Flood Disaster Risk Reduction Manual for Tajikistan

Part I: Flood Management Guideline

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Dr. Hubert Lohr
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Flood Management Guideline Tajikistan

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

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).
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).

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.
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. |
| 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/trmm
https://pmm.nasa.gov/data-access/downloads/trmm
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](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](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](https://landcover.usgs.gov/global_climatology.php) |

The site [http://gisgeography.com/free-global-land-cover-land-use-data/](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](image)

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:

<table>
<thead>
<tr>
<th>LUCAS Topsoil</th>
<th><a href="https://esdac.jrc.ec.europa.eu/content/lucas-2009-topsoil-data">https://esdac.jrc.ec.europa.eu/content/lucas-2009-topsoil-data</a></th>
</tr>
</thead>
</table>

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:

$$Q_{\text{ungauged}} = Q_{\text{gauged}} \cdot \frac{\text{Area}_{\text{ungauged}} \left[ km^2 \right]}{\text{Area}_{\text{gauged}} \left[ km^2 \right]}$$

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>
<thead>
<tr>
<th>Rainfall</th>
<th>Remarks</th>
<th>Location</th>
<th>Observer</th>
<th>Rainfall depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin</td>
<td>End</td>
<td>Location</td>
<td>Observer</td>
<td>Estimated: not</td>
</tr>
<tr>
<td>14 March 2018 07:30</td>
<td>14 March 2018 12:00</td>
<td>High intensity rain between 10:00 and 10:30, low intensity during the rest of the time</td>
<td>Coordinates of location, for example from mobile phone’s GPS</td>
<td>more than 8 litre/m² (if an estimate can be given)</td>
</tr>
</tbody>
</table>
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.


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

<table>
<thead>
<tr>
<th>Reading</th>
<th>Remarks</th>
<th>Location</th>
<th>Observer</th>
<th>Snow depth</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 March 2018</td>
<td>Still snowing, temperature &lt; 0°C</td>
<td>Coordinates of location, for example from mobile phone’s GPS</td>
<td>Name, mobile phone number and address of observer</td>
<td>Figure in mm</td>
<td>Photo from the site with the board</td>
</tr>
<tr>
<td>08:52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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)
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.

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.

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

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

**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).
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).

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

where $K_b$ = Watershed torrent coefficient [-]
$H$ = Density of hydrographic network [km $\cdot$ 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 [km$^2$]
$L$ = Length of the main stream [km]
$S_Z$ = Area of the afforested part of the watershed [km$^2$]

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

$$H = \frac{L + \sum L_i}{S}$$  \hspace{1cm} \text{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 [km$^2$]

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.

$$V_S = V_P - V_U$$  \hspace{1cm} \text{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.

$$V_P = \frac{\sum S_i \cdot h_i}{S}$$  \hspace{1cm} \text{Equation 4}

where $V_p$ = Average altitude of the catchment [km]
$S_i$ = Area of watershed between two neighbouring contour lines [km$^2$]
$h_i$ = Mean altitude between two neighbouring contour lines [km]
$S$ = Watershed area [km$^2$]
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.

$$S_Z = 0.6 \ S_F + 0.8 \ S_G + 1.0 \ S_B$$

\text{where} \quad S_Z = \text{Forested catchment area [km}^2\text{]} \quad S_F = \text{Afforested part of catchment [km}^2\text{]} \quad S_G = \text{Grassland (meadows, pasture) covered watershed [km}^2\text{]} \quad S_B = \text{Part of catchment with predominant arable land or bare soils [km}^2\text{]}$$

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.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{Degree of soil permeability} & \textbf{Type of soil} & \textbf{P} \\
\hline
Totally impervious & Rocks & 1.00 \\
& Heavy clayey soil & \\
\hline
Impervious & Clayey soil & 0.90 \\
& Peat & 0.80 \\
& Swamps & \\
\hline
Not very permeable & Clay loam & 0.70 \\
& Grey forest podzol & \\
& Loam to clay loam & 0.65 \\
\hline
Permeable & Loamy soil & 0.60 \\
& Limy chernozem & \\
& Loamy sand & 0.55 \\
& Loamy sand to sandy loam & 0.50 \\
\hline
Very permeable & Sandy soils & 0.45 \\
& Sands & \\
& Gravels & \\
\hline
\end{tabular}
\caption{Coefficients of mean soil permeability of the catchment ($P$) for different types of soil (Dvořák & Novák, 1994)}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Intensity of erosion in the catchment and stream channel} & \textbf{E} \\
\hline
Whole watershed affected by all types of erosion, stream channel devastated by both lengthwise and crosswise erosion, rough sediment continuously removed, transported & 1.0 \\
\hline
\end{tabular}
\caption{Coefficient $E$ of a watershed’s tendency for erosion (Dvořák & Novák, 1994)}
\end{table}
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)

<table>
<thead>
<tr>
<th>$K_b$</th>
<th>Category</th>
<th>Characteristics of the water course</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interval</td>
<td>Class</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>&lt; 0.1</td>
<td>I</td>
<td>Water course of non-torrential nature</td>
</tr>
<tr>
<td>0.1 – 0.4</td>
<td>II</td>
<td>Torrent with a low intensity of erosion</td>
</tr>
<tr>
<td>0.4 – 0.7</td>
<td>III</td>
<td>Torrent with medium strong torrent characteristics</td>
</tr>
<tr>
<td>0.7 – 1.0</td>
<td>IV</td>
<td>Torrent with strong torrent characteristics</td>
</tr>
<tr>
<td>&gt; 1.0</td>
<td>V</td>
<td>Torrent with very strong torrent characteristics</td>
</tr>
</tbody>
</table>

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, scarp 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.

![Probability-damage relationship](image)

**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 often 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, capacity 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.
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>
<thead>
<tr>
<th>Level of protection</th>
<th>Values at risk</th>
<th>Design discharge for channel capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compact built-up urban area, larger housing estates, larger villages, industrial plants, important linear structures running parallel (highways, railways, etc.), protected monuments</td>
<td>Q_{50} – Q_{100}</td>
</tr>
<tr>
<td>2</td>
<td>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</td>
<td>Q_{20} – Q_{50}</td>
</tr>
<tr>
<td>3</td>
<td>Outside built up areas – intensive agricultural protection, skidding and other forest roads</td>
<td>Q_{5} – Q_{20}</td>
</tr>
<tr>
<td>4</td>
<td>Outside built up areas – meadows, production forests, irrigation and drainage facilities</td>
<td>Q_{5} – Q_{10}</td>
</tr>
</tbody>
</table>

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

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)

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

<table>
<thead>
<tr>
<th>Task</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean out of debris</td>
<td>Diversion</td>
</tr>
<tr>
<td>Floodway</td>
<td></td>
</tr>
</tbody>
</table>

## Debris control

<table>
<thead>
<tr>
<th>Transformation process</th>
<th>Debris flow breaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition debris under controlled conditions</td>
<td>Permanent debris deposition</td>
</tr>
<tr>
<td>Debris flow deflection to adjacent areas</td>
<td>Temporary debris deposition</td>
</tr>
<tr>
<td>Organ debris filtration</td>
<td>Deflection to area of lower consequence</td>
</tr>
<tr>
<td>Protection of roads</td>
<td>Debris shooting channel</td>
</tr>
<tr>
<td></td>
<td>Organic debris rake</td>
</tr>
<tr>
<td></td>
<td>Debris sheds</td>
</tr>
</tbody>
</table>

## Preventive

<table>
<thead>
<tr>
<th>Objective</th>
<th>Task</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of potential loss</td>
<td>Debris flow transport and deposition without damage</td>
<td>Land-use planning (local, regional)</td>
</tr>
<tr>
<td>Local protection of objects (e.g. house, person, traffic rout)</td>
<td>Soil and watershed protection legislation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crop change and alternative land use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Restrict use of hazard area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information, Education, Awareness, Preparedness, disaster risk management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specification of construction rules</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flood and waterproofing (building regulations)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regular maintenance of protection structures</td>
<td></td>
</tr>
</tbody>
</table>

## Event response

<table>
<thead>
<tr>
<th>Objective</th>
<th>Task</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of potential loss</td>
<td>Debris flow transport and deposition without damage</td>
<td>Flood monitoring and warning system</td>
</tr>
<tr>
<td></td>
<td>Information/Warning system (before, during, after event)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warning and evacuating of hazardous areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Closing of traffic route</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Immediate technical assistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upkeep of protective measures</td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th><strong>Factsheet: Integrated watershed management</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main objective(s)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td><strong>Scale</strong></td>
</tr>
<tr>
<td><strong>Description</strong></td>
</tr>
</tbody>
</table>

---

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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. |
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(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.

<table>
<thead>
<tr>
<th>Duration until max. effectiveness</th>
<th>Medium/Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Low/Medium</td>
</tr>
</tbody>
</table>
| 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, brush 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)
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 withstand 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 force 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

<table>
<thead>
<tr>
<th>Traverse channel protection measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main objective(s)</strong></td>
</tr>
<tr>
<td>Channel stabilization</td>
</tr>
<tr>
<td>Erosion control</td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td>Active (Structural)'</td>
</tr>
<tr>
<td>Soft (EbA) / Hard</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>Transport reach</td>
</tr>
<tr>
<td><strong>Sphere of influence</strong></td>
</tr>
<tr>
<td>Local/Catchment</td>
</tr>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Evaluation criteria</th>
<th>Reduction of erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notes</td>
<td>-</td>
</tr>
</tbody>
</table>

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:**

![Loose stone check dam](image)

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:**

![Boulder check dam](image)
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:**

![Gabion Check Dam Diagram]
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.

<table>
<thead>
<tr>
<th>Stabilising forces</th>
<th>Destabilising forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Weight of the structure</td>
<td>• Hydrostatic pressure upstream face</td>
</tr>
<tr>
<td>• Weight of earth above foundation</td>
<td>• Horizontal earth pressure</td>
</tr>
<tr>
<td></td>
<td>• Uplift (occurs only if the bed material is</td>
</tr>
</tbody>
</table>
earthen material with porosity; uplift can be neglected in combination with solid rocks as bed material)

![Diagram](image)

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 beared 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:

- \( \gamma \): 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

<table>
<thead>
<tr>
<th>Longitudinal channel protection measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main objective(s)</strong></td>
</tr>
<tr>
<td>Channel stabilization,</td>
</tr>
<tr>
<td>Prevent widening of channels</td>
</tr>
<tr>
<td>Hill slope toe stabilization</td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td>Active (Structural)</td>
</tr>
<tr>
<td>Soft (EbA) / Hard</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>Transport reach, deposition area</td>
</tr>
<tr>
<td><strong>Sphere of influence</strong></td>
</tr>
<tr>
<td>Local/Catchment</td>
</tr>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>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...</td>
</tr>
</tbody>
</table>
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                          | -  

### 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)
5.2.4 Debris flow breaker

<table>
<thead>
<tr>
<th>Debris flow breaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main objective(s)</td>
</tr>
<tr>
<td>Type</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Location</td>
</tr>
<tr>
<td>Sphere of influence</td>
</tr>
</tbody>
</table>
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 achieved 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)
### Debris breakers

- **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 dam, where a cascade of dams can be built if necessary to reach the desired energy dissipation.

<table>
<thead>
<tr>
<th>Duration until max. effectiveness</th>
<th>Immediate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>High</td>
</tr>
</tbody>
</table>
| **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) |

### 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 temporarily 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)
### 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.

---

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

*Large slot grill barrier* (Mazzorana, et al., 2015)
Upholding of structure during events.

Notes

<table>
<thead>
<tr>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mazzorana, et al., 2015), (Rudolf-Miklau &amp; Suda, 2011), (Bergmeister, Suda, Hübl, &amp; Rudolf-Miklau, 2009)</td>
</tr>
</tbody>
</table>

5.2.6 Retention Barriers

<table>
<thead>
<tr>
<th>Main objective(s)</th>
<th>Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Active (Structural) Hard</td>
</tr>
<tr>
<td>Location</td>
<td>Transport reach/Deposition area</td>
</tr>
<tr>
<td>Sphere of influence</td>
<td>Local/Catchment</td>
</tr>
<tr>
<td>Description</td>
<td>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)</td>
</tr>
</tbody>
</table>

Schematic view of a large slot grill barrier for dosing and filtering (Rudolf-Miklau & Suda, 2011)
## Large sot grill barrier (Mazzorana, et al., 2015)

<table>
<thead>
<tr>
<th>Design criteria</th>
<th>Dimensioning for transport capacity of downstream reaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration until max. effectiveness</td>
<td>Immediate</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
</tr>
</tbody>
</table>
| 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)

<table>
<thead>
<tr>
<th>Net barrier/flexible barrier (Wendeler, 2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main objective(s)</td>
</tr>
</tbody>
</table>
| 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 one 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)

**Design criteria**

Support ropes span from one channel bank to the other, 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.

<table>
<thead>
<tr>
<th>Duration until max. effectiveness</th>
<th>Immediate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Medium</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Main objective(s)</th>
<th>Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Active (Structural)</td>
</tr>
<tr>
<td></td>
<td>Hard</td>
</tr>
<tr>
<td>Location</td>
<td>Headwater, (Transport reach)</td>
</tr>
<tr>
<td>Sphere of influence</td>
<td>Catchment</td>
</tr>
<tr>
<td>Description</td>
<td>Sabo dams have been developed in Japan. In contrast to aforementioned a Sabo dam aims at fully retaining sediment load.</td>
</tr>
</tbody>
</table>

Various functions of a sabo dam (IDI, 2004)
### 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

<table>
<thead>
<tr>
<th>Main objective(s)</th>
<th>Deflection/Control of debris flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Active (Structural)</td>
</tr>
<tr>
<td>Hard</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Deposition area, alluvial fan, debris cone</td>
</tr>
<tr>
<td>Sphere of influence</td>
<td>Deposition area, alluvial fan, debris cone</td>
</tr>
</tbody>
</table>

**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, ?)
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.

<table>
<thead>
<tr>
<th>Design criteria</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration until max. effectiveness</td>
<td>Short – Long</td>
</tr>
<tr>
<td>Cost</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Observe compliance with legislation</td>
</tr>
<tr>
<td>Evaluation criteria</td>
<td>Consistency of actual land use with land use according to legislative restrictions. Risk maps and land use maps coordinated and issued</td>
</tr>
<tr>
<td>Notes</td>
<td>-</td>
</tr>
<tr>
<td>Literature</td>
<td>(Jakob &amp; Hungr, 2005)</td>
</tr>
</tbody>
</table>
6 REFERENCES


