* WIT Press. doi:10.2495/safe070081

Gavrilovic, Z., Stefanovic, M., Milovanovic, I., Cotric, J., & Milojevic, M. (2008). Torrent classification – Base of rational management of erosive regions. *IOP Conference Series: Earth and Environmental Science, 4*, 012039. Retrieved from http://iopscience.iop.org/article/10.1088/1755-1307/4/1/012039

Graf, F. (2017). *Heft 56, WSL Berichte ISSN 2296-3448*. Pflanzenwirkungen zum Schutz vor flachgründigen Rutschungen: WSL-Institut für Schnee und Lawinenforschung SLF and Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL.

GRDC. (2017). *Statistics by Country*. Retrieved from Global Runoff Data Centre, World Meteorological Organisation (WMO), hosted by German Federal Institute of Hydrology, Koblenz, Germany.: http://www.bafg.de/GRDC/EN/Home/homepage_node.html

Hübl, J. (2014, 9). Regulations and strategies for debris flow mitigation in Austria.

ICIMOD. (2012). *Resource Manual on Flash Flood Risk Management. .* Kathmandu, Nepal.: International Centre for Integrated Mountain Development (ICIMOD). ISBN 978 92 9115 265 0 (printed), 978 92 9115 266 7 (electronic).

IDI. (2004). *Guidelines For Construction Technology Transfer - Development Of Warning And Evacuation System Against Sediment Disasters In Developing Countries.* Tech. rep., Ministry of Land, Infrastructure and Transport; Infrastructure Development Institute; Japan.

Jakob, M., & Hungr, O. (2005). *Debris-flow Hazards and Related Phenomena* (1 ed.). Springer-Verlag Berlin Heidelberg. doi:10.1007/b138657

Jany, A., & Geitz, P. (2013). *Ingenieurbiologische Bauweisen an Fließgewässern, Teil 1 - Leitfaden für die Praxis.* Tech. rep., WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH, LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg.

Knauf, D. (1980). *Die Berechnung des Abflusses aus einer Schneedecke*. DVWK, Analyse und Berechnung oberirdischer Abflüsse. Band 46, Hamburg: Parey, 97–133.

Llano, F. L. (1993). *Torrent control and streambed stabilization* (FAO Land and Water Development Series ed.). Food and Agriculture Organization of the United Nations.

Maidment, D. (1998). *Handbook of Hydrology. ISBN 0-07-039732-5.* McGraw-Hill Inc.

Mays, L. (2010). *Water Resources Engineering.* John Wiley & Sons.

Mazzorana, B., Piton, G., Picco, L., Jošt, S., Moser, M., Jäger, G., . . . Sturm, M. (2015, 6). *Guideline for planning/designing of efficient torrent control structures with low impact on sediment continuity between upstream torrential headwaters and downstream river reaches (In: SedAlp project report WP6 "Interactions with structures").* Tech. rep., sedalp.eu. Retrieved from https://www.researchgate.net/publication/279394587

Merz, ,. J., Dhakal, M., Dongol, B., & Weingartner, R. (2010). Rainfall amount and intensity in a rural catchment of the middle mountains, Nepal. pp. 51:1, 127-143, DOI: 10.623;.

Milanesi, L., Pilotti, M., Clerici, A., & Gavrilovic, Z. (2015). Application of an improved version of the Erosion Potential Method in Alpine areas. *Italian Journal of Engineering Geology and Environment*. doi:DOI: 10.4408/IJEGE.2015-01.O-02

Mizuyama, T. (2008). Structural Countermeasures for Debris Flow Disasters. *International Journal of Erosion Control Engineering, 1*, 38-43. doi:10.13101/ijece.1.38

Niţă, M. D., Tudose, N. C., & Clinciu, I. (2011). Estimating And Mapping Torrentiality Risk In Small Forested Watersheds. *Bulletin of the Transilvania University of Braşov, 4 (53)*.

Patt, H. (1998). *Naturnaher Wasserbau: Entwicklung und Gestaltung von Fließgewässern.* Springer Verlag. ISBN 3-540-61666-7.

Renard, K., Foster, G., Weesies, G., McCool, D., & Yoder, D. (1997). *Predicting Soil Erosion by Water: A guide to conservation planning with the Revised Universal Soil Loss Equation. Handbook No. 703.* U.S. Department of Agriculture. Agriculture.

Rickenmann. (1996). *Fließgeschwindigkeit in Wildbaehen und Gebirgsfluessen*. Wasser, Energie, Luft, 88 (11/12), 298–304.

Rimböck, A. (2015). Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. Höhne, Rainer; Mayer, Karl; Wolter-Krautblatter, Ronja: Wildbachbericht Bayern – Teil 2, Wildbachverbauung in Bayern -Daten und Fakten aus zwei Jahrhunderten.

Rimböck, A., Höhne, R., Mayer, K., & Wolter-Krautblatter, R. (2015). *Wildbachbericht Bayern – Teil 1,Grundlagen • Gefahren • Herausforderungen.* Tech. rep., Bayerisches Staatsministerium für Umwelt und Verbraucherschutz.

Rudolf-Miklau, F., & Suda, J. (2011). Technical standards for debris flow barriers and breakers. *Italian Journal of Engineering Geology and Environment*. doi:10.4408/IJEGE.2011-03.B-117

Schillinger, H. (2001). *Ingenieurbiologische Ufersicherungen an Bundeswasserstrassen.* Karlsruhe: Federal Waterways Engineering and Research Institute, Germany.

Seng, N. K. (2011). *Guidelines For Design and Construction Of Check Dams For Prevention and Control Of Peatland Fire.* Design and Dam Division, DID Malaysia.

STC. (2000). *Sabo Methods and Facilities made of Natural Materials.* Tech. rep., Sabo Technical Center, Japan. Retrieved from http://www.sabo-int.org/

SYDRO. (2017). *Emergency Preparedness Plan, Nam Paw Hydro Power Plant.* Muse (Myanmar), Darmstadt (Germany).

Totschnig, R., & Fuchs, S. (2013, 3 14). Mountain torrents: Quantifying vulnerability and assessing uncertainties. *Eng Geol, 155*, 31-44. doi:10.1016/j.enggeo.2012.12.019

TxDOT, T. D. (2016, 07). Retrieved from Hydraulic Design Manual. Revised July 2016.: http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

UNEP. (2013). *Global Risk Data Platform*. Retrieved from UNEP/GRID-Geneva and UNISDR: http://preview.grid.unep.ch/

Unknown. (?). Debris Flow Preventive Measures. Retrieved from http://step.ipgp.fr/images/e/e3/09_02_Debris_Flow_Mitigation.pdf

USACE. (2016). Staff Gage Setup Instructions: US Army Corps of Engineers.

Volkwein, A., Wendeler, C., & Guasti, G. (2011). Design of flexible debris flow barriers. *Italian Journal of Engineering Geology and Environment*. doi:10.4408/IJEGE.2011-03.B-117

WB. (2017). Hazard Assessment Report - Flood Protection No. 1. *Natural Hazard Assessment for Reconstruction of Critical Transport and Flood Protection Infrastructure in the Republic of Tajikistan*. Dushanbe, Tajikistan: World Bank.

Wendeler, C. (2016). *Debris-Flow Protection Systems for Mountain Torrents - Basic Principles for Planning and Calculation of Flexible Barriers.* techreport, Swiss Federal Institute for Forest, Snow and Landscape Research WSL. Retrieved from download www.wsl.ch/publikationen/pdf/15501.pdf

Whittaker, J. J. (1986). *Blockschwellen, Proceeding No. 91.* Zürich, Switzerland: Hydraulic Laboratory, ETH Zürich.

Wischmeier, W., & Smith, D. (1978). *Predicting rainfall erosion losses – a guide to conservation planning. Handbook No. 537.* U.S. Department of Agriculture. Agriculture.

WWF. (2016). World Wildlife Fund, Washington, DC USA: Natural and Nature-based Flood Management: A Green Guide (Flood Green Guide). Retrieved from http://envirodm.org/flood-management