FLOOD DISASTER RISK REDUCTION MANUAL FOR TAJIKISTAN

Empowered lives.
Resilient nations.

Part I: Flood Management Guideline

Acknowledgements

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

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March 28, 2018

Dr. Hubert Lohr

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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.

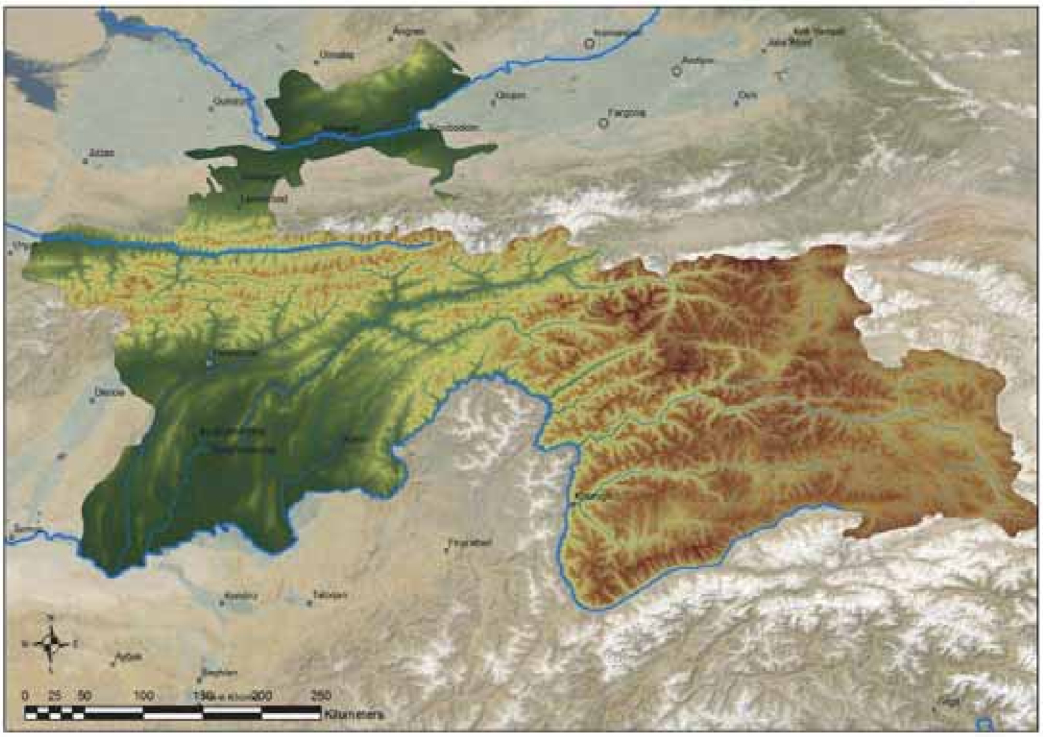


Figure 1: Map of Tajikistan

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

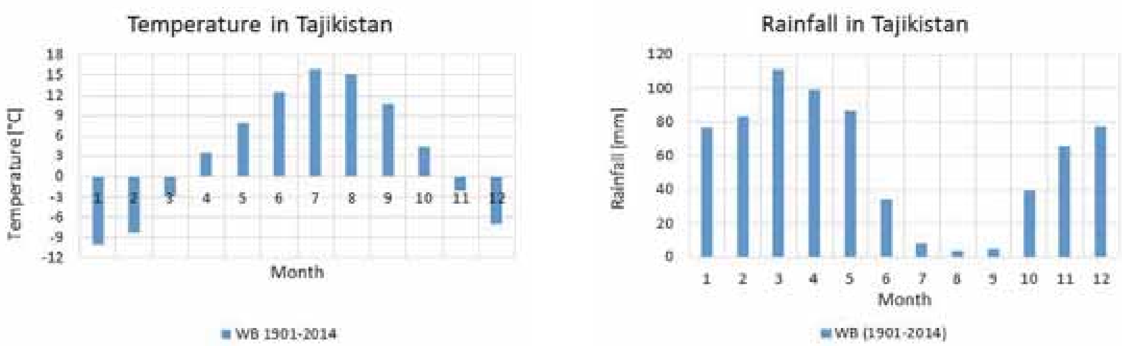


Figure 2: Monthly distribution of temperature and precipitation (World Bank, 2017)

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.

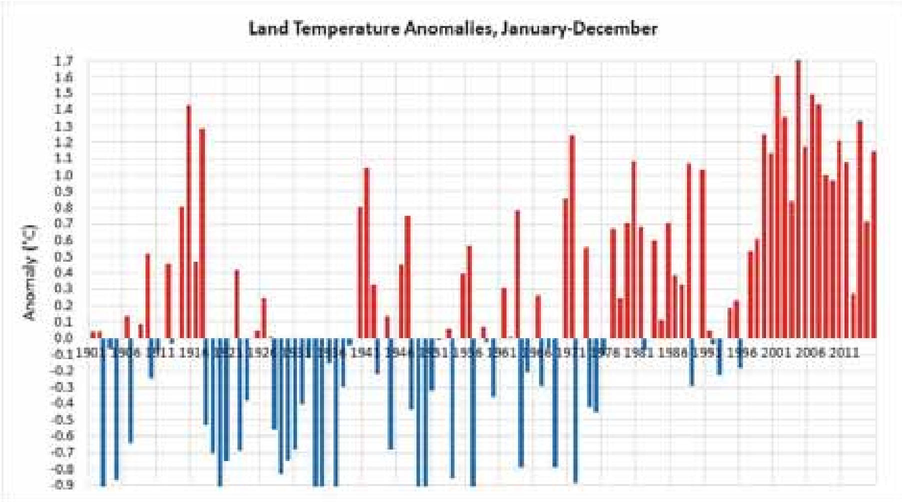


Figure 3: Land temperature anomalies 1910 to 2015, calculated based on World Bank data (World Bank, 2017)

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)

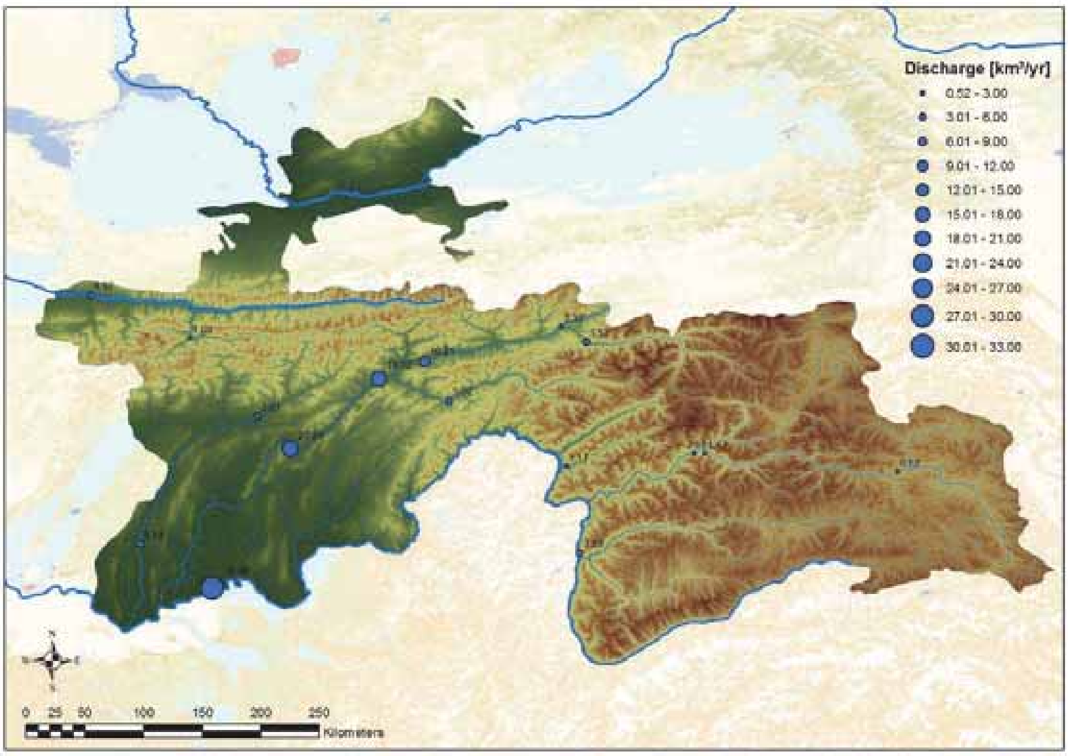


Figure 4: Annual discharge in [km³/yr] at GRDC stations, (GRDC, 2017)

2.1 Flood

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

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

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

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

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

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

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

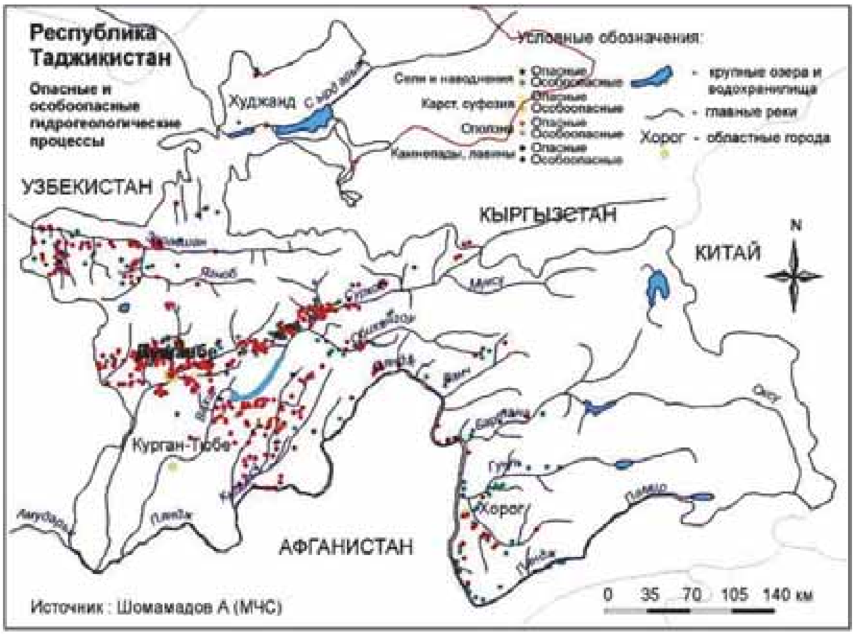


Figure 5: Occurrence of hydro-geological incidents in the country (source: (ADRC, 2006))

2.2 Flood risk

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

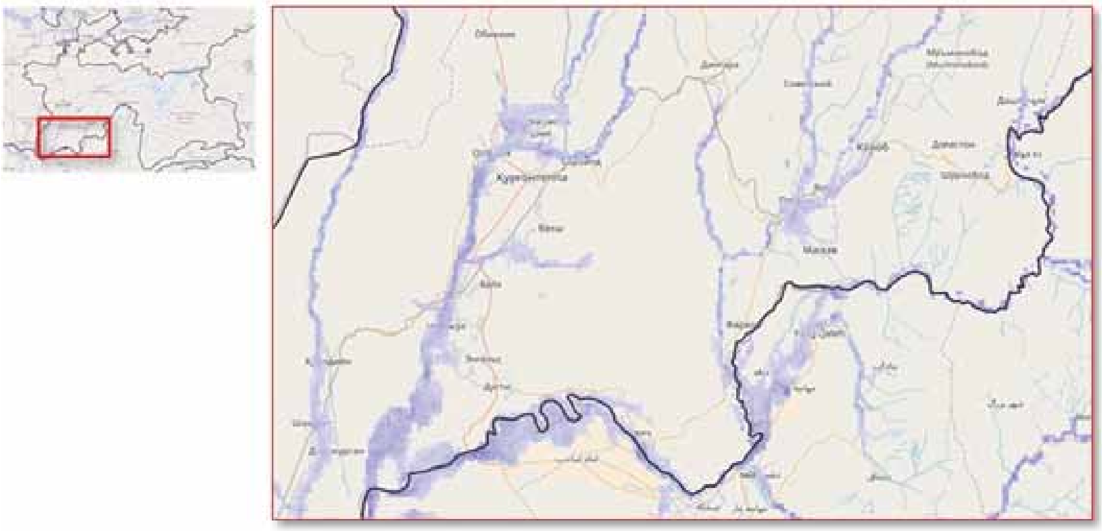


Figure 6: Estimate of 100 year flood return period, extract from the map of Tajikistan from Global Data Risk Platform (UNEP, 2013)

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

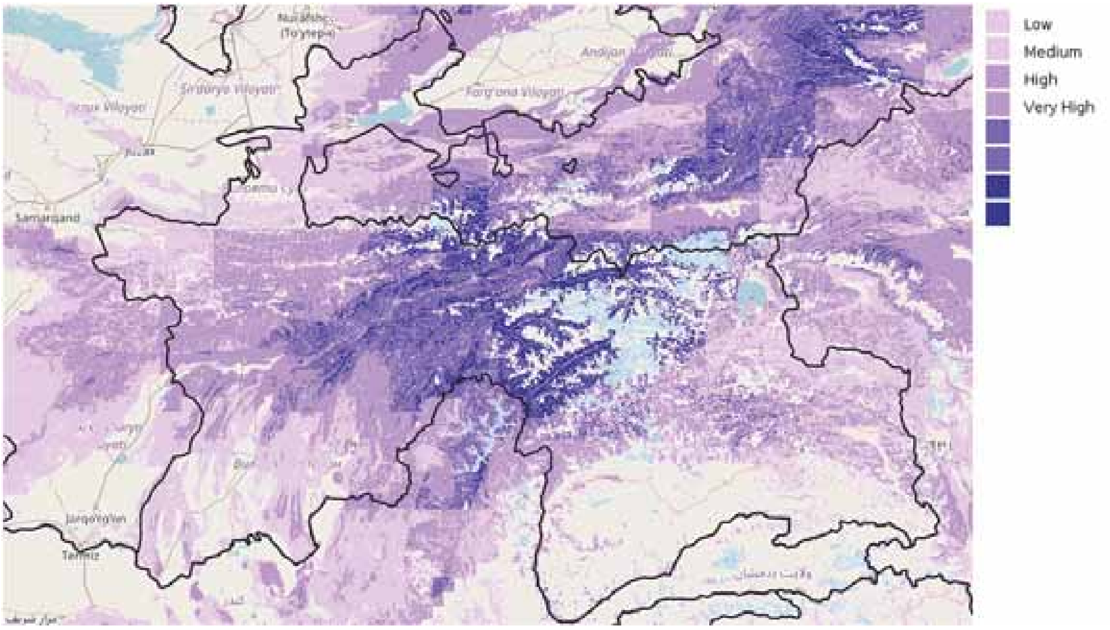


Figure 7: Estimate of landslide risk in Tajikistan (UNEP, 2013)

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

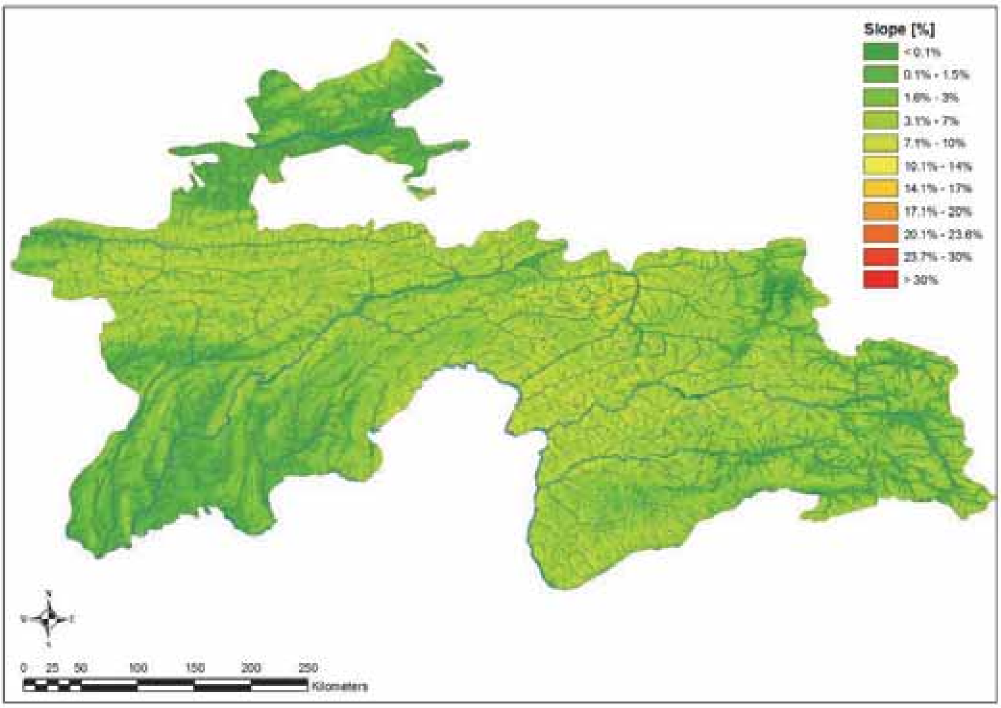


Figure 8: River network and slopes derived from SRTM 90

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

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

- Steep slopes

- Poor vegetation cover
- Less permeable and shallow soils

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

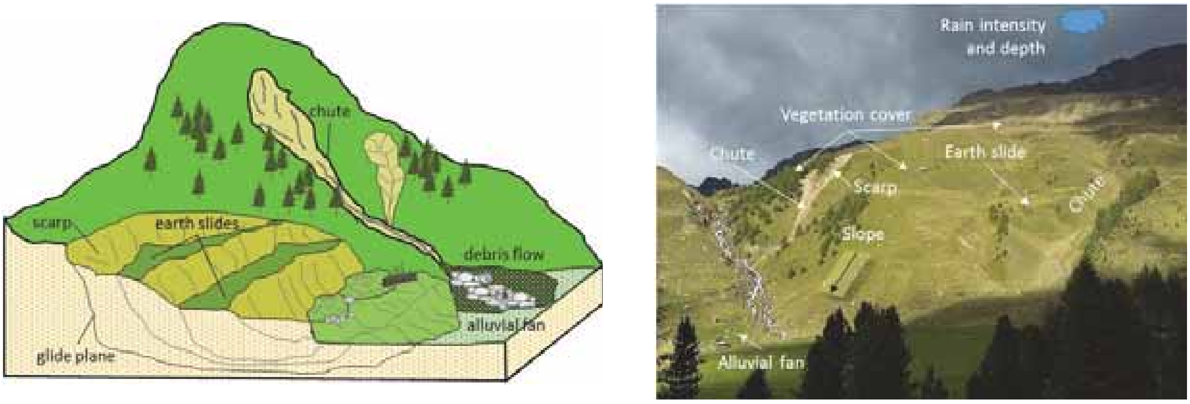


Figure 9: Hydrological features associated with floods, erosion, landslides and mudflows

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

- Design
- Monitoring
- Operation
- Preparedness

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

3 DATA AND DATA SOURCES

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

3.1 Official data and data sources

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

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

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

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

Agency of Hydro-Meteorology – Hydrological Department

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

Agency of Hydro-Meteorology – Meteorological Department

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

3.2 Data and data sources from the internet

3.2.1 GIS

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

3.2.2 Digital Elevation Model (DEM)

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

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

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

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

3.2.3 Climate

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

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

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

The main data sources are:

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

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

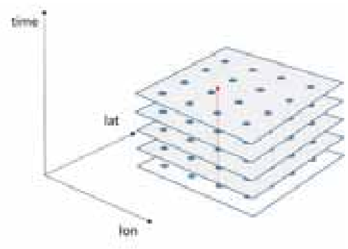
An example application of TRMM data with a 3-hour resolution is explained below.

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

Download files

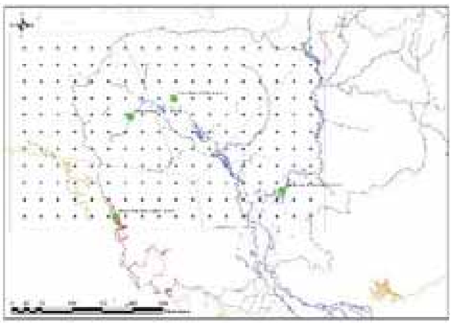
The link is given above.

Extracting values



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

Assigning grid cells to ground stations



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

Aggregation

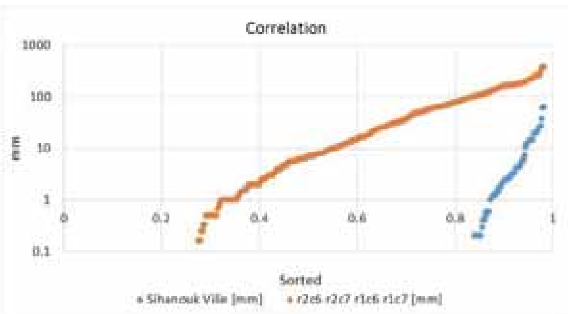
The time series with a 3 hourly resolution must be aggregated to daily values by preserving the total daily rainfall depth.

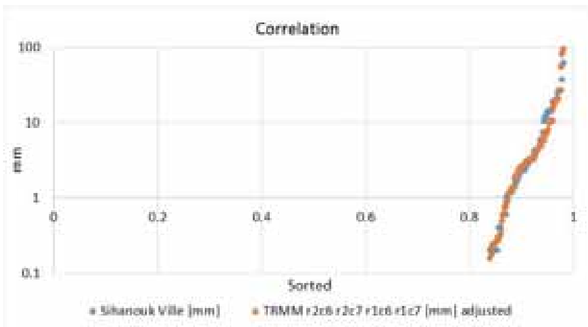
Screening out of outliers

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

Conducting bias correction

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





Scaling

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

3.2.4 Land use

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

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

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

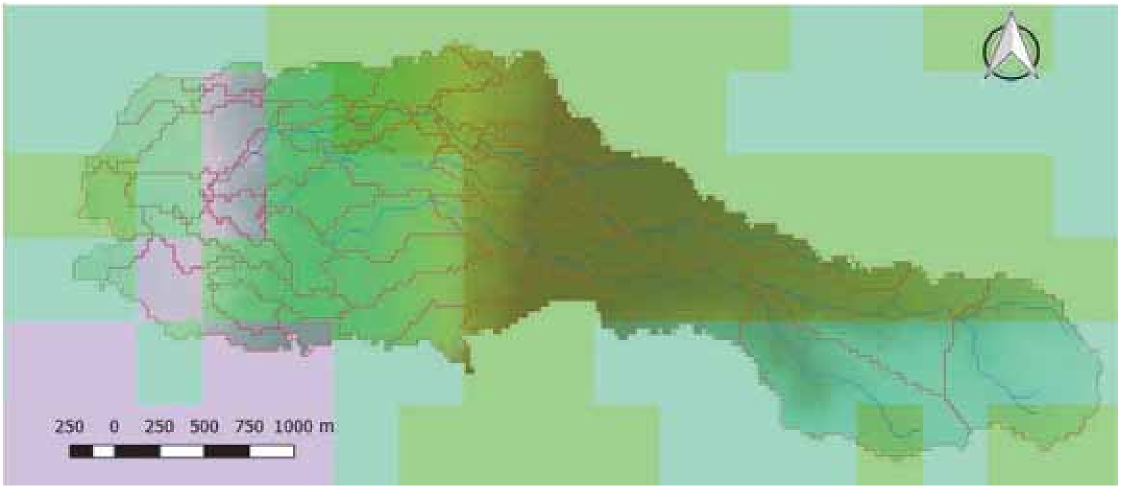


Figure 10: Land use grid from MODIS with 500m resolution

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

3.2.5 Soil

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

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

3.2.6 Satellite images

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

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

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

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

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

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

3.2.7 Estimating erosion

Data sources relevant for estimating erosion are:

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

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

3.3 How to determine flow for an ungauged location

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

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

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

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

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 1: Example for making rainfall observations

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

Snow:

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

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

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

Table 2: Example for making snow observations

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

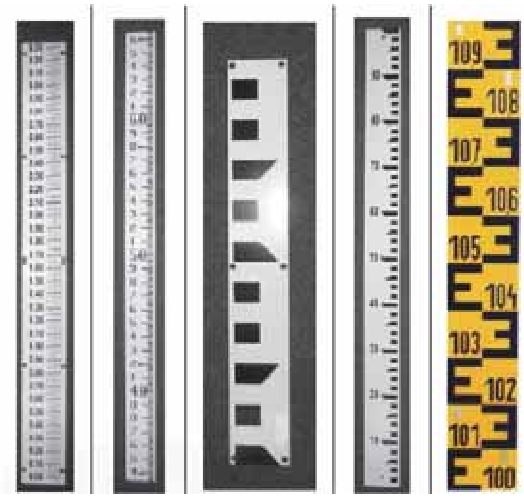
Water level:

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

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

Picture: (USACE, 2016)

Staff gauge at the Mbuluzi River, Swaziland



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

Picture: (USACE, 2016)

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

South Thailand, 2013

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

Table 3: Example for making water level observations

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

Keeping the records

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

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

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

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

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

http://www.globalfloodsystem.com

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

3.5 Reliability of data

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

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

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

- Precipitation
- Discharge
- Snow
- Sediment transport
- Erosion

4 COURSE OF ACTION FOR PLANNING MEASURES

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

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

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

1. The **risk analysis** combines information about possible hazards with current or planned land use and damage potential. In this step, a clear understanding of the physical processes and effects leading to (flood) hazards is very important as this knowledge is crucial for selection effective and long-lasting mitigation measures. In areas, where exposure to a flood hazard is determined, a risk arises.
   Depending on the risk area, a desired protection level needs to be derived. The level of protection may and should vary depending on e.g. damage potential, necessary protection effort, physical limits of protection, etc. If a protection deficit exists, the planning of mitigation measures follows.
2. Based on the risk analysis, the **action planning** follows, where suitable mitigation measures are selected. The different measures need to be considered in an integrated manner in order to exploit synergy effects and prevent counteracting processes between the different measures.
3. The next step is the action plan **evaluation**. Critical questions that need to be answered are the achieved protection level and the residual risks, the cost-effectiveness and the technical feasibility of the measures and their impacts in the socio-political sector. If the outcome of the evaluation is unsatisfactory, either the selection of measures (action planning), the risk analysis (verification of boundary conditions, selection of desired protection levels) or both need to be re-evaluated. In case that the evaluation of the action plan is satisfactory, the selected measures can be implemented.
4. During the **implementation** phase, the combine mitigation measures are realised. Based on the type of the measure, the implementation of measures can range from building concrete protection infrastructure to policy changes or stakeholder training courses. In all cases, it includes emergency planning and the maintenance of the protective structures.
5. Once implemented, the hazard risk management approach should undergo a **periodic checking**. This includes a repetition of the risk analysis to evaluate if the level of protection is still sufficient or not. If it is still sufficient, the current state of the catchment (land-use and spatial planning, maintenance of infrastructure, stakeholder engagement, policy compliance, etc.) should be safeguarded. This is important as changes of the current state may lead to a major increase of hazard potential, damage potential or both. If the level of protection becomes insufficient over time, the hazard risk management plan needs to be extended until an evaluation is satisfactory again.

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

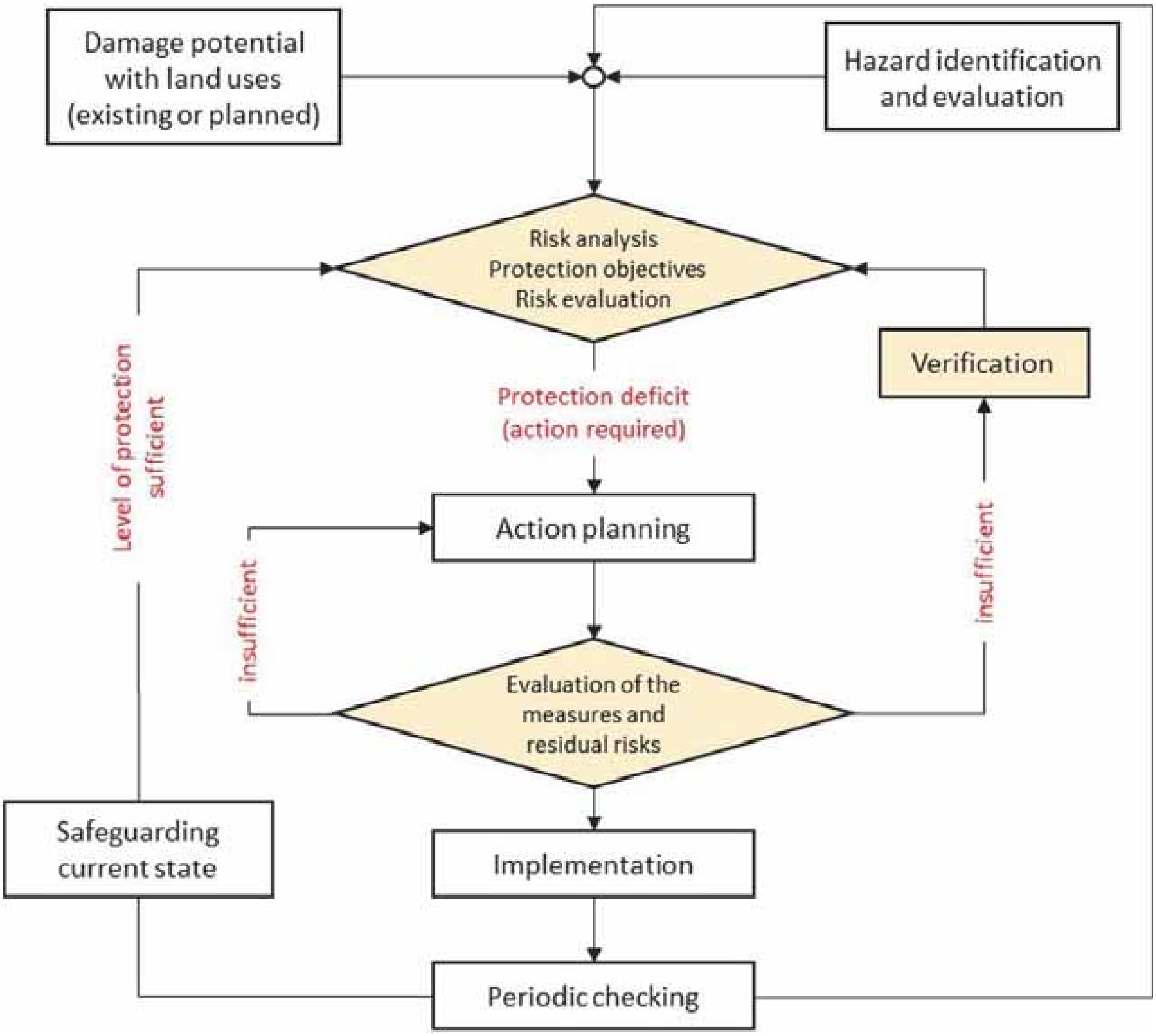


Figure 11: Action planning procedure (adopted from (FOEN, 2016)

4.1 Hazard identification

The development of an effective and sustainable hazard protection plan depends on a proper identification of the potential hazard(s), the respective catchment characteristics and their interaction with human land use. The WWF Flood Green Guide (FGG) defines different flood hazard types

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

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

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

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

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

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

4.2 Torrent classification

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

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

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

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

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

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

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

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

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

where	V_P	=	Average altitude of the catchment [km]
	S_i	=	Area of watershed between two neighbouring contour lines [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.

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

Equation 5

where S_Z = Forested catchment area [km²]

S_F = Afforested part of catchment [km²]

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

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

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

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

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

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

Intensity of erosion in the catchment and stream channel	E
Whole watershed affected by all types of erosion, stream channel devastated by both lengthwise and crosswise erosion, rough sediment continuously removed, transported and deposited. Exposed soil surface without sufficient vegetation cover prevails in the whole watershed. The slopes have a gradient of more than 50%.	1.0
Up to 80% of the watershed area is affected by rill and gully erosion. Transport and accumulation of rough sediment prevail in the stream channel.	0.9
Up to 50% of the area of the watershed is affected by furrow, rill and gully erosion. The gradient of the slopes is above 30%. There is significant transport and intensive accumulation of coarse sediment in the stream channel.	0.8
Furrow and rill erosion types prevail in the watershed. The slope gradient is above 20%. Gravel and cobbles are transported in the stream channel.	0.7
Sheet erosion and sporadically also rill erosion, prevail in the watershed. There is significant crosswise and lengthwise erosion in the channel, with transport of gravel.	0.6
Sheet erosion affects up to 50% of the watershed, furrow erosion becomes rill erosion, and gravel is transported and accumulated in the channel. The slopes in the watershed have gradients of up to 20%.	0.5
25 - 30% of the watershed area is affected by sheet erosion, furrow erosion occurs in some places. There are sites of movement of finer sediment - this sediment is transported and deposited in the stream channel. The gradient of the slopes is 10- 15%. The vegetation cover is disturbed - forests are affected by industrial emissions.	0.4
About 20% of the watershed area is affected by sheet erosion, in some places by furrow erosion. There are distinct signs of the topsoil's being washed away. Fine sediment is transported in the channel of the stream.	0.3
The whole watershed is free of distinct signs of erosion. There is a large proportion of farmed land in the watershed. Sediment largely develops through erosion in the stream channel. The slopes have gradients of up to 20%.	0.2
Whole watershed free of visible signs of erosion. Forest covers a prevailing part of the area and has a good species and age structure. The remaining area is perennial grassland. The channel of the water course is stabilized in both direction and gradient.	0.1 - 0.0

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

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

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

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

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

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

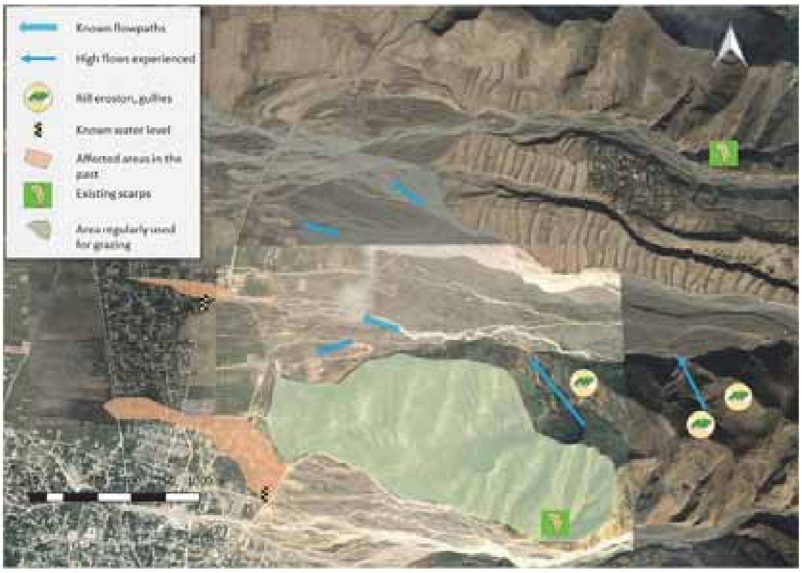
4.3 Risk assessment

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

Inventory of past flood events

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

- Type of floods that have occurred in the past including spatial and temporal extent frequency, month, duration
- Draw their spatial extent on a map and indicate severity with colours
- Draw the duration of the flood with different colours on a map
- Indicate points of known or estimated water levels in the map
- Indicate major flood formation areas in the map



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

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

Factors contributing to flooding

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

Damage incurred or expected

The locations affected should be indicated on a map and damages listed with as much detail as possible. Valuing damage in monetary terms is preferred. After the catalogue of damage is developed, a monetary value should be determined for each type of loss based on replacement costs. In a second step, apply the damage inventory to support the development of inundation-damage functions which ideally determine damage as a function of water depth. The following tasks are suggested (adopted and modified from (Mays, 2010)):

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

The result of the procedure is depicted in Figure 13. It enables water resources engineers and planners to compare effects of different measures in terms of damage incurred by flood events. The procedure requires the knowledge of the magnitude and extent of flood events with various return periods. Hydrological and hydraulic modelling is a prerequisite.

In rural areas, it is often the best solution in terms of cost-effectiveness to develop measures that contain frequent flood events (2 to 10 year return interval) if these floods cause significant damage. Flood protection against rare and extreme events, e.g. a 100 year flood or more, in high risk areas –

unfortunately large rural areas in Tajikistan are high risk areas – is so expensive and often associated with negative environmental impacts, that no solution fulfilling the following five criteria can be found:

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

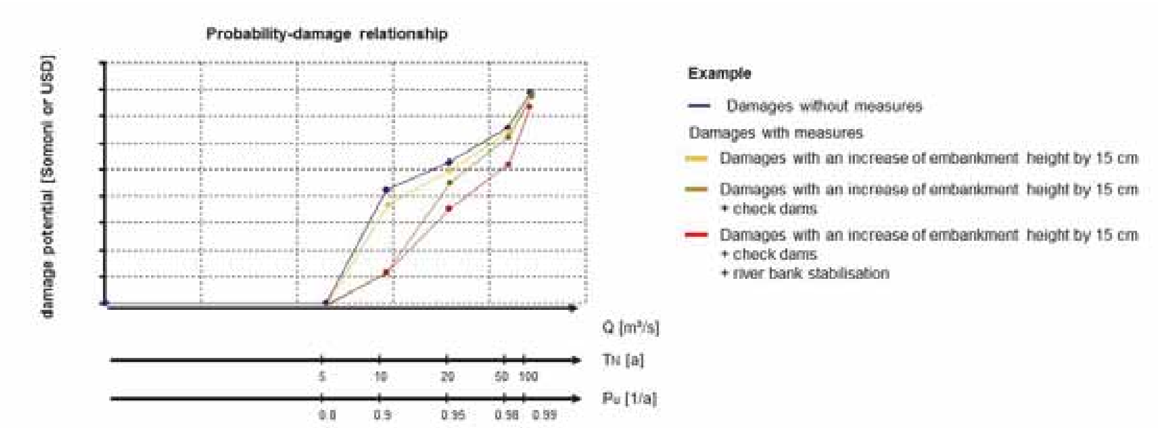


Figure 13: Probability-damage relationship for different measure

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

Vulnerable groups

A list of the groups that have been most affected by flooding in the past and/or could be affected by future flooding should be developed. Vulnerable groups are those who do not have the resources to protect themselves or to recover with own resources after a hazard strikes (e.g. less wealthy, elderly people, people with disabilities, etc. These groups should be marked on the map and special attention should be paid while dealing with flood management and planning measures.

Capacities to respond to flooding

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

Communities and institutions are commonly seen as the authority who takes the lead in responding to flooding. If their capacity is weak, flood management will be weak and response mechanisms are most likely not adequately in place.

This means that flood management has two components, namely

- water resources engineering with risk assessment, planning measures and
- institutional development determining clear roles and responsibilities, capacticy development, financing mechanisms and an appropriate regulatory framework

4.4 Flood risk maps

Maps of actual or potential flood areas are paramount in the assessment and planning process. Flood maps help proof flood risk, verify actual flood damage, indicate changes in flood impact if based on flood modelling. Different types of flood maps should be developed to support the selection process of proper measures but also to account for emergency preparedness. Four maps are shown with different information.

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

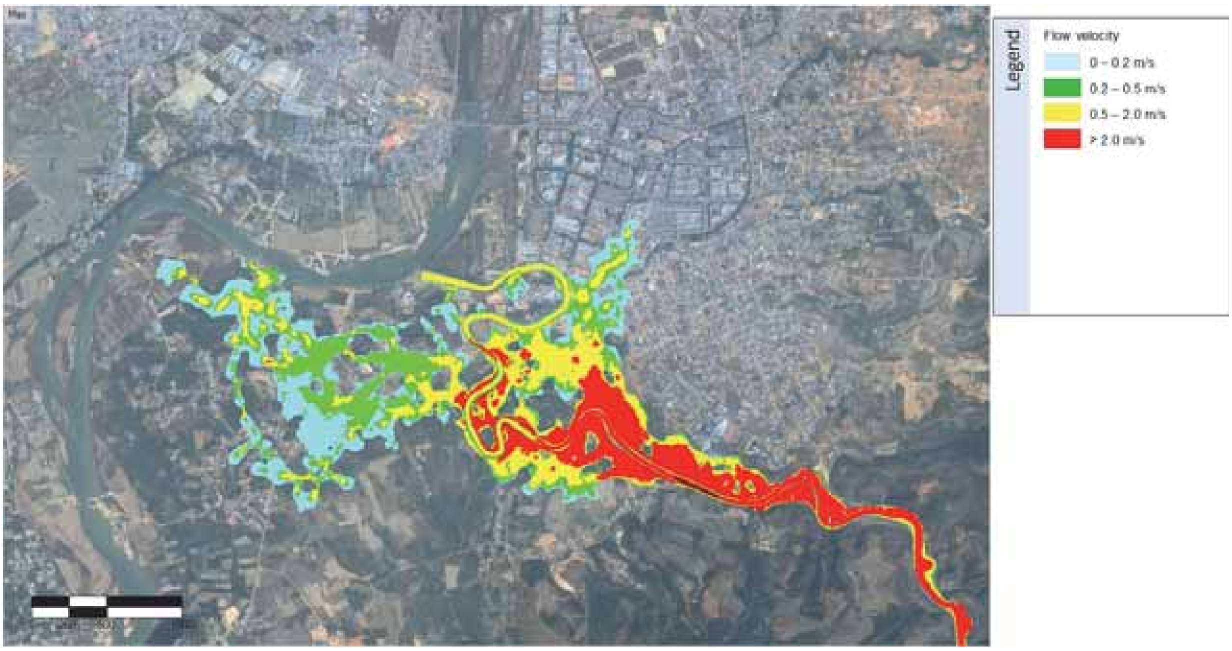


Figure 15: Flow velocity map indicating the risk to be washed away

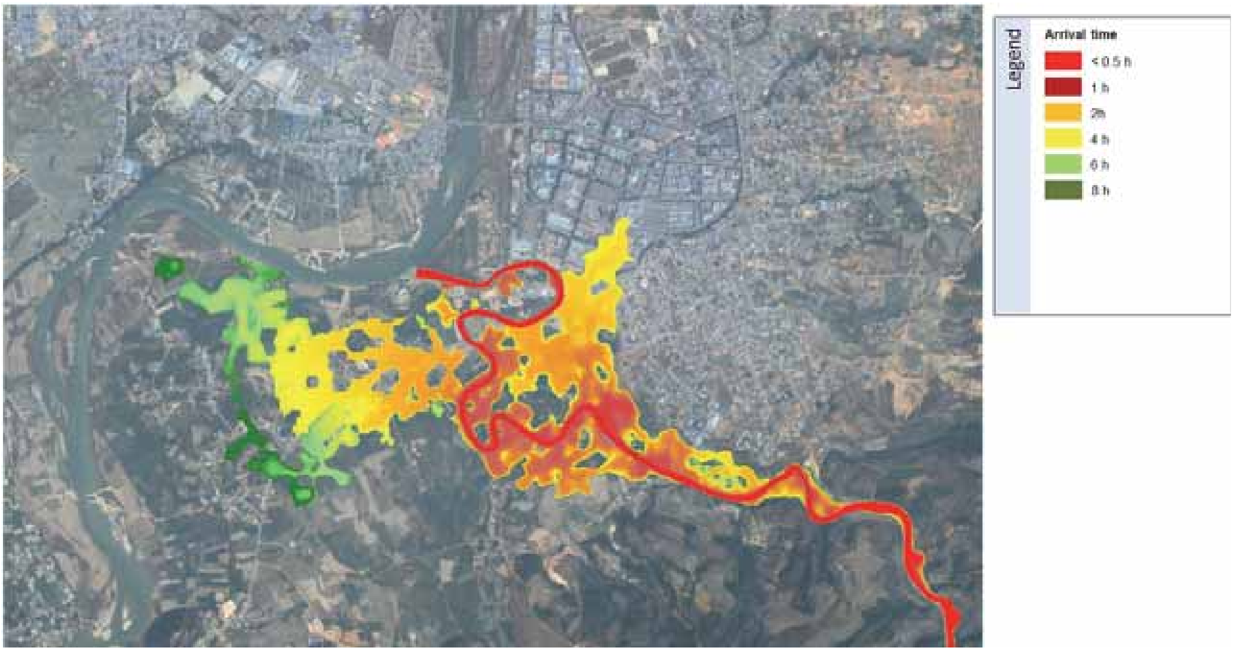


Figure 16: Arrival time map indicating time for preparation

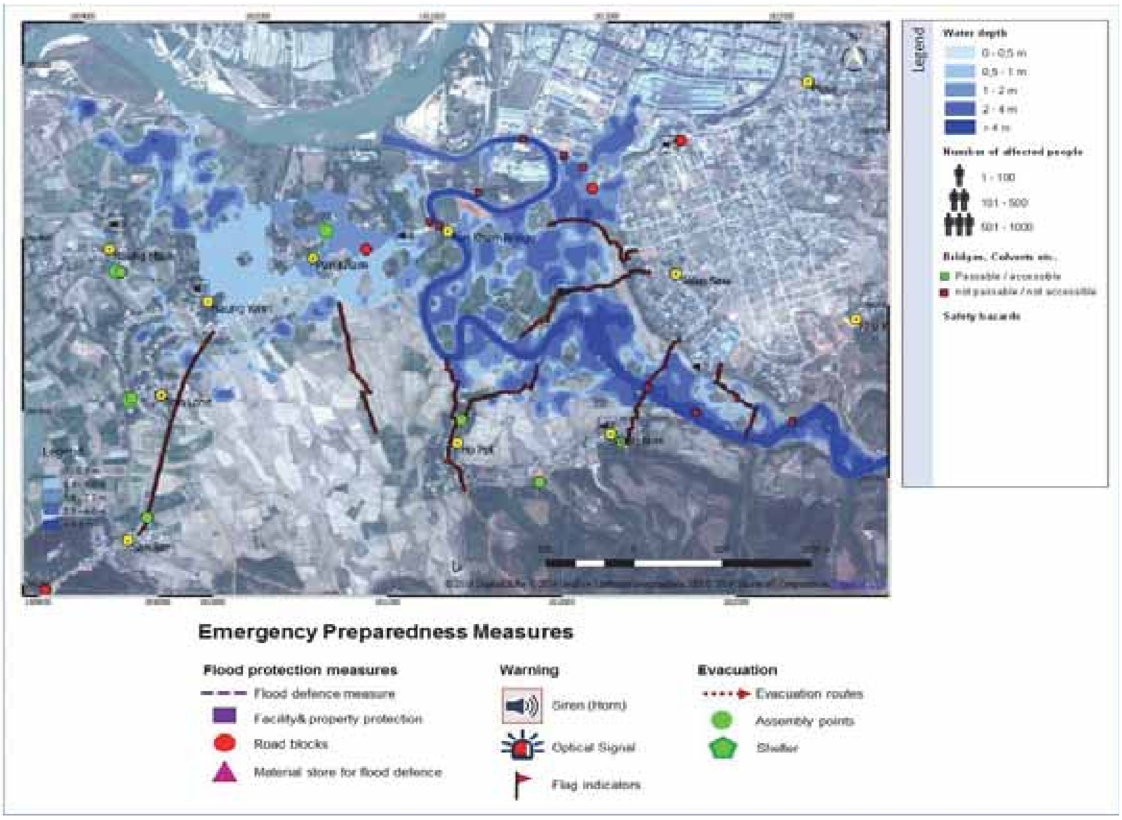


Figure 17: Flood action and emergency preparedness map (SYDRO, 2017)

Requirements for flood mapping are:

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

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

4.5 Design flood

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

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

Level of protection	Values at risk	Design discharge for channel capacity
1	Compact built-up urban area, larger housing estates, larger villages, industrial plants, important linear structures running parallel (highways, railways, etc.), protected monuments	$Q_{50} – Q_{100}$
2	Smaller villages, groups of houses, sporadically built up valleys (distance between homes not less than 100 m), roads of local importance, forest haulage roads, dumps, recreational resorts, fields of endangered by gullying	$Q_{20} – Q_{50}$
3	Outside built up areas – intensive agricultural protection, skidding and other forest roads	$Q_{5} – Q_{20}$
4	Outside built up areas – meadows, production forests, irrigation and drainage facilities	$Q_{5} – Q_{10}$

4.6 Selection of measures

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

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

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

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

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

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

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

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

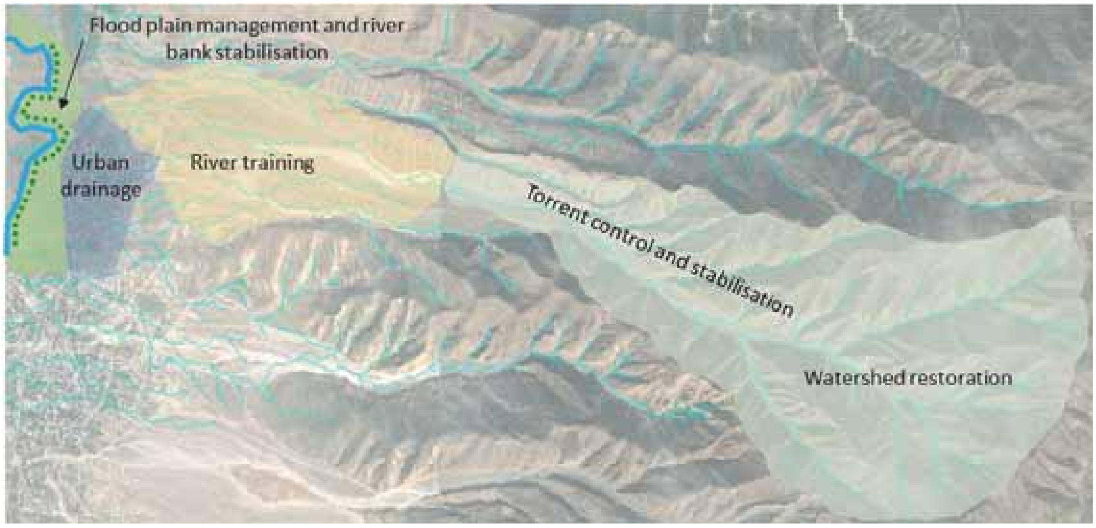


Figure 18: Watershed characterisation regarding potential interventions

Accordingly, the three main strategic pillars for intervention are:

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

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

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

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

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

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

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

5 STRUCTURAL AND NON-STRUCTURAL MEASURES

5.1 Watershed management

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

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

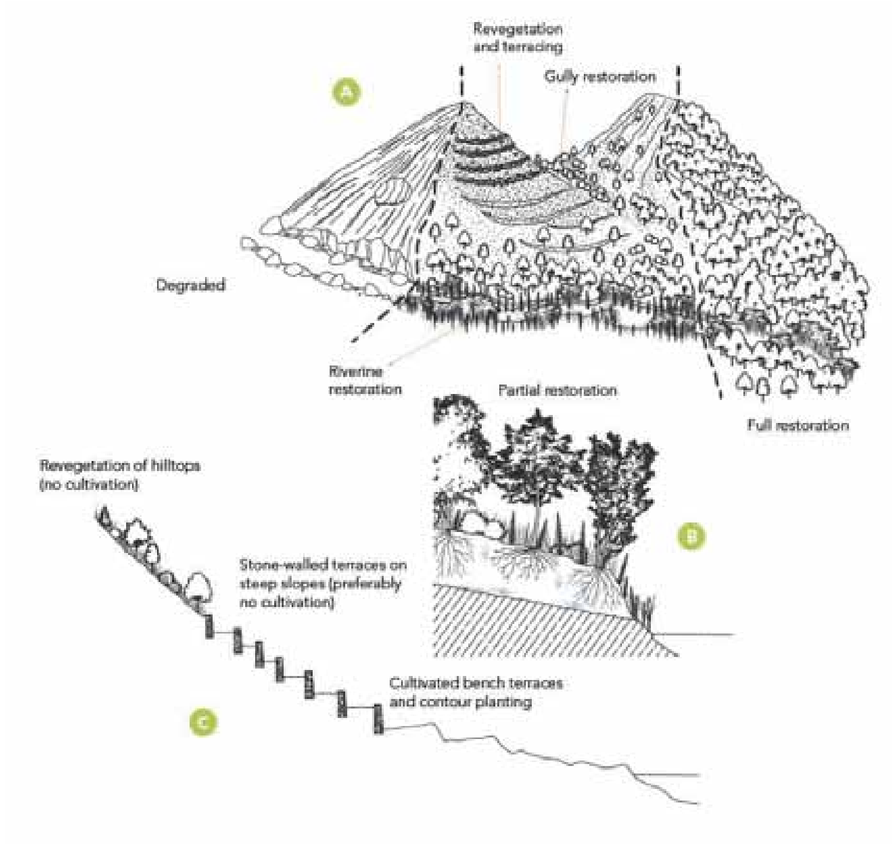
(adopted and modified from (ICIMOD, 2012)*)*

5.1.1 Integrated watershed management

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

catchment part. Major components are:

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



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

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

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

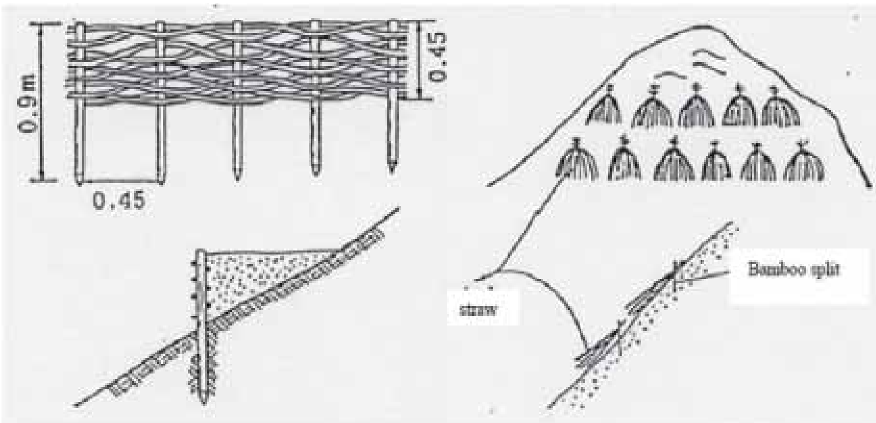
	(Extensive) Fertilizer application should be avoided. Failure of erosion control structures, bioengineering features and drainage system may cause safety issues, thus proper design is essential.
Duration until max. effectiveness	Medium/Long
Cost	Low/Medium
Maintenance	Regular control Regular revegetation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

5.1.2 Soil bioengineering

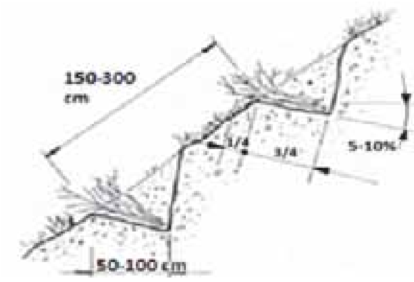
Factsheet: Soil bioengineering	
Main objective	Reduction of protection measures in transport reach and runout zone Reduction of loss of fertile soils Erosion prevention, runoff reduction
Type	Active (Structural) Soft (EbA)
Location	Headwater/ Water body
Scale	Local/Catchment
Description	Soil bioengineering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

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

Slope stabilization, Austria (Jakob & Hungr, 2005)

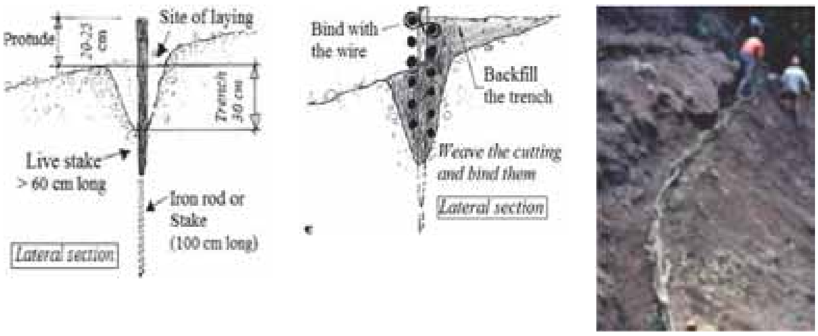


Example erosion prevention measure (STC, 2000) – Wooden post fence (left), Straw covering works (right), many more examples are given in (STC, 2000)



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

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



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

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

5.1.3 Recommendation

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

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

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

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

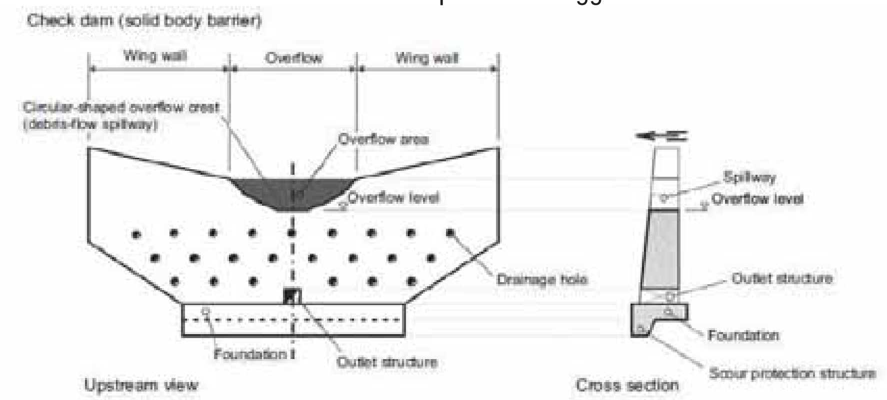
5.2 Measures for torrent control and streambed stabilisation

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

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

5.2.1 Traverse channel protection measures

<table>
<tr><th colspan="2">Traverse channel protection measures</th></tr>
<tr><td>Main objective(s)</td><td>Channel stabilization
Erosion control</td></tr>
<tr><td>Type</td><td>Active (Structural)’
Soft (EbA) / Hard</td></tr>
<tr><td>Location</td><td>Transport reach</td></tr>
<tr><td>Sphere of influence</td><td>Local/Catchment</td></tr>
<tr><td>Description</td><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.



Sketch of a typical check dam (Jakob & Hungr, 2005)</td></tr>
</table>

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

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

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

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

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

Loose stone check dams:

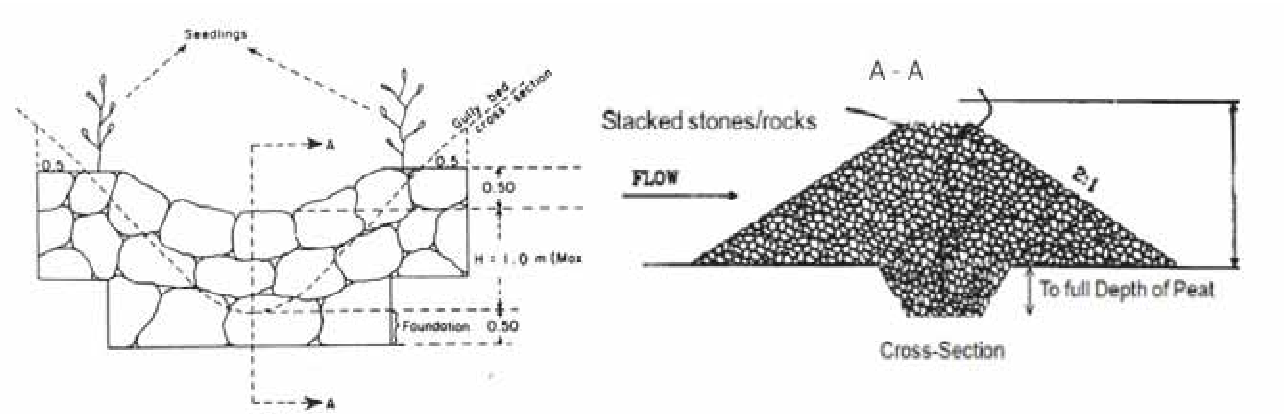


Figure 19: Loose stone check dam (FAO, Gully Control, 1986) and (Seng, 2011).

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

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

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

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

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

Boulder check dams:

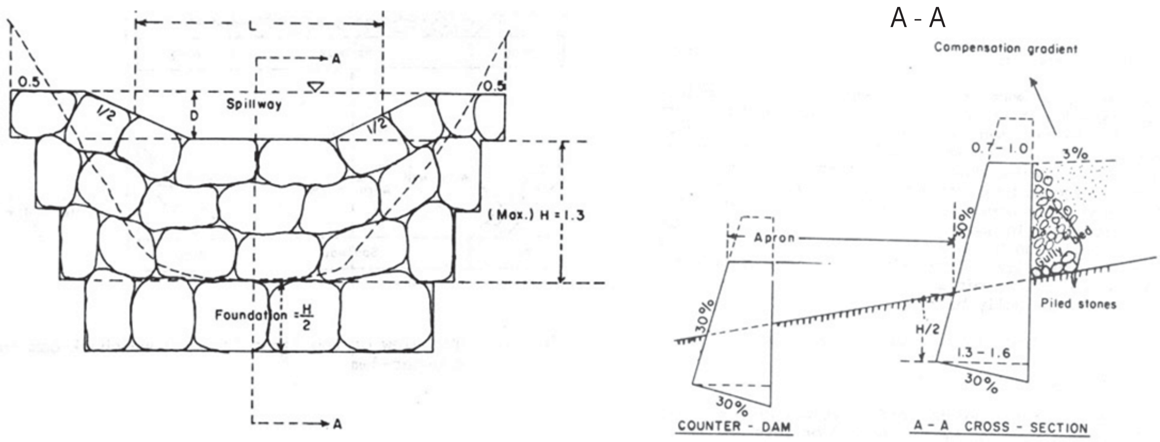


Figure 20: Boulder check dam (FAO, Gully Control, 1986).

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

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

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

Gabion check dam:

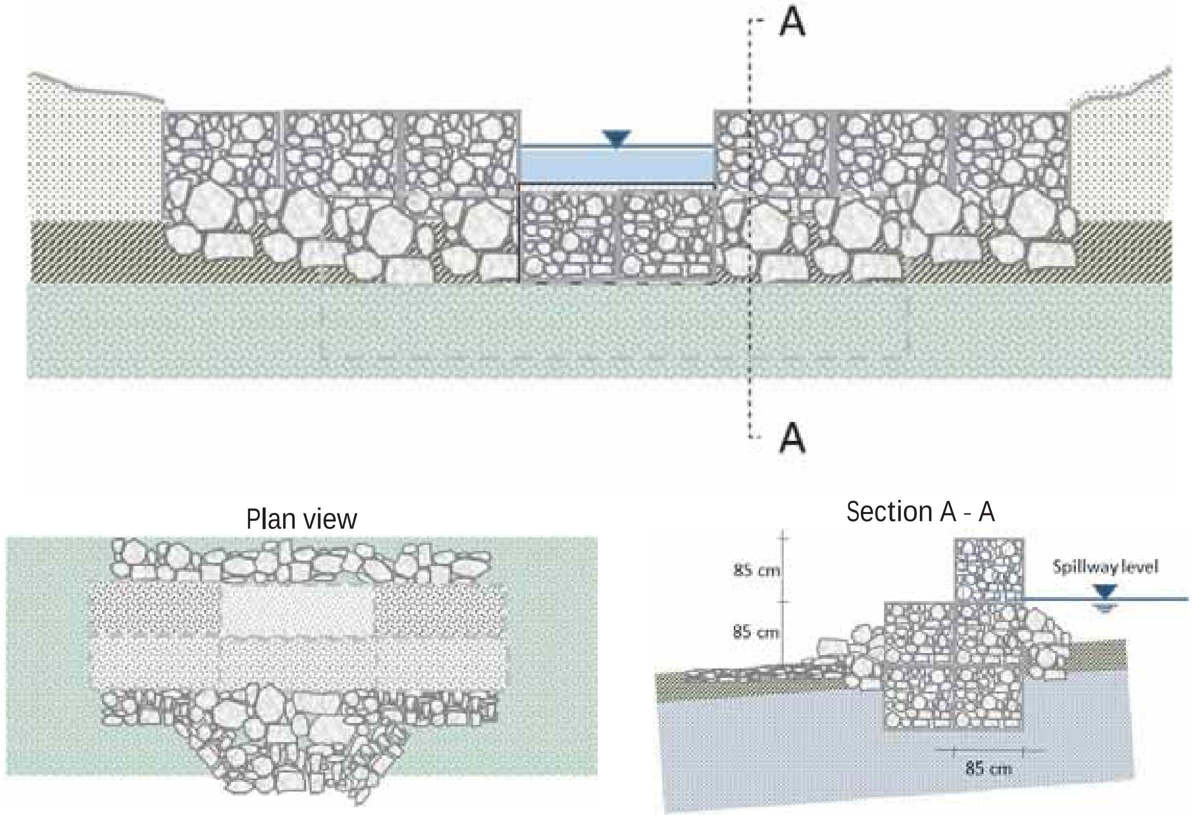
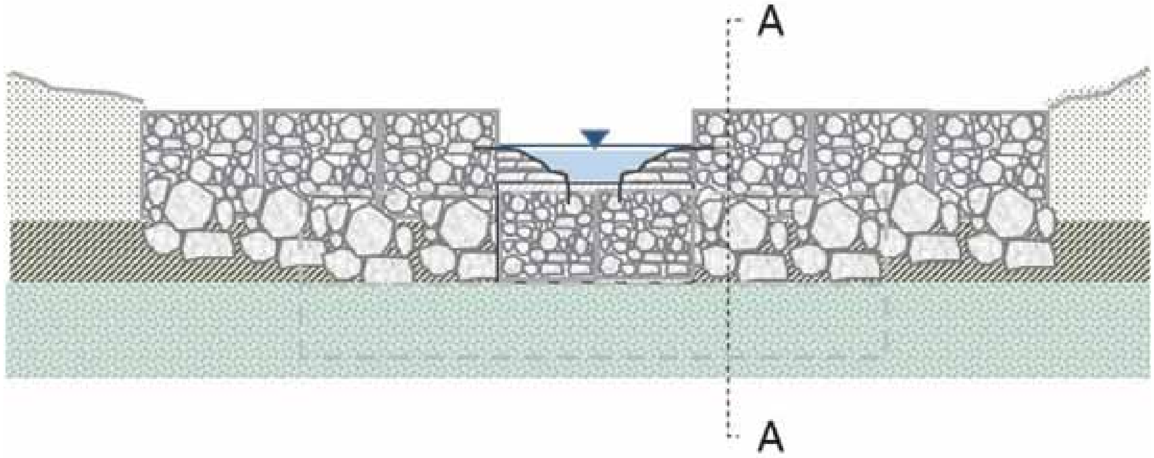


Figure 21: Gabion check dam



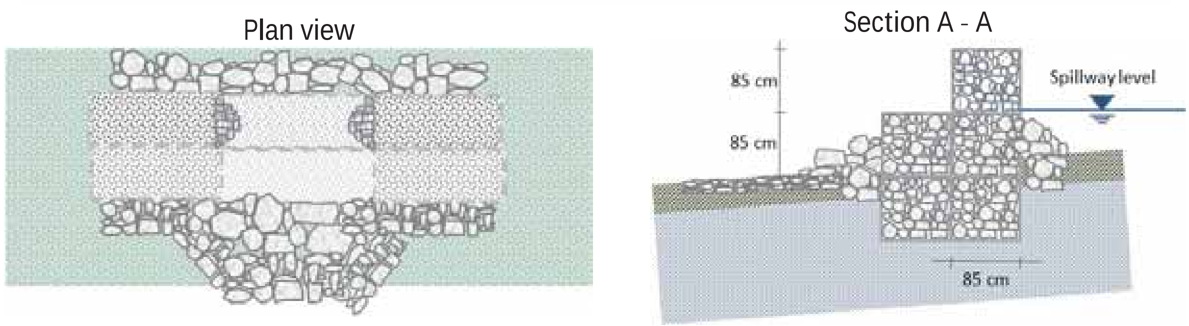


Figure 22: Gabion check dam

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

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

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

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

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

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

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

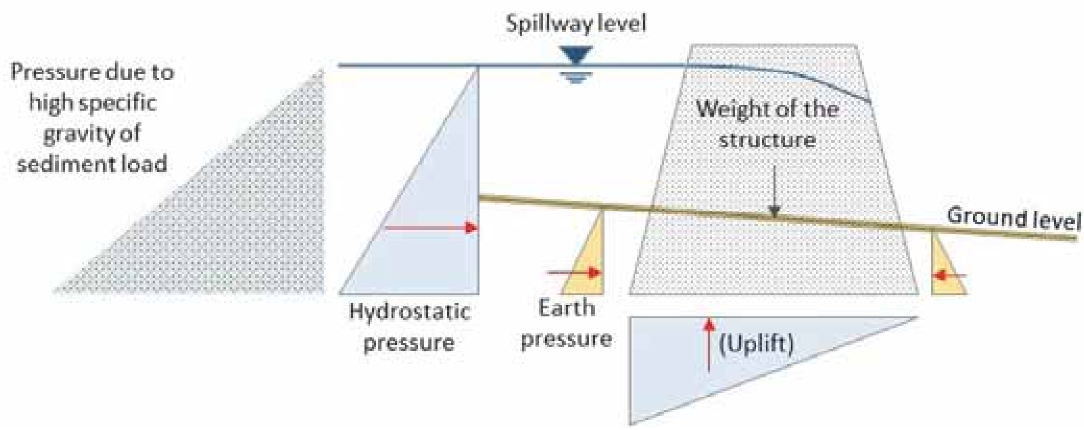


Figure 23: Forces impacting on Gabion check dams, modified according to (Llano, 1993)

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

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

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

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

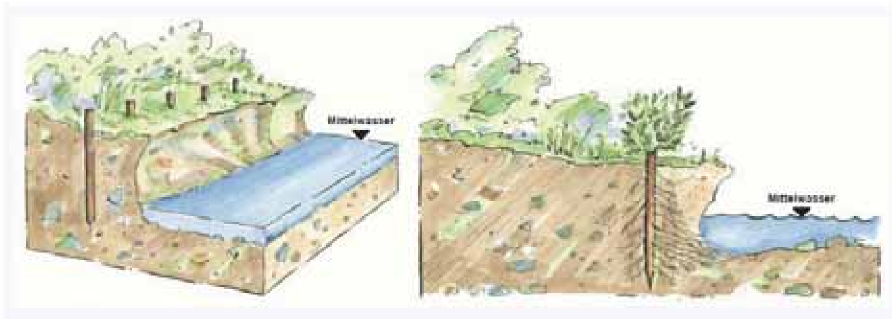
5.2.2 Longitudinal channel protection measures

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

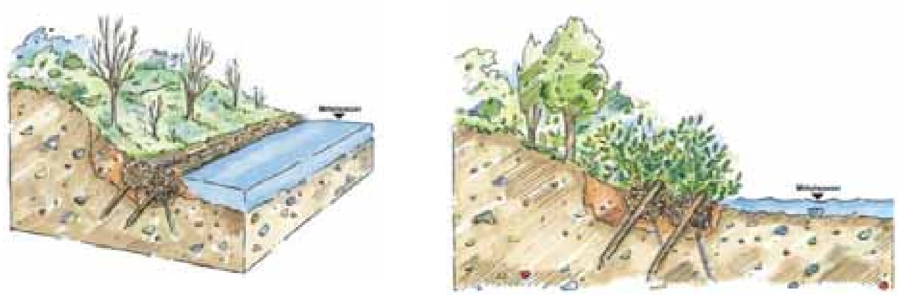
of flood and potential debris floods in bigger water courses or debris-prone torrents, the recommended materials are stone or concrete (Jakob & Hungr, 2005).

Longitudinal toe slope stabilization (Jakob & Hungr, 2005)

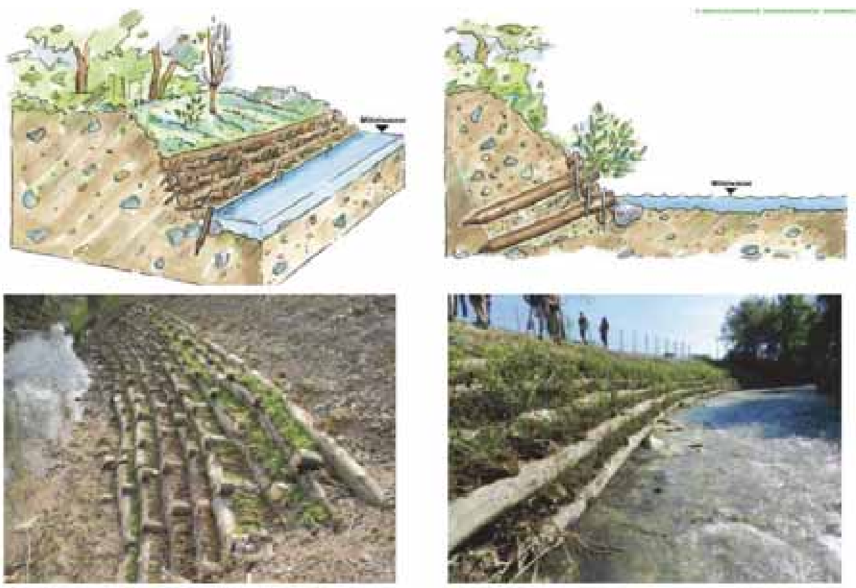
Longitudinal protection measures: Concrete wall (left), stone wall (right) (Rimböck, Höhne, Mayer, & Wolter-Krautblatter, 2015)



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



Embankment stabilization by fascines (Jany & Geitz, 2013)



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

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

5.2.3 Debris flow control

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

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

- Energy dissipation
- Dosing/Filtering
- Retention
- Diversion

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

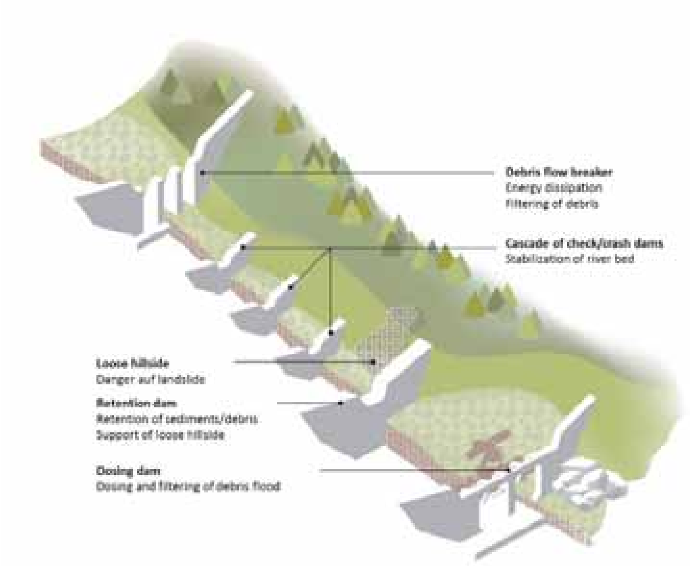


Figure 24: Chain of measure, modified (Rimböck A. , 2015)

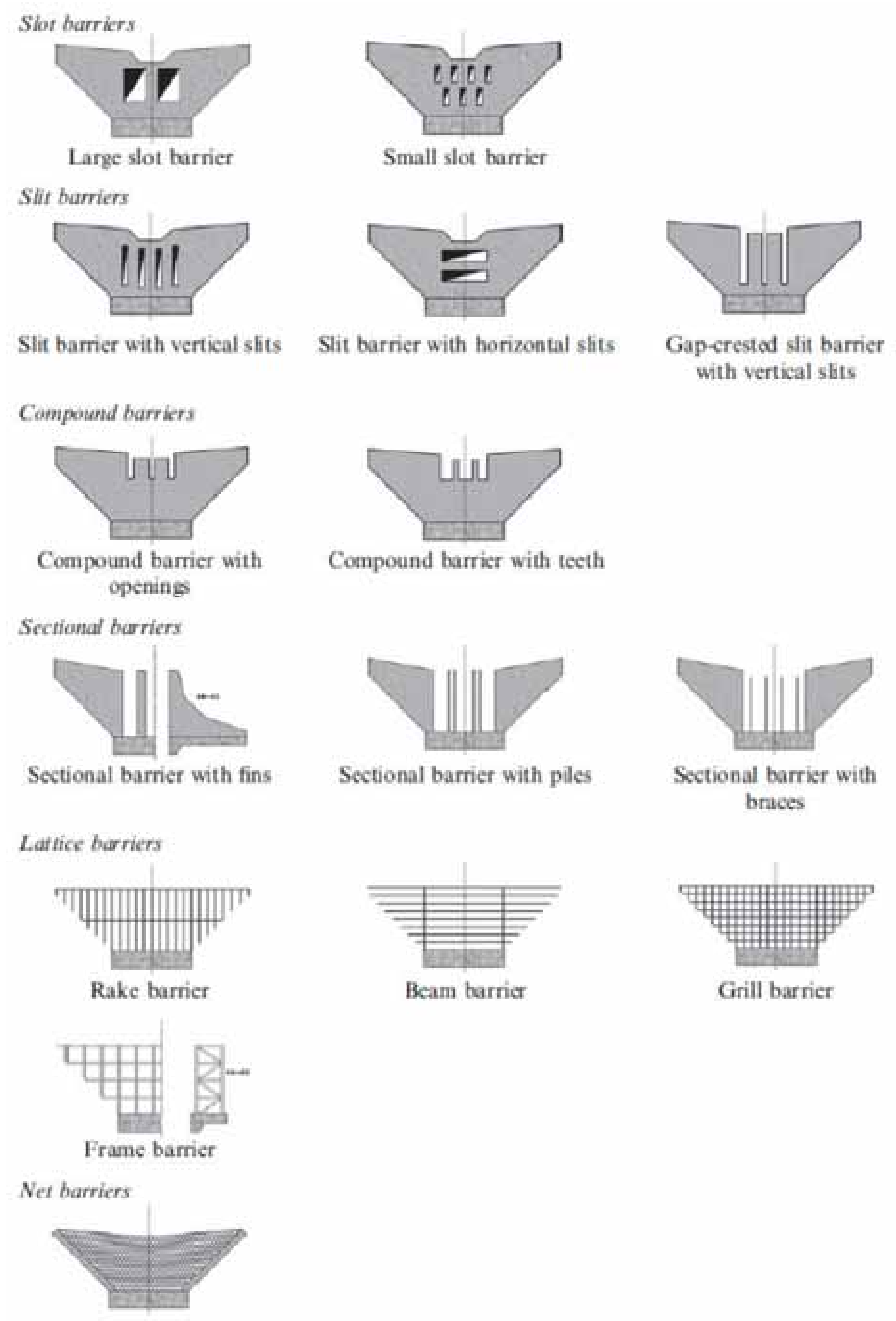


Figure 25: Types of (open) barriers (Jakob & Hungr, 2005)

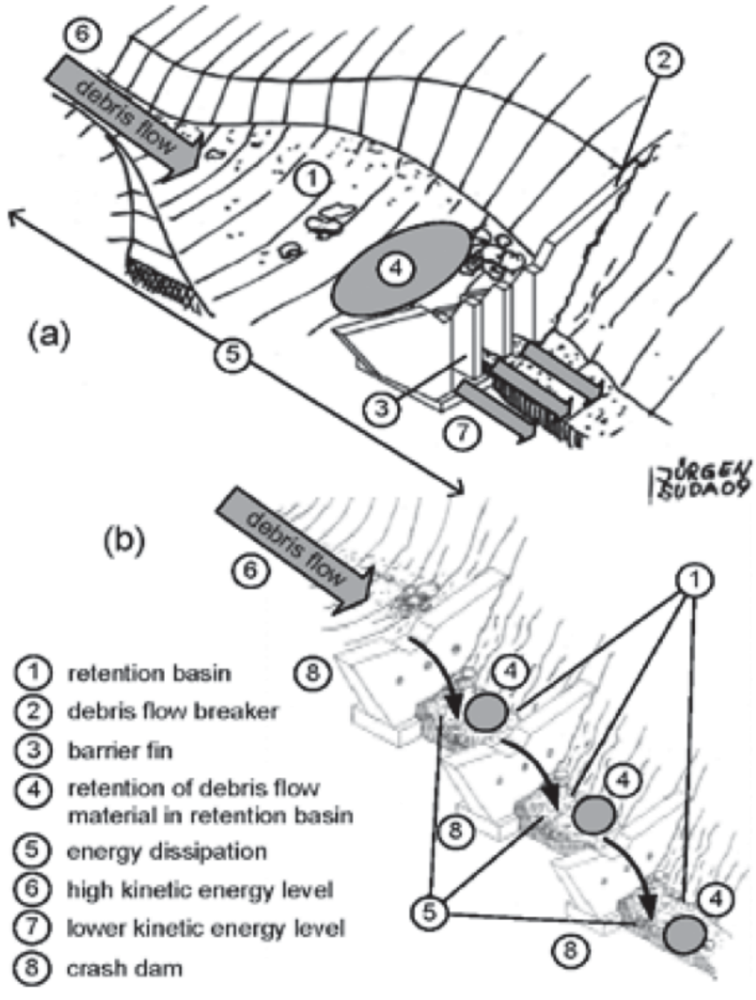
5.2.4 Debris flow breaker

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

Description

Debris flow breakers or a cascade of crash dams aim at the dissipation of debris flow energy.

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

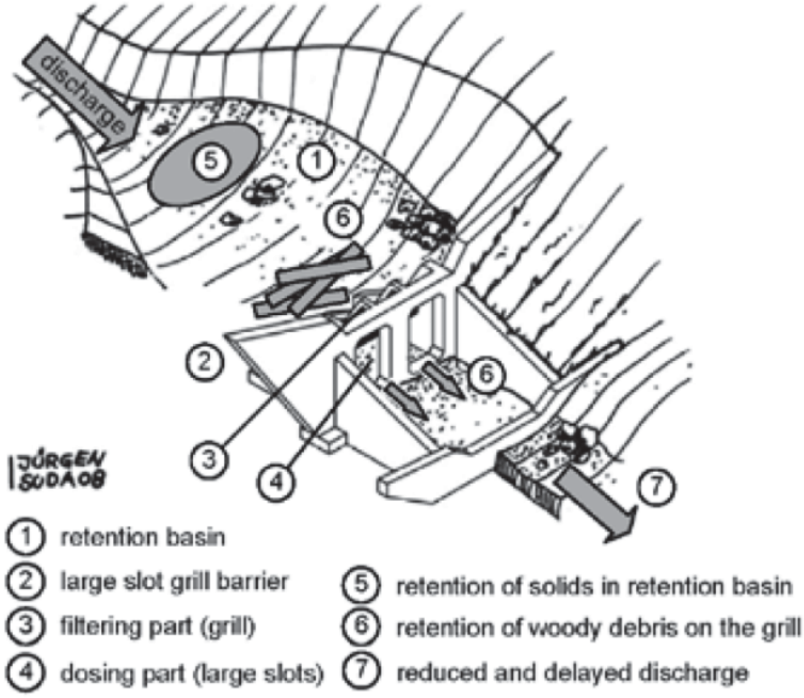


Schematic view of (a) a debris flow breaker for energy dissipation and (b) a cascade of crash dams for transformation of debris flow process (Rudolf-Miklau & Suda, 2011)

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

5.2.5 Dosing and filtering dams

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



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

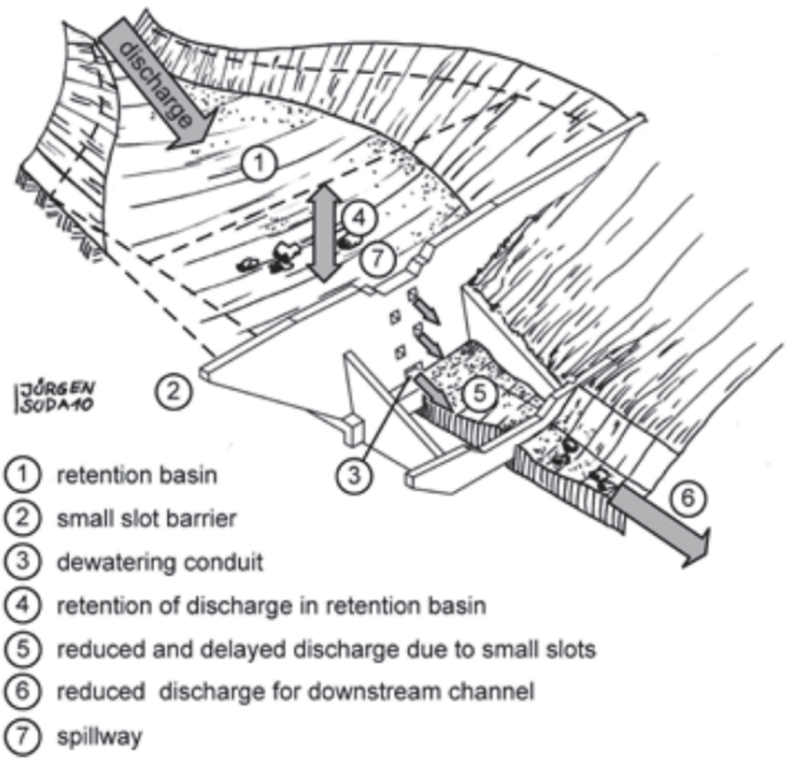
Large sot grill barrier (Mazzorana, et al., 2015)

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

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

5.2.6 Retention Barriers

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



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

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

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

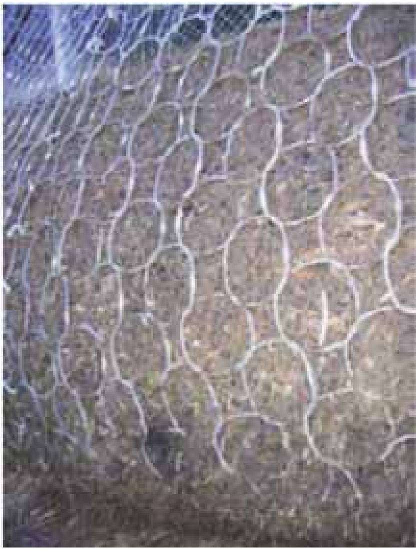
5.2.7 Net barrier/flexible barrier (Wendeler, 2016)

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

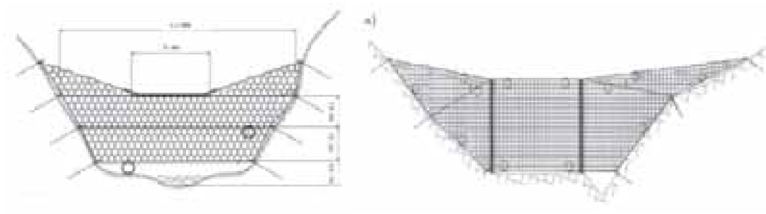
retain fine, organic matter.

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

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



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



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

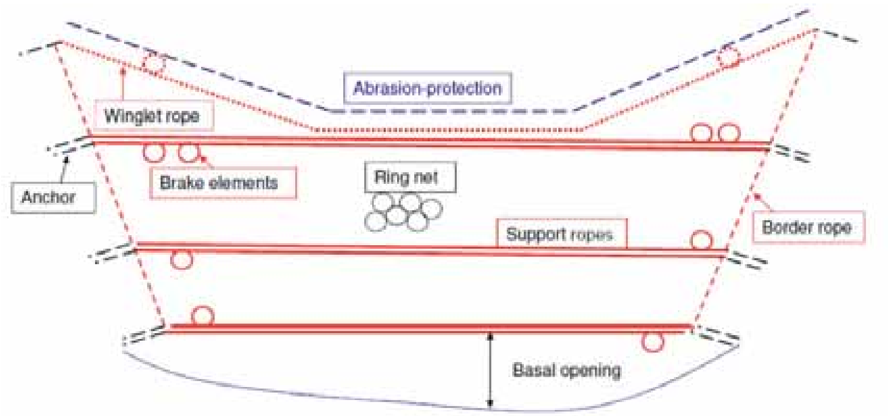
Design criteria	Support ropes span from on channel bank to channel bank, usually with one or more brake elements integrated. The winglet rope extends from top anchor to top anchor with winglets on both channel sides. The winglets function is to avoid lateral bank erosion, once the barrier is filled by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

When the barrier is loaded, the ring formed brake element reduce in diameter, became longer and the rope lengths increases respectively. Thus, brake elements dissipate energy of the debris flow, thereby reducing the load of the net barrier construction.

Anchoring of net barriers is crucial and, in general, difficult. Often, the substrate cannot bear enough load. In rocky substrates, rock anchors can be drilled. For less solid substrate, self-drilling anchors or drilled rope anchors with casing are usually recommended. Necessary anchor length can reach up to and more than 10 meter. For lower anchors, probable washout of anchor heads should be taken into account when estimating anchor lengths.

The ring net consist of interwoven wire rings. The diameter size depends on both the ring net construction and the intended grain size that should be retained by the net. Typical diameter range from 300 to 350 mm, with wire diameters around 3 mm.

Once the net barrier is filled up, the remaining debris flow cannot be retained and flows over the net. The load and shear stress of the remaining debris flow would damage the net, thus a robust abrasion protection is added on top of the ring net.



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

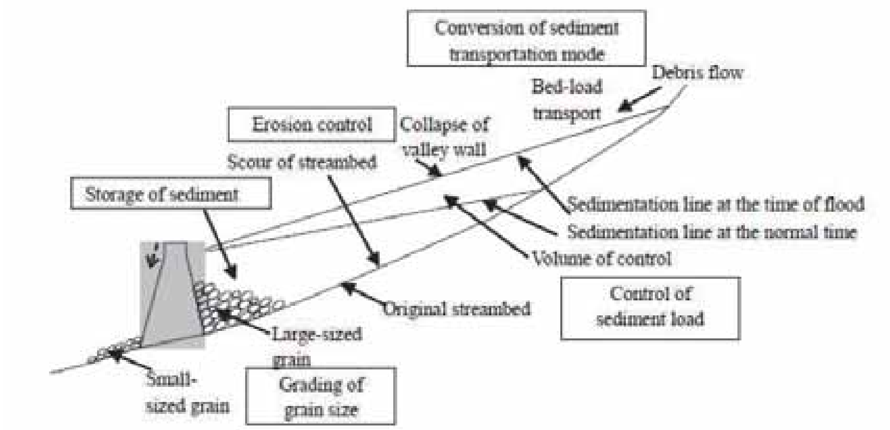
Left: Pulling up of a ring net during installation; Right: Alternative mesh size at Gaviota Pass, Canada (Wendeler, 2016)

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

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

5.2.8 Sabo dam (c.f. Retention barriers)

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



Various functions of a sabo dam (IDI, 2004)

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

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

5.2.9 Deflection and conduction structures

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

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

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

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

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

5.3 Land use planning and risk reduction

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

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

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Part II: Hydraulic Calculations with Step-by-Step Example

Empowered lives.
Resilient nations.

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Weinheim, March 6, 2018

Dr. Hubert Lohr

Contents

Figures

Tables

Flood Disaster Risk Reduction Manual for Tajikistan

Document Information

Project	Strengthening disaster risk redaction and response capacity
Project Countries	Tajikistan
Document	Flood Disaster Risk Reduction Manual for Tajikistan
Date	28.03.2018
Consultant	Dr.-Ing. Hubert Lohr
Financing Organisation	Government of Japan, UNDP Tajikistan

1 STEP BY STEP EXAMPLE

This section provides a step-by-step example from site analysis over rainfall evaluation to flood calculation. A five steps approach can be taken:

1. GIS Analysis
2. Rainfall analysis
3. Discharge analysis
4. Assessment of flow paths
5. Selection of measures

1.1 The example site

The example site is located in the south of Tajikistan close to Muminabad.

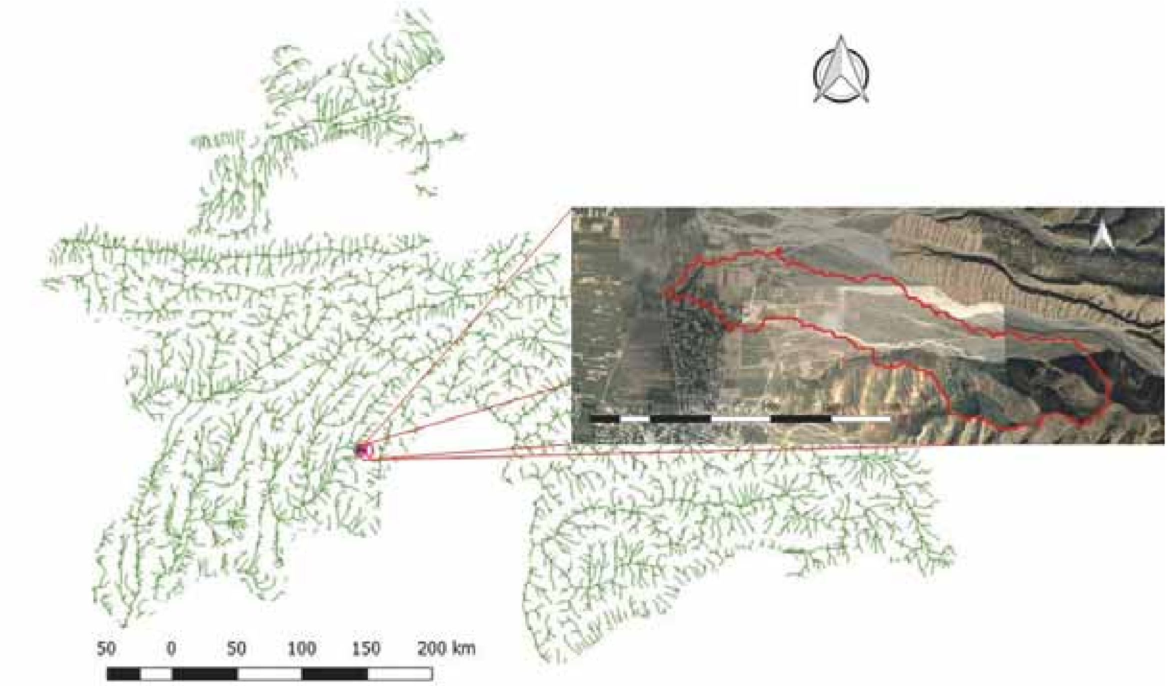


Figure 1: Location of the example site

The example site incorporates some aspects which might be representative for small tributaries and watersheds in Tajikistan. High and partly steep headwater areas, steep and narrow valleys which level off in a large alluvial fan. This area has only seasonal streams which bear water after rainfall. The catchment area comprises 378 hectares, the elevation ranges from 1213 m to 1886 m along a distance of approximately 5km. The headwater areas are mountainous with few agricultural activities. Most of the hills used as pasture show only sparse vegetation, if any. Some signs for erosion are visible. One hill is replanted with shallow plants, shrubs and cultivated with trees and vegetable which was done under the supervision of Caritas Switzerland (Caritas, Chukurak Watershed Activity Plan, 2012) and (Caritas, 2006) (see Part III). The transport reaches are short and steep forming incised ditches which carry water only for a short period of time. Downstream the transport reaches, the area widens and the gradient reduces. The narrow valleys open forming the deposition area with a wide braided river bed and a number of minor flow paths. Settlements are located further downstream and south of the main river bed where some buildings are erected in or very close to the minor flow paths.

The braided river bed in the background

Cultivated hill left with planting by Caritas

Tributary valley

New swales in the foreground, established swales with trees in the background

Figure 2: Pictures of the example site

1.2 GIS Analysis

The GIS analysis contains six steps from which parameters for calculating discharge have been derived.

Step 1: Obtain the digital elevation model for the project site

Select the area of concern and download the STRM30 (1-arc second).

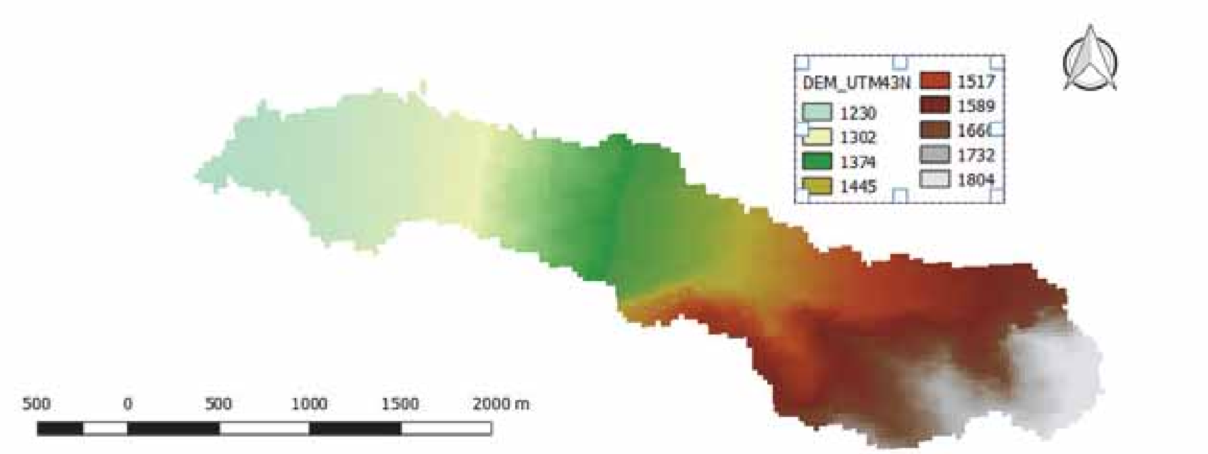


Figure 3: SRTM30 DEM for the surrounding of Muminabad

Step 2: Calculate the flow directions from the SRTM30

By using a GIS, the flow directions can be computed. This is a prerequisite for all subsequent actions.

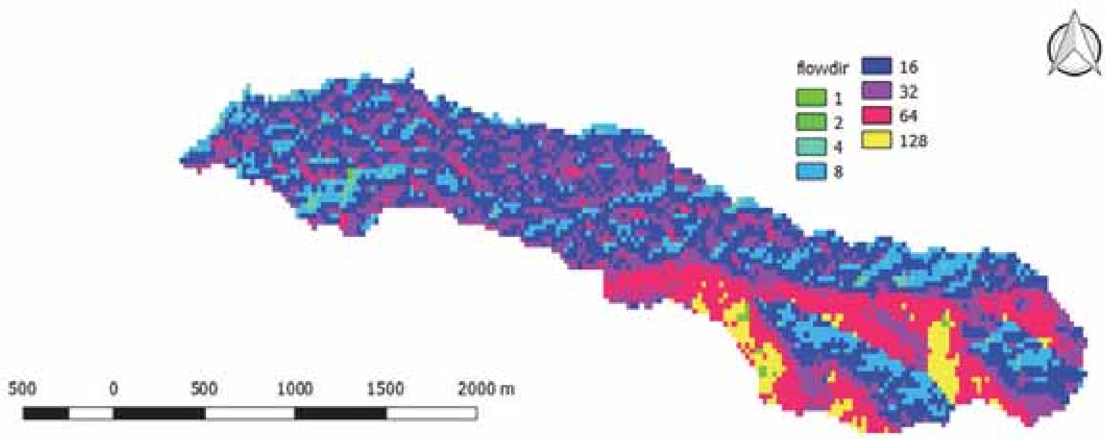
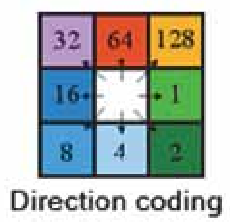


Figure 4: Flow directions

Each colour represents a flow direction. The number depends on the tool used. The principle can be shown by using the example from ArcGIS.



ArcGIS interpretation)

Step 3: Calculate the flow accumulation from the SRTM30

Flow accumulation is required to determine sub-basins in a subsequent step. The number of upstream cells is stored in each cell. This step is also used to ascertain the stream network.

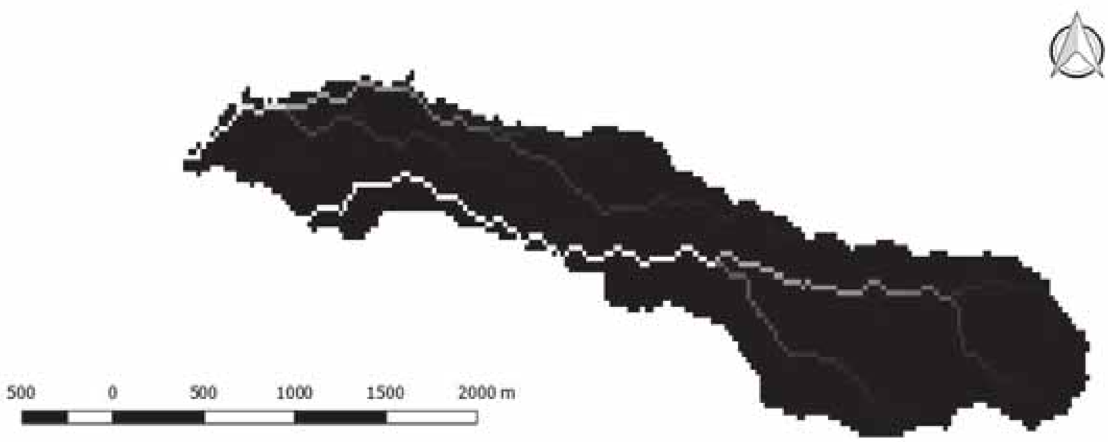


Figure 5: Flow accumulation

The grey shade indicates the number of upstream cells flowing through the respective cell. Black means no upstream cell.

Step 4: Generation of the stream network from the SRTM30

The stream network is relevant to obtain vectorised data about flow paths. The result does not necessarily follow real rivers, it indicates the steepest flow paths based on the analysis of flow direction derived from the DEM. A high number of upstream cells makes it very likely that a calculated stream from SRTM30 coincides with a real river.

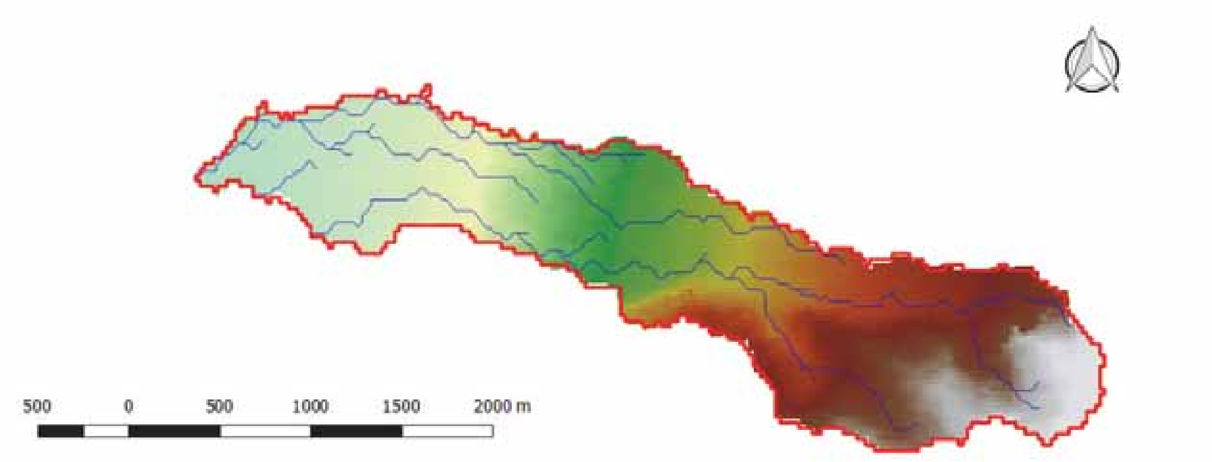


Figure 6: Stream network calculated

The stream network provides the means to identify possible flow paths and gives a direction for further measures. It is advisable to cross check and to support the stream network on site by means of a field visit and by making use of local knowledge.

Step 5: Determine sub-basins from the SRTM30

From the flow accumulation and stream network procedure, sub-basins can be derived by applying a threshold value for the number of cells forming one sub-basin. The larger the number the less sub-basins are created. Alternatively, pour points are created at which location a sub-basin is built.

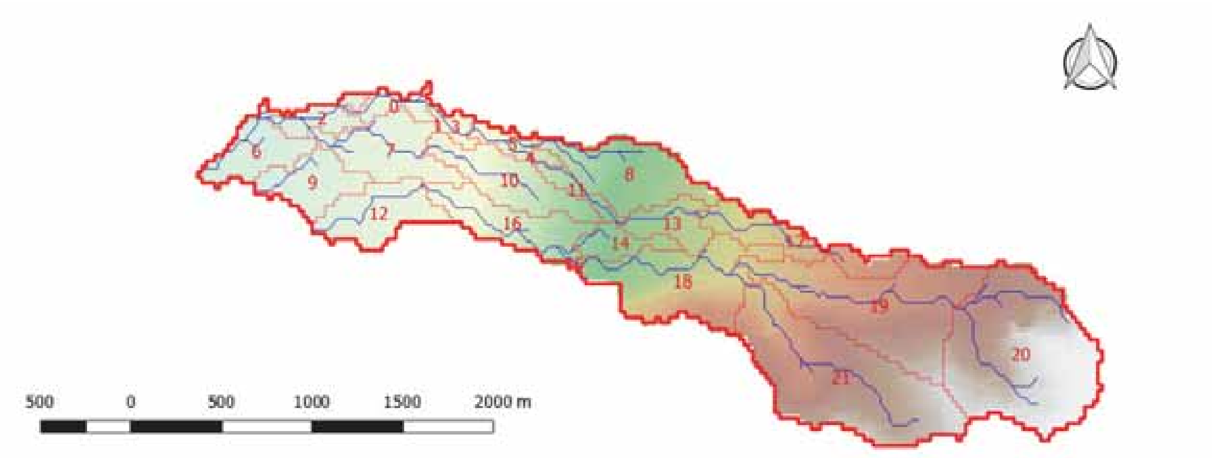


Figure 7: Sub-basins

Step 6: Generation of slopes

A very useful tool of GIS is to derive slopes from a DEM. The slope is a strong indicator for erosion proneness and is used in many applications, e.g. estimation of erosion, time of concentration, runoff, planning and siting of measure. Slope is also required to derive parameters for calculating discharge.

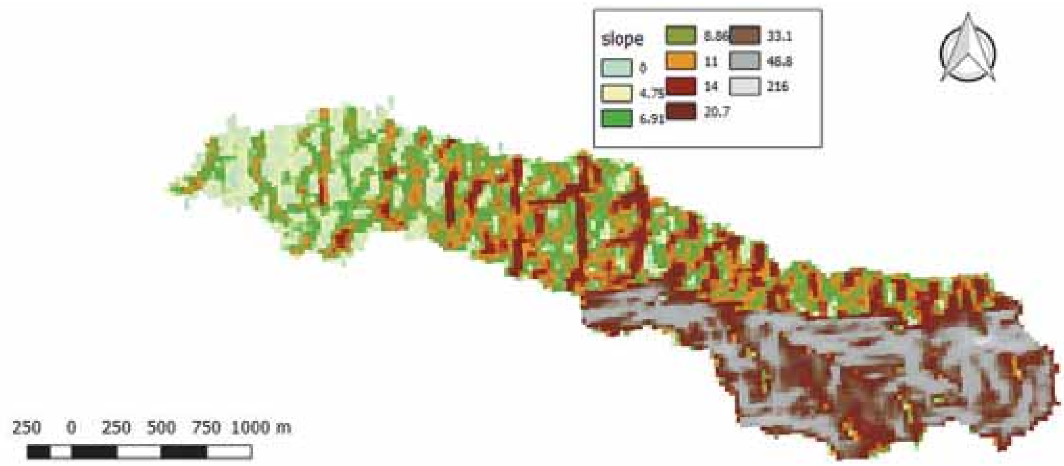


Figure 8: Slope calculated from SRTM30 DEM

It is not necessary to build categories but it makes it easier to read the map.

1.3 Rainfall analysis

A flood analysis requires a rainfall-runoff calculation to obtain flow and flood peaks in case no discharge observations and discharge statistics are available. This is probably the case for most of the tributaries and valleys which are not located close to one of the 89 hydropost stations in Tajikistan.

A prerequisite for rainfall-runoff calculations is the availability of information about rainfall depth/rainfall duration linked to return periods.

The assessment of rainfall yields the load for any subsequent computation. This process must be conducted carefully and effort should be made to obtain rainfall data which are relevant for the project site. This is especially challenging given the sparse data situation in Tajikistan.

There are two options:
1) an analysis of rainfall depth/duration/return periods is available
2) no analysis is available and it is necessary to derive the information

The first option is convenient and no further action is required. Here, option 2 is considered as standard so we concentrate on option 2.

For the example site of Muminabad, a rainfall time series located in the Khovaling district was used. Rainfall time series can be obtained from the Meteorological Department (see Part I) or this department conducts the analysis on request.

Additionally, this example uses data obtained from the Climate Forecast System Reanalysis (CFSR).

	Source	Request	Timeframe	Temporal resolution
1	Khovaling, Meteorological Department	Direct request	Jan. 79 – Dec. 2011	daily
2	Muminabad region, CFSR	download	Jan. 79 – Jul. 2014	daily

The platform for downloading data indicates if the area selected contains data or not depending on the number of points of the CFSR system which are incorporated in that area.

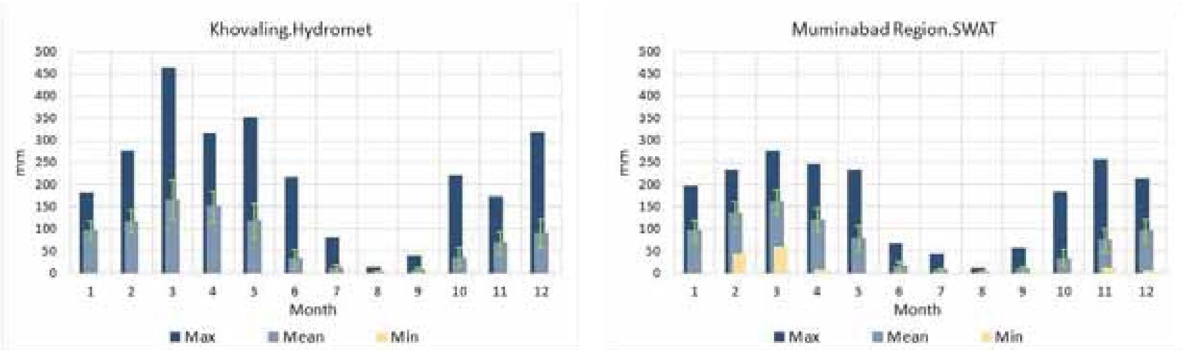


Figure 9: Monthly rainfall pattern from the Khovaling station and from CFSR

Step 1: Elimination of outliers

The time series (1) contains daily values of rainfall depth from 1979 to 2011. Before any analysis takes place, the series must be checked for outliers.

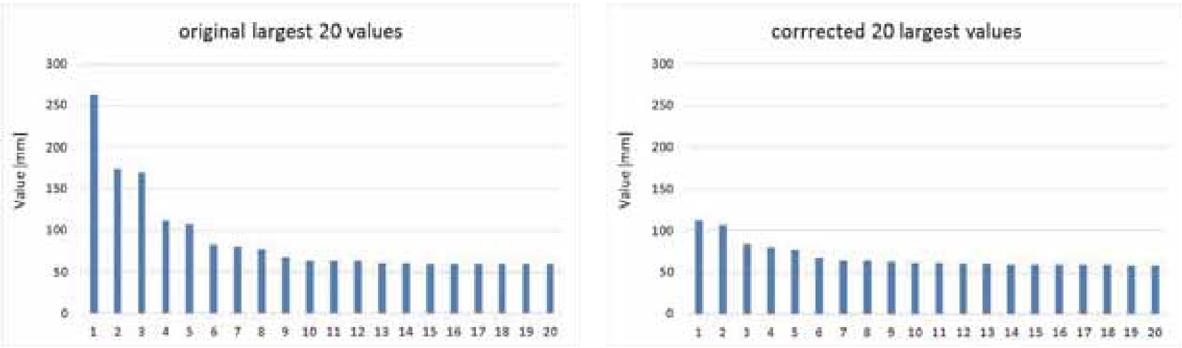


Figure 10: Elimination of daily rainfall outliers for Khovaling

The identification of outliers is difficult when values seem possible but still are beyond the expected range. It is recommended investigating in this matter as extreme rainfall depths are most important for the statistical analysis. Usually, extreme rainfall events are memorized and people in the region affected can remember it. It is worth obtaining the perception of local people if there is no other way of determining the reliability of outliers.

Step 2: Generation of Intensity-Duration-Frequency curves

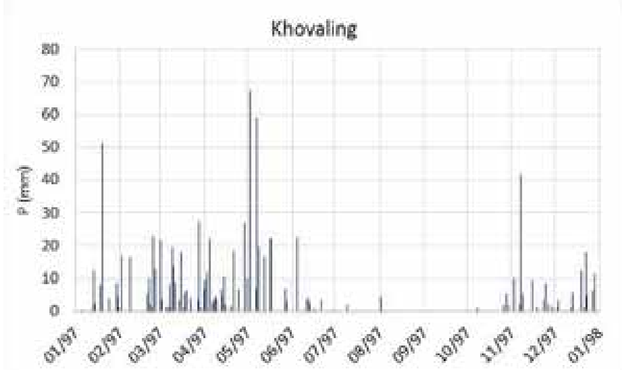
The background of Intensity-Duration-Frequency curves (IDF) of Depth-Duration-Frequency curves (DDF) is explained in Section 2.2. It is one of the most important analysis and constitutes a worldwide standard (Maidment, 1998).

An IDF analysis yields the necessary input for calculating flood events. The approach links rainfall depth/rainfall duration with return periods. Calculating discharge based on an IDF curves assumes that the peak discharge has the same return period as the rainfall event. This is a simplification but reflects common practice in deriving design floods.

The process of obtaining IDF or DDF curves requires some effort and background knowledge. It is recommended having the analysis carried out by the Hydro-Meteorological Centre in Dushanbe. A pragmatic way of deriving IDF curves is given below to familiarise those readers who haven’t been in touch with this kind of analysis.

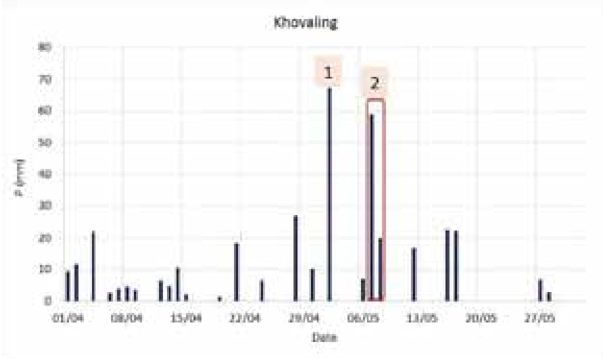
1 Select the maximum rainfall for each year. Start with 1 day maximum, then consecutive 2 days period, consecutive 3 days period up to consecutive 6 days period.

The maximum daily value is easily visible (right image = May), the cumulative sum of the other consecutive days is not that easy to identify. The analysis is shown below.



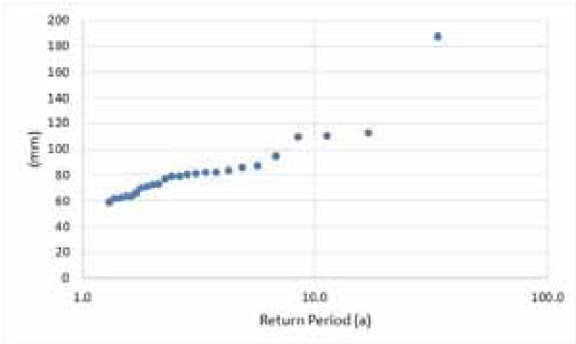
Max values			
1 day	2 day	3 day	4 day
1	**2**	**3**	**4**
P (mm)	P (mm)	P (mm)	P (mm)
67.3	**78.6**	**85.5**	**85.5**
02/05	07/05	06/05	05/05

Daily maximum (2nd of May) and 2-days maximum (7th of May) are illustrated in the right image.

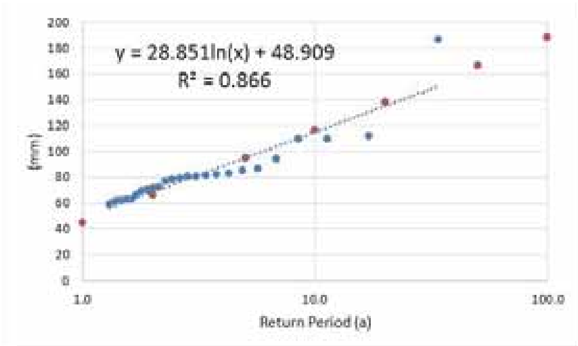


2 Sort all maximum values for all years and the 1 to 6 days and calculate the return period by means of a simple empirical function RP(a) = (N+1)/i where:
N = Number of years
i = rank (1 = largest, N = smallest)

The result is displayed for cumulative 2 days rainfall.



3 Create logarithmic trendlines in the form of RF (mm) = A x LN(x) + B for 1 day up to 6 days where x is the return period in years. Evaluate the parameters A and B. Having A and B at hand, the formulas for calculating rainfall depth depending on return periods for rainfall durations equal or longer than 24h are ready. For shorter rainfall durations continue with point 4.

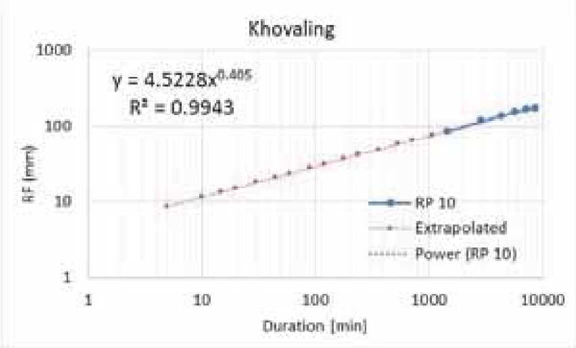


4 Select a return period and use all formulas for 1 day to 6 days to calculated the rainfall depth in mm. The table right shows the values for a 10 year return period.

	RP 10 a	RF (mm)
Rainfall duration	1 day	84
	2 day	116
	3 day	134
	4 day	153
	5 day	166
	6 day	173

5 The calucaled rainfall from point 4 is used to evaluate a trendline as a power function in the form of:
RF (mm) = A x D^B where:
D = Rainfall duration (min)

With both axis, duration in minutes and rainfall in mm, in logarithmic form the power function shows a strong linearity from which shorter rainfall durations can be extrapolated.



Calculating a set of return periods and displaying them in one graph, a complete Depth-Duration-Frequency curve is established. By referring the calculated rainfall depth to one hour, the Intensity-Duration-Frequency curve is accomplished. AEP is Annual Exceedance Probability and is the inverse of frequency or return periods.

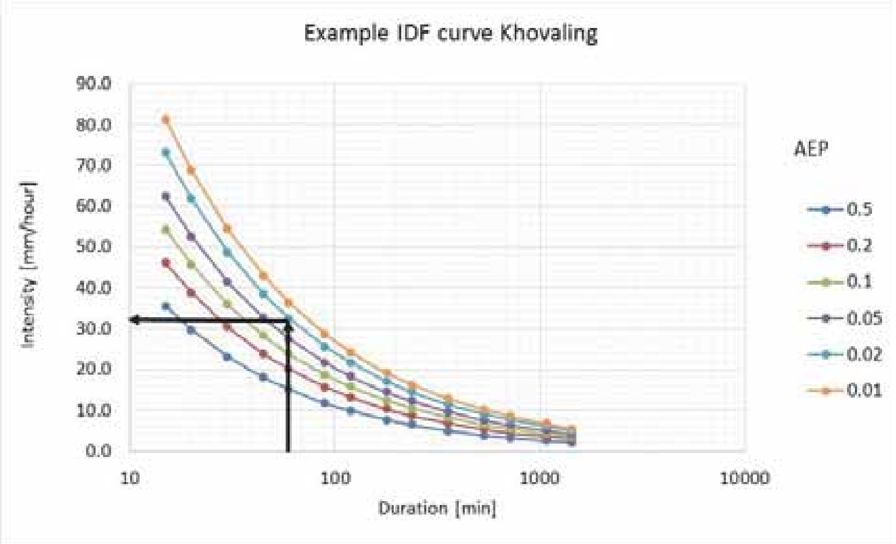


Figure 11: IDF curve derived with daily values for Khovaling rainfall station

In theory, any rainfall duration can be extrapolated. In practice and without any verification, rainfall duration shorter than 1 hour should not be used.

For the example a 50 year return period or 0.02 AEP and a 60 min rainfall duration was chosen. From Figure 11 a value of 32 mm is obtained. For the sake of simplicity, snow is not regarded. However, it could be embedded by evaluating rain and snow in combination.

Table 1: Matrix of rainfall Depth, Duration and Frequency. Cells >= 30mm indicated as blue

Rainfall duration	Return period [a]							
	0.5	1	2	5	10	20	50	100
5 min	3.9	4.7	5.8	7.4	8.7	9.9	11.6	12.8
10 min	4.8	6.0	7.6	9.8	11.5	13.2	15.4	17.2
15 min	5.3	7.0	8.9	11.5	13.5	15.6	18.3	20.3
20 min	5.8	7.7	9.9	12.9	15.2	17.5	20.6	22.9
30 min	6.5	8.9	11.6	15.2	17.9	20.7	24.4	27.1
45 min	7.3	10.3	13.5	17.8	21.1	24.4	28.8	32.2
1 hour	7.9	11.4	15.1	20.0	23.7	27.5	32.5	36.3
1.5 hour	8.9	13.1	17.6	23.5	28.0	32.5	38.4	43.0
2 hours	9.7	14.6	19.6	26.3	31.4	36.5	43.3	48.4
3 hours	10.9	16.8	22.9	30.9	37.0	43.2	51.2	57.4
4 hours	11.8	18.6	25.5	34.7	41.6	48.6	57.7	64.7
6 hours	13.2	21.5	29.8	40.8	49.1	57.4	68.3	76.6
9 hours	14.9	24.8	34.8	47.9	57.8	67.7	80.8	90.8
12 hours	16.1	27.5	38.8	53.7	65.0	76.2	91.1	102.4
1 hours	18.1	31.7	45.3	63.1	76.5	90.0	107.8	121.2
1 day	22.0	36.4	50.8	69.9	84.4	98.8	117.9	132.3
2 day	23.5	45.0	66.5	95.0	116.5	138.0	166.5	188.0
3 day	23.0	48.8	74.6	108.7	134.4	160.2	194.3	220.1
4 day	23.8	53.7	83.7	123.2	153.2	183.1	222.7	252.6
5 day	33.5	64.2	95.0	135.6	166.4	197.1	237.8	268.5
6 day	39.8	70.5	101.2	141.8	172.5	203.2	243.8	274.5

1.4 Parameter of the sub-basins

In total 20 sub-basins were created by means of the GIS analysis. The parameters area, min/max elevation, flow length and slope were calculated with GIS features while land use was taken from Google Earth and verified during a field trip. If available, land use, soil and geological maps should be used for parameter evaluation.

The basin ID refers to the numbers given in Figure 7.

Table 2: Parameters of the sub-basins

BasinID	AREA [ha]	MIN [m]	MAX [m]	MEAN [m]	Max. Flow-length [m]	mean Slope [%]	Land cover
0	5.3	1251	1279	1265	554	5.1	Gravel, sand
2	7.2	1233	1260	1246	474	5.1	Cultivated to gravel
3	3.3	1276	1300	1287	294	6.9	Gravel, sand
5	5.4	1292	1342	1315	618	8.7	Gravel, sand
6	13.6	1213	1245	1231	770	5.3	Urban, green spots, gravel
7	19.7	1243	1298	1267	804	6.4	Gravel to sparse veg.
8	23.1	1324	1430	1377	1238	10.3	Gravel, sand
9	13.6	1231	1264	1246	772	5.5	Urban, dirt roads, gravel
10	18.8	1276	1373	1318	1164	9.5	Gravel, debris
11	4.3	1325	1382	1353	577	9.9	Gravel, sand
12	17.2	1244	1294	1265	799	7.1	Gravel, sand
13	9.4	1379	1429	1407	499	9.9	Gravel, sand
14	6.9	1357	1417	1382	660	10.1	Gravel, sand
16	18.8	1280	1372	1324	1110	9.9	Gravel, debris
17	16.4	1418	1547	1475	1362	10.6	Gravel, sand
18	32.3	1362	1550	1443	1171	26.4	Half gravel, half shrubs
19	47.3	1445	1737	1558	1442	28.5	Sparse veg. to bare soil
20	59.4	1564	1886	1709	1107	41.1	Sparse veg. to bare soil
21A	28.2	1451	1754	1610	1685	33.6	Shrubs, grass, cultivated
21B	28.2	1451	1754	1610	1685	33.6	sparse veg. to bare soil

1.5 Discharge analysis

The discharge analysis can be conducted in different ways. Here, three ways will be shown and compared to each other. The first option is a discharge analysis based on the application of the rational method. The second option is the application of the SCS approach and the third a hydrological model.

1.5.1 Rational method

The rational method is explained in Section 2.3.1. The approach computes peak discharges based on the size of the area, the rainfall intensity and a runoff coefficient. The latter was selected by distinguishing topography, soil permeability, vegetation and storage capacities. The values were taken from Table 8.

Table 3: Parameters for calculating peak discharge with the rational method

Name	BasinID	AREA [ha]	Cr [-]	Ci [-]	Cv [-]	Cs [-]	C [-]	Qp [m³/s]
Valley	0	5.3	0.14	0.08	0.14	0.1	0.46	0.19
Urban edge	2	7.2	0.14	0.08	0.1	0.08	0.4	0.23
Valley	3	3.3	0.14	0.08	0.14	0.1	0.46	0.12
Valley	5	5.4	0.16	0.08	0.14	0.1	0.48	0.21
Urban	6	13.6	0.14	0.08	0.08	0.07	0.37	0.40
Valley	7	19.7	0.14	0.08	0.1	0.1	0.42	0.66
Valley	8	23.1	0.2	0.08	0.14	0.1	0.52	0.97
Urban	9	13.6	0.14	0.08	0.08	0.07	0.37	0.40
Valley	10	18.8	0.19	0.08	0.14	0.1	0.51	0.77
Valley	11	4.3	0.19	0.08	0.14	0.1	0.51	0.18
Urban outskirts	12	17.2	0.16	0.08	0.14	0.1	0.48	0.66
Valley	13	9.4	0.19	0.08	0.14	0.1	0.51	0.39
Valley	14	6.9	0.2	0.08	0.14	0.1	0.52	0.29
Valley	16	18.8	0.19	0.08	0.14	0.1	0.51	0.77
Valley	17	16.4	0.2	0.08	0.14	0.1	0.52	0.69
Outflow Caritas site	18	32.3	0.2	0.1	0.08	0.1	0.48	1.25
Mountain+valley	19	47.3	0.28	0.1	0.12	0.1	0.6	2.28
Mountain	20	59.4	0.32	0.12	0.12	0.1	0.66	3.15
Caritas site	21A	28.2	0.32	0.1	0.1	0.07	0.59	1.34
not cultivated hill side	21B	28.2	0.32	0.12	0.14	0.1	0.68	1.54

1.5.2 SCS Approach

The SCS approach is explained in Section 2.3.2. The approach requires the Curve Number (CN) and time of concentration. The first table shows the values for computing time of concentration, the second table is the calculation of the peak discharge, all according to the formulas in Section 2.3.2.

Table 4: Parameters for calculating flood volume and peak discharge with the SCS approach

Name	BasinID	AREA_ha	CN [-]	S [mm]	Qv [mm]	Length [m	Min [m]	Max [m]	Slope [%]	S (ret)	tc [min]	Qp [m³/s]
Valley	0	5.3	88	34.6	9.225	554	1251	1279	5.08	1.36	0.17	0.20
Urban edge	2	7.2	75	84.7	1.747	474	1233	1260	5.1	3.33	0.23	0.05
Valley	3	3.3	88	34.6	9.225	294	1276	1300	6.9	1.36	0.09	0.13
Valley	5	5.4	88	34.6	9.225	618	1292	1342	8.67	1.36	0.14	0.20
Urban	6	13.6	70	108.9	0.578	770	1213	1245	5.28	4.29	0.39	0.03
Valley	7	19.7	88	34.6	9.225	804	1243	1298	6.39	1.36	0.21	0.75
Valley	8	23.1	88	34.6	9.225	1238	1324	1430	10.26	1.36	0.23	0.88
Urban	9	13.6	70	108.9	0.578	772	1231	1264	5.54	4.29	0.38	0.03
Valley	10	18.8	88	34.6	9.225	1164	1276	1373	9.53	1.36	0.23	0.72
Valley	11	4.3	88	34.6	9.225	577	1325	1382	9.91	1.36	0.13	0.16
Urban outskirts	12	17.2	75	84.7	1.747	799	1244	1294	7.09	3.33	0.30	0.12
Valley	13	9.4	88	34.6	9.225	499	1379	1429	9.94	1.36	0.11	0.36
Valley	14	6.9	88	34.6	9.225	660	1357	1417	10.05	1.36	0.14	0.26
Valley	16	18.8	88	34.6	9.225	1110	1280	1372	9.91	1.36	0.22	0.72
Valley	17	16.4	88	34.6	9.225	1362	1418	1547	10.6	1.36	0.25	0.63
Outflow Caritas site	18	32.3	88	34.6	9.225	1171	1362	1550	26.35	1.36	0.14	1.24
Mountain+valley	19	47.3	88	34.6	9.225	1442	1445	1737	28.52	1.36	0.16	1.81
Mountain	20	59.4	80	63.5	3.704	1107	1564	1886	41.14	2.50	0.14	0.91
Caritas site	21A	28.2	65	136.8	0.050	1685	1451	1754	33.61	5.38	0.33	0.01
not cultivated hill side	21B	28.2	80	63.5	3.704	1685	1451	1754	33.61	2.50	0.22	0.43

1.5.3 Hydrological modelling

Generally, modelling has become the state-of-the-art approach in hydrology, in flood management and in designing flood measures. Applying a model is advisable as it is able to better reflect the physical characteristic of a watershed. Provided that the concept of modelling is fully understood and parameters are available and wisely used, it results in higher accuracy. A higher accuracy is also a very relevant economic factor. The rational method and to a lesser extent the SCS approach incorporate safety factors to address the simplifications embedded in the approaches, which, of course, result in lager dimensions when it comes to designing measures. Economic viability is often a matter of balancing acceptable risk and provision of flood mitigation. A better understanding of processes and their interplay in combination with a higher accuracy foster viability and risk-informed decision-making. The modelling approach is explained in Section 2.9.1. The model Talsim-NG (www.sydro.de) is applied.

Step 1: Generating the flow network

The stream network and the locations of the sub-basins are used to compose the flow network of the model. Each model has its own approach but commonly sub-basins and river reaches are the elements used to construct the flow network.

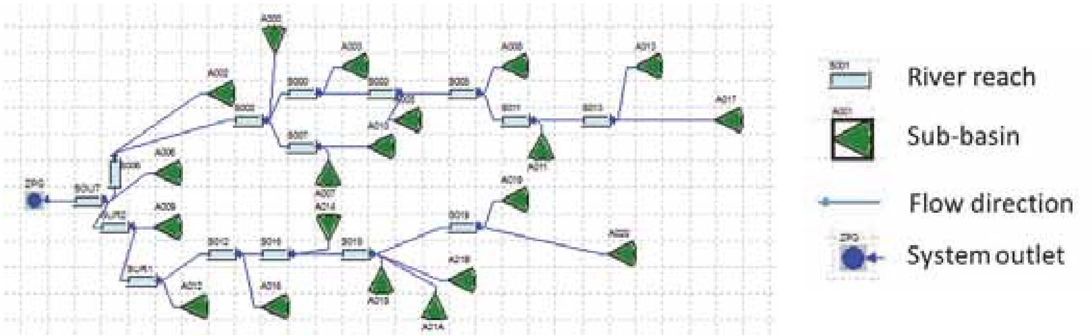
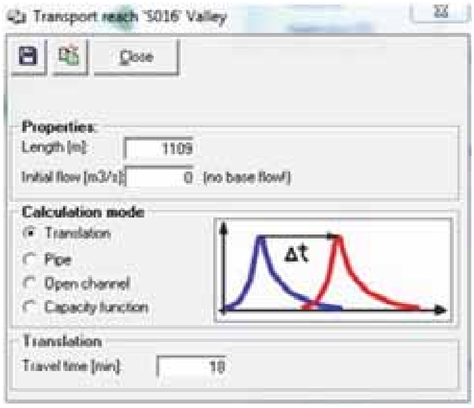


Figure 12: Flow network of the example site based on Talsim-NG

Step 2: Parameters

The user must enter the parameters for all elements. The Talsim-NG model is equipped with a graphical user interface which guides the user through the application. As the model is scalable, it offers different modes for computing sub-basins and river reaches, for example, a sub-basin can be modelled with a simple runoff coefficient, the SCS approach (as it was used here) and complex soil-moisture accounting.



River reaches can be modelled as:

- Translation
- Pipe
- Open channel
- Stage-discharge curve

Figure 13: Graphical user interface for sub-basins and river reaches - Talsim-NG

Step 3: Simulation

Simulation requires to setup the model stress in form of rainfall. In Section 1.3 a rainfall depth of 30 mm/h was selected. The storm profile, which is the distribution of the rain within the 60 min, must be determined.

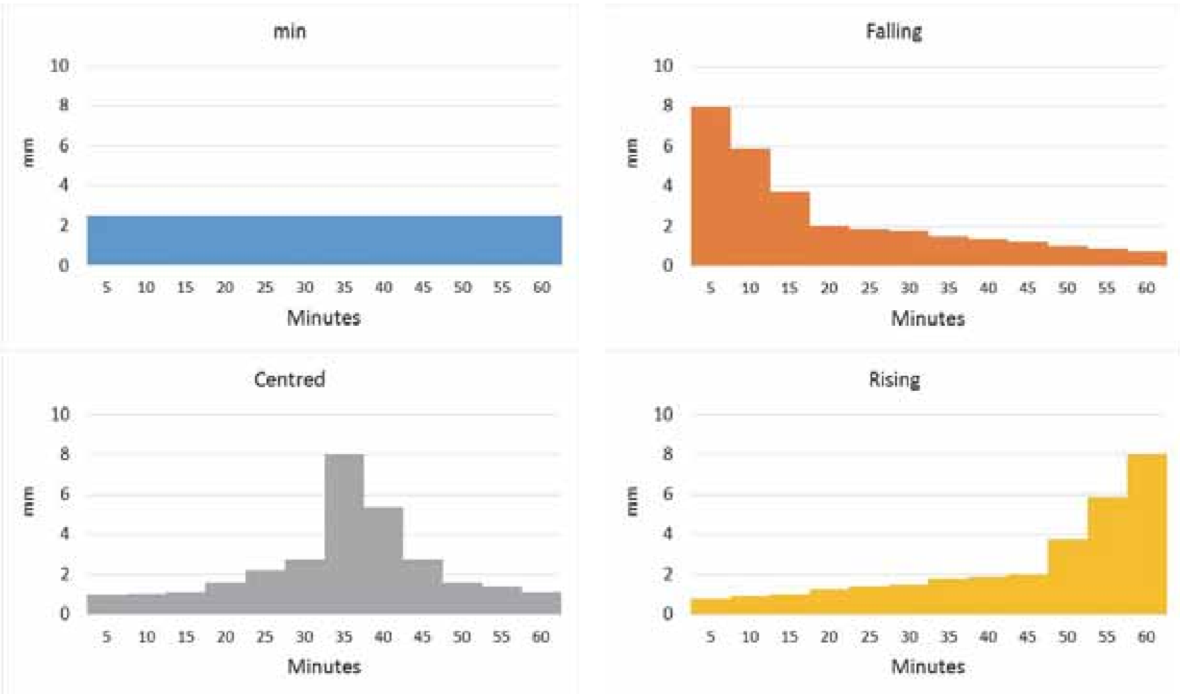


Figure 14: Distribution or storm profile of rainfall within the 60 min rainfall duration

A uniform distribution is applied. Results of the simulation are illustrated in Section 2.9.1.

1.5.4 Peak discharge and flood volume

All three above mentioned approaches yield the peak discharge. The values are shown below. As expected, the rational method owns the largest safety factors to compensate uncertainty and results in the highest values. SCS comes second and the model approach shows the smallest peak discharges. This is understandable as the hydrological model transforms not only rainfall in runoff but also allows for overland flow and transport in the river reaches. This slows down runoff as it happens in reality and gives smaller peak flows.

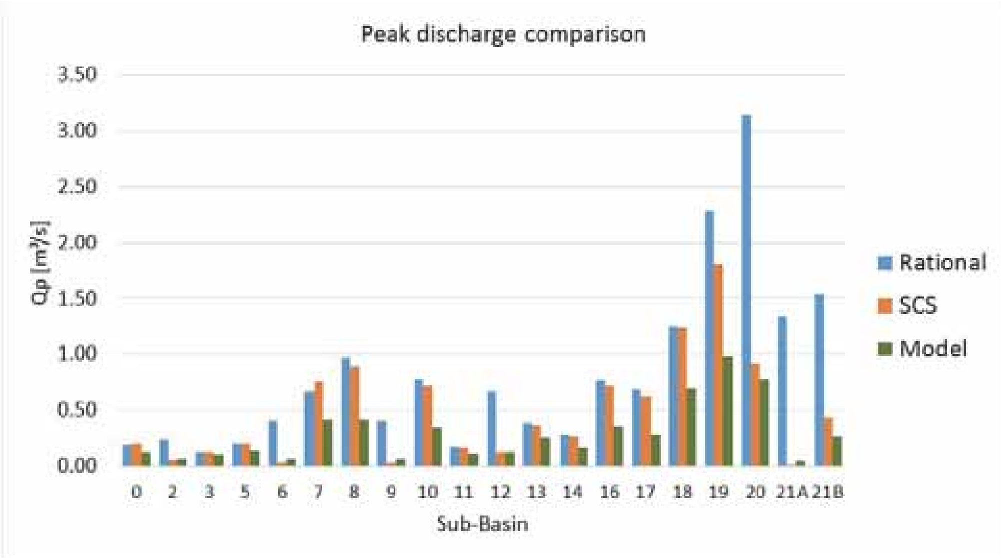


Figure 15: Comparison of peak discharge for the sub-basins

Table 5: Comparison of peak discharge

	Sub-Basin		Rational	SCS	Model
Name	BasinID	AREA_ha	Qp [m³/s]	Qp [m³/s]	Qp [m³/s]
Valley	0	5.3	0.19	0.20	0.12
Urban edge	2	7.2	0.23	0.05	0.07
Valley	3	3.3	0.12	0.13	0.10
Valley	5	5.4	0.21	0.20	0.13
Urban	6	13.6	0.40	0.03	0.07
Valley	7	19.7	0.66	0.75	0.42
Valley	8	23.1	0.97	0.88	0.41
Urban	9	13.6	0.40	0.03	0.07
Valley	10	18.8	0.77	0.72	0.34
Valley	11	4.3	0.18	0.16	0.11
Urban outskirts	12	17.2	0.66	0.12	0.13
Valley	13	9.4	0.39	0.36	0.25
Valley	14	6.9	0.29	0.26	0.17
Valley	16	18.8	0.77	0.72	0.35
Valley	17	16.4	0.69	0.63	0.29
Outflow Caritas site	18	32.3	1.25	1.24	0.70
Mountain+valley	19	47.3	2.28	1.81	0.98
Mountain	20	59.4	3.15	0.91	0.78
Caritas site	21A	28.2	1.34	0.01	0.04
not cultivated hill side	21B	28.2	1.54	0.43	0.26

The SCS method assumes a triangular flood hydrograph and the hydrological model computes a hydrograph according to the topography, soil and land cover parameters. The rational method gives no hydrograph at all.

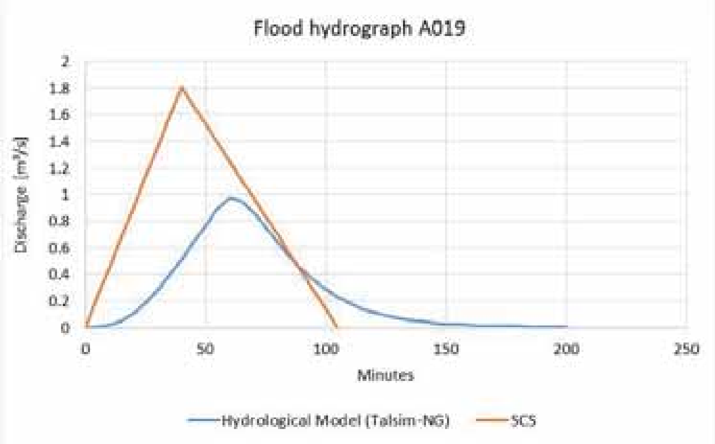


Figure 16: Flood hydrograph displayed for sub-basin 19

Considering that the flood hydrograph is not only relevant at one location, there is the need to overlay the flood hydrograph from different sub-basins and to assess peak discharges and flood volumes further downstream up to the settlement. Only the modelling approach propagates the flood from upstream to downstream automatically. The other approaches require assumptions with respect to the time of travel along the stream network.

A pragmatic way of propagating hydrographs along the stream network is to calculate the distance from the sub-basin up to the point of interest, to apply an appropriate formula for flow velocity from Section 2.6 or 2.10 for a mean cross-section of the stream and to calculate the flow velocity for the mean flow of the hydrograph. Subsequently, the time of travel can be calculated with the flow velocity and the distance from the sub-basin up to the point of interest. An example is given below for a distance of 300 m and a mean flow velocity of 0.5 m³/s.

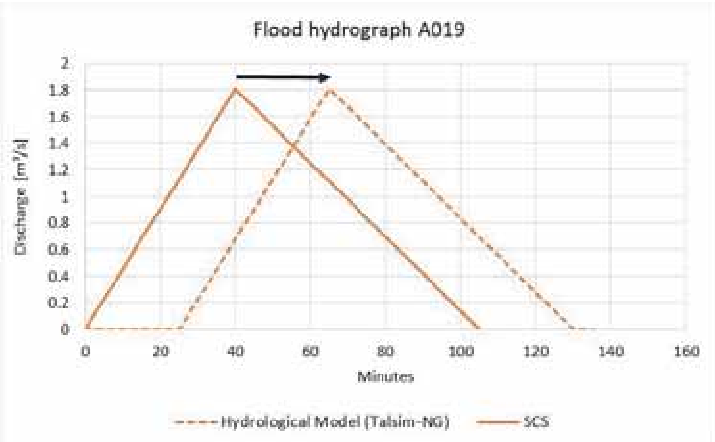


Figure 17: Simple translation of a flood hydrograph along a stream

Translation and retention through the watershed is given by the hydrological model automatically, depending on the calculation modes and parameters applied.

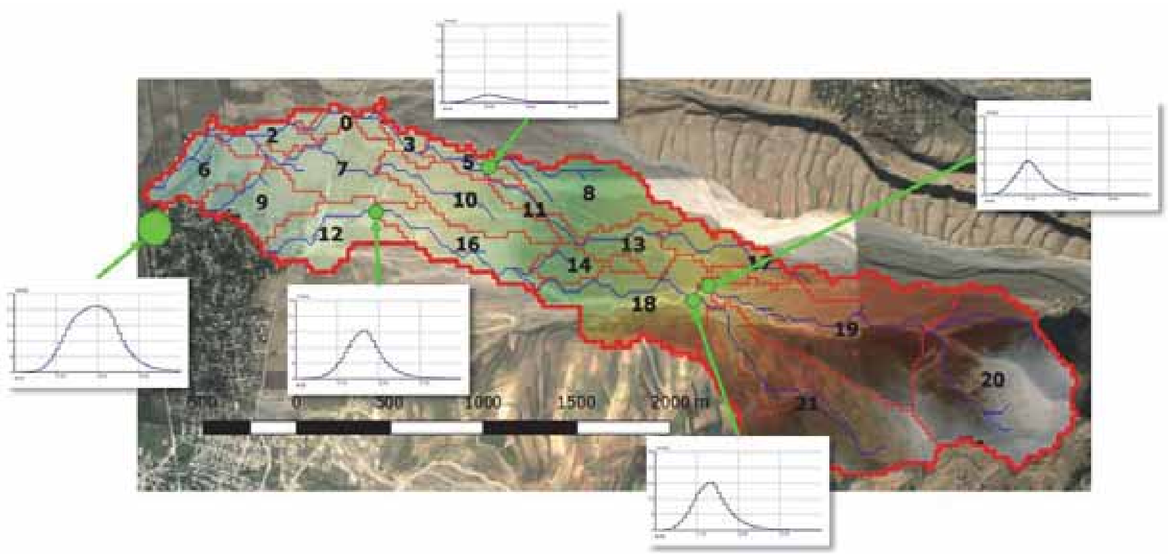


Figure 18: Flood hydrographs of the hydrological model at various nodes in the watershed

1.6 Flood inundation and risk map

Before any decision regarding measures can be made, it is necessary to identify the risk of flooding and to draw an inundation map from which informed decision-making can start.

There are two options:

1. Calculating water levels manually
2. Running a hydraulic model

1.6.1 Calculating water levels manually

Step 1: Identification of adequate cross sections

From the maps and stream network developed in GIS, the right locations for cross-sections can be identified. It makes sense to select locations which affect assets like settlements, vulnerable places of value etc.

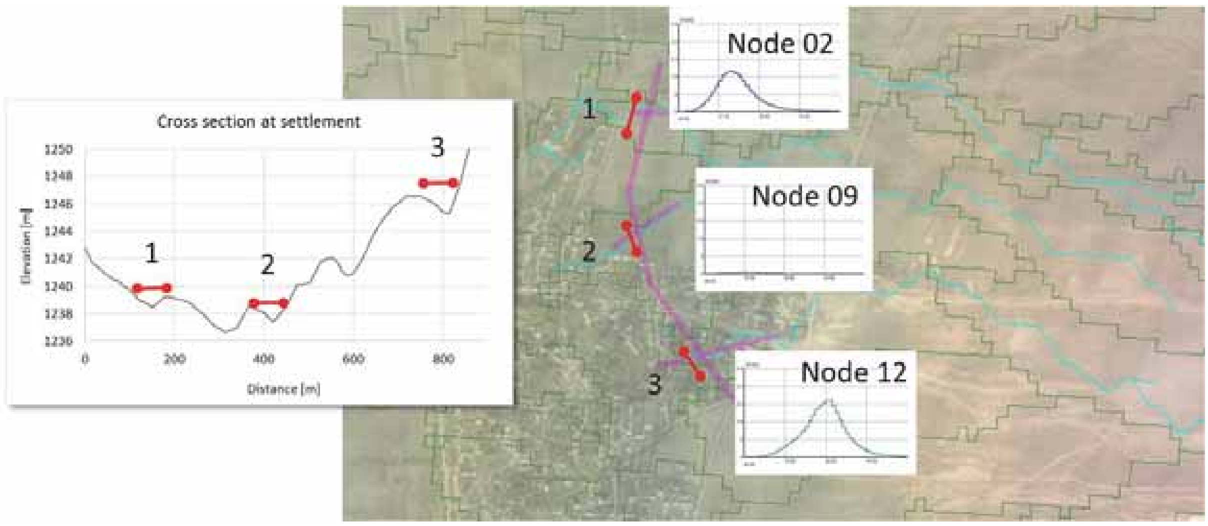


Figure 19: Identification of relevant cross sections for hydraulic computation

Three streams discharge into the settlement. According to the hydrological model, cross section 1 and 3 obtain higher flows compared to 2. Cross-section 1 is demonstrated.

Step 2: Calculating water levels

From the hydrological model, we obtain at node 02 a peak discharge of 1.8 m³/s. The stream discharge may not be mixed up with the outflow of a sub-basin. In contrast to sub-basins, the stream discharge at a node gives the accumulated flow from all upstream sub-basins.

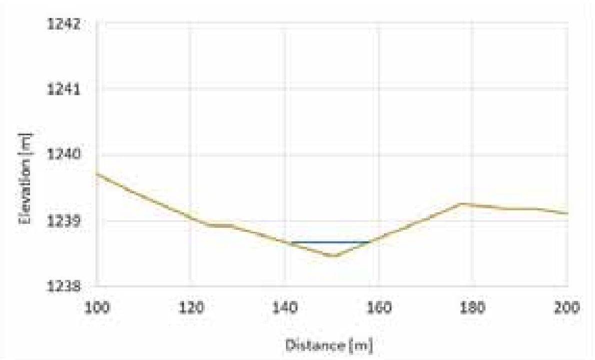
The water level is calculated by $v = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$. A roughness coefficient of n = 0.05 is used for natural channels with a stream bed consisting of gravel, cobbles and few boulders. The slope at this cross section was taken from the slope map and is Is = 0.033.

Left Bank		Right Bank	
Angle	0.02	Angle	0.03
W (m)	9.01	W (m)	7.36
WP (m)	9.02	WP (m)	7.36
A (m²)	0.97	A (m²)	0.80

Cross-Section	
A (m²)	1.77
WP (m)	16.37
R (m)	0.108062

Angle of the left and right bank refers to the gradient of the river banks. W is the horizontal width measures from the lowest point in the cross section and WP is the wetted perimeter. R is the hydraulic radius (A/WP).

Using the function is best done with Excel as the formula requires an iteration.
The resulting water level is 22 cm and the flow velocity is 1 m/s which is quite fast.



The result indicates that the water level itself is not very high but still can cause problems if it reaches doorsteps or when items block the drainage path and increase the water level. However, the flow velocity could give rise to problems. A speed of 1 m/s exerts enough energy to wash items away which are not fixed or cause a threat for children.

1.6.2 Running a hydraulic model

Step 1: Model setup

The model setup requires the determination of a suitable cell size which suffice the needs and is appropriate to obtain reliable and stable results. This is not always easy in steep terrain. For simplification a 10x10 m grid was chosen.

The image below shows the boundary of the hydraulic model and the maximum extent of inundation for a 50 year return period with 30mm or rain within one hour. Light blue indicate cells where either water level was over 10 cm or flow velocity was over 0.1 m/s.

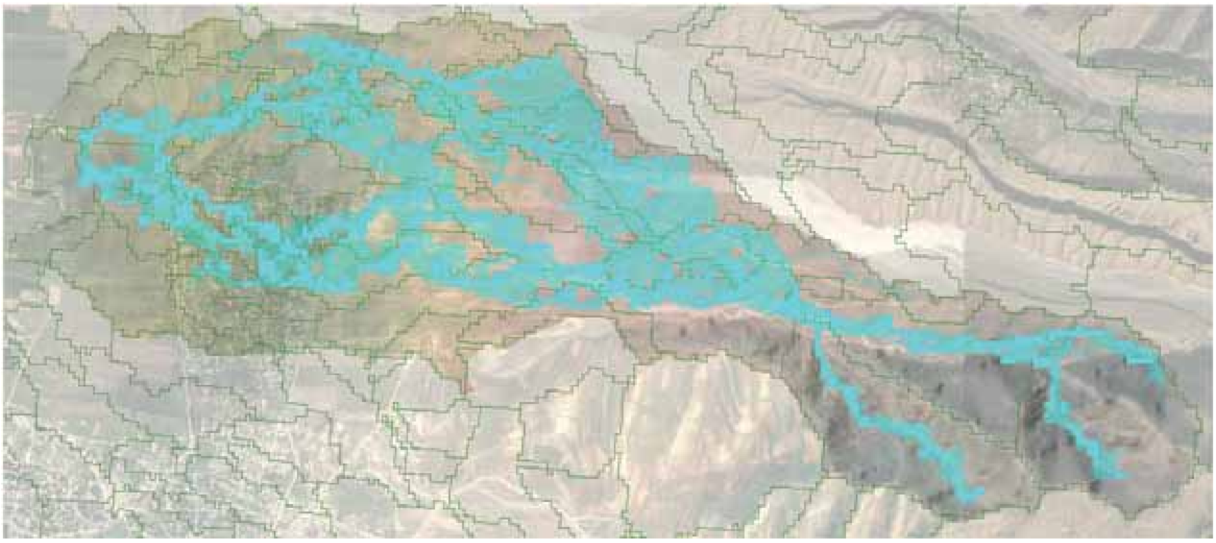


Figure 20: Inundation map of a 50 year return period rainfall with 30 mm within one hour (50a/1h)

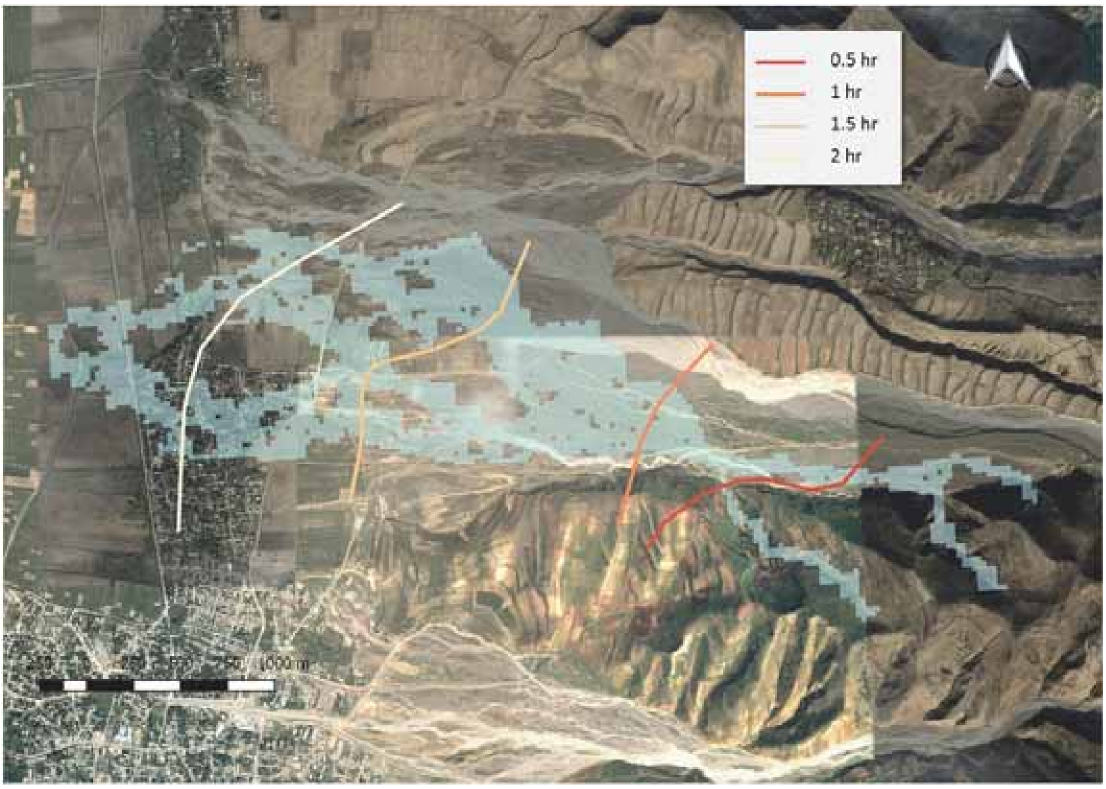
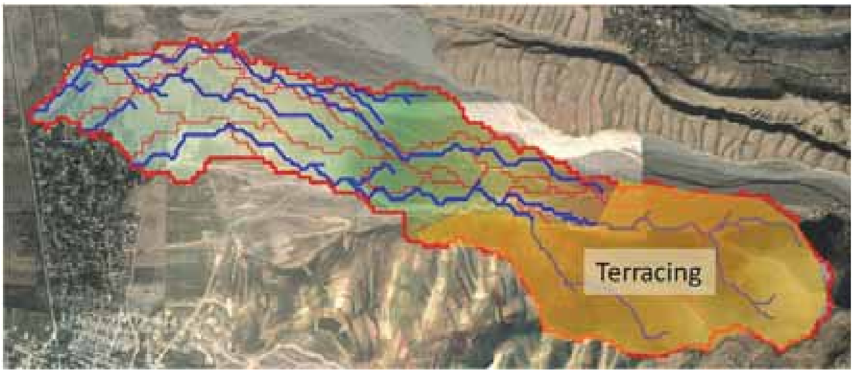


Figure 21: Arrival time of the flood peak after heavy rainfall (50a/1h)

1.7 Watershed management - terracing

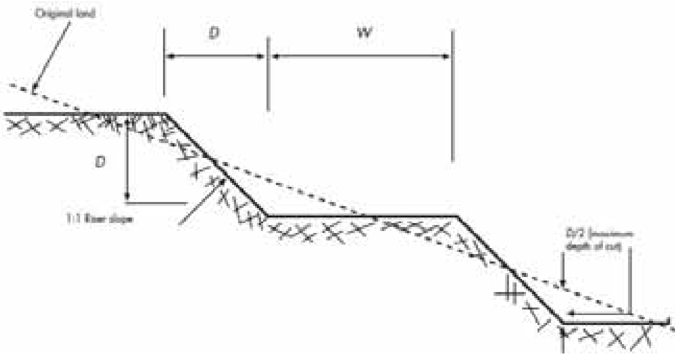
Terracing is the technique of converting a slope into a series of horizontal step-like structures. It is very effective and was applied in Tajikistan.



Typical areas for terracing are steep headwater regions where erosion largely originates.

Figure 22: Headwater area for watershed management measures

From the viewpoint of flood control, the aim of terracing is to slow down surface runoff and to convey it to a suitable outlet with non-erosive velocity. Depending on the form of terraces, additional effects are the trapping of soil in the terraces and the preparation of land suitable for cultivation.

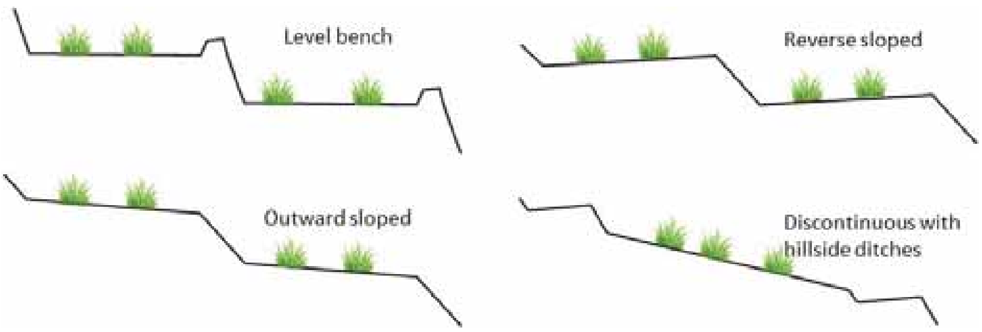


The design of terraces requires considerations in regard to the type, width, spacing between terraces, height of the riser, length (perpendicular to slope) and so on.
Design considerations should also include hydraulic calculation of runoff for safe drainage.

Source: (ICIMOD, 2012)

Not all aspects of terracing can be examined here. More information can be found in (FAO, Watershed management field manual: Slope treatment measures and practices, 2017).

The type of terraces are selected according to slope, soil and rainfall. Terraces can either strictly follow contour lines (contour terraces) or have a gradient perpendicular to the thalweg so that runoff runs along the terrace.



Rule of thumb:
Reverse slope = 5%
Outward slope = 3%
(FAO, 2017)

Figure 23: Type of terraces according to (FAO, Watershed management field manual: Slope treatment measures and practices, 2017)

Soil depth limits the width and thus the spacing of terraces. The shallower the soil layer, the smaller is the width of the terraces. According to (ICIMOD, 2012) and (FAO, Watershed management field manual: Slope treatment measures and practices, 2017) the following considerations and formulas assist in planning and designing terraces.

As a rule of thumb, level bench, reverse and outward sloped terraces are applicable with deep soils and slopes up to 25° while discontinuous terraces with hillside ditches may be feasible up to 30°. Level bench terraces are good for crops like rice which require flood irrigation and impounding water. Reverse sloped types are more suitable in humid regions and outward sloped types in arid or semi-arid regions. Discontinuous types are less labour-intensive.

Spacing of the terraces can be estimated according to (FAO, Watershed management field manual: Slope treatment measures and practices, 2017) by using the formula:

$$VI = \frac{S \cdot Wb}{100 - (S \cdot U)}$$

where:

VI:	Vertical Interval [m]
S:	Slope [%]
Wb:	Width of bench excluding the width of the riser [m] (is indicated above as W)
U:	Slope of riser (with 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers)

The volume required due to cut and fill is computed as

$$Vol = \left(\frac{Wb \cdot VI}{8} + DC \right) \cdot L$$

where

Vol:	Volume to be cut and filled [m³]
VI:	Vertical Interval [m]
DC:	Mean cross-section of the dyke along the length L [m²], if any
L:	Length of the terrace [m]

(FAO, 2017) recommends building the terraces from top of a hill and proceed downslope. If building has to start from the bottom, temporary protection measures are necessary to avoid soil is washed away in case of heavy rain.

Scheduling the work requires to estimate the effort of time needed. Generally speaking, a man can cut and fill 3 to 4 m^3 of earth with eight hours of work. Supported by draught animals, FAO indicates 12 to 14 m^3 within 8 hours what can be increase to 20 m^3 or more when using small machinery.

When the layout of a terrace system is made, it is necessary to proof safe drainage in terms of hydraulic capacity and erosion. An example is given how to calculate runoff and to check the hydraulic capacity and erosion. The formulas given in Section 2 are applied.

Example:

The examples uses a bench terrace (reverse slope) with a length of 140 m with a hillside of 16% gradient. The width is set to 5 m. The riser has a height of 1 m and a slope of 0.75:1 (man-made earth riser). The traverse slope of the terrace is 5% and the soil type is loamy silt.

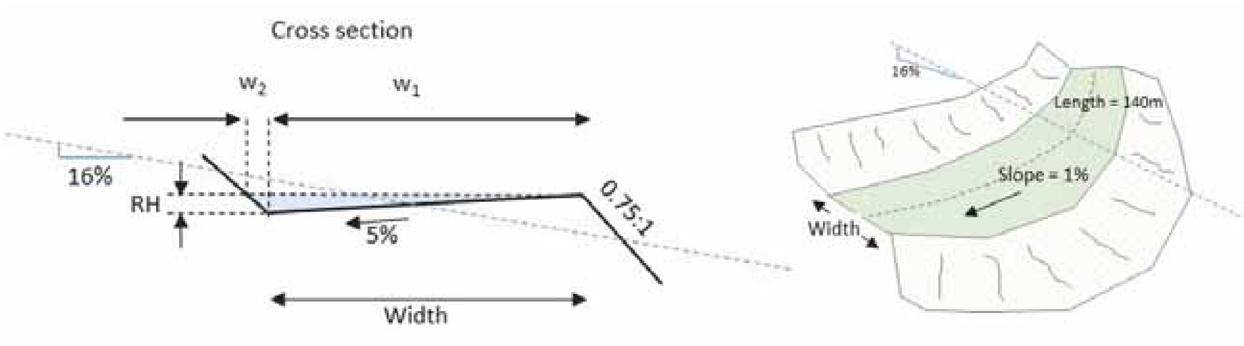


Figure 24: Example bench terrace

The reverse height is calculated to RH = Width x Traverse slope = 5 x (5/100) = 0.25 m

The drainage area of the terrace is A = Width x Length = 5 x 140 = 700 m² = 0.07 ha.

For the peak discharge, the SCS approach and the rational method is used. We assume rainfall of 50 mm within one hour as a 10 year storm. Two different stages are calculated.

- Stage 1: bare soil, not yet cultivated (CN=90, n = 0.02, runoff_coef = 0.1)
- Stage 2: vegetated with grass (CN=70, n = 0.035, runoff_coef = 0.05)

First, the peak discharge is computed. For the SCS method the potential retention S = 25.4*(1000/90-10) results in 28.2 mm. With 50 mm or rainfall the runoff volume Qv = (50 – 0.2*S)^2 / (50 + 0.8*S) is 27.1 mm. Time of concentration with the Kirpich formula gives tc = 0.066 hour. Applying the formula requires the conversation factor 0.3048 for the overflow length. The peak discharge Qact according to the SCS approach results in 0.007 m/s or 7 l/s.

When using the rational formula with a rainfall intensity of 50mm/hr and a runoff coefficient of 0.1, which represents an undeveloped plain area, the peak discharge amounts to 0.010 m³/s or 10 l/s. The results show that selecting the CN value or runoff coefficient are sensitive parameters.

SCS method: Qact = 0.007 m³/s; Rational Method: Qact = 0.01 m³/s

If the cross-section is large enough to carry the peak discharge can be answered by comparing the actual discharge with the maximum capacity. The Manning formula is applied to compute the flow velocity from which the maximum carrying capacity can be derived. The flow cross-section in Figure 24 is indicated as blue.

The maximum cross section is: Amx = (0.5 * w1 * RH) + (0.5 * w2 * RH) = 0.667 m²

with w1 = RH /5 m; w2 = RH / RHslope = 0.25/0.75 = 0.33 m

The maximum wetted perimeter $P = \sqrt{w1^2 + RH^2} + \sqrt{w2^2 + RH^2}$ = 5.42 m

With the Manning coefficient n = 0.02 (≈ earth channel) and
the hydraulic radius rhy = Amx/P = 0.667/5.42 = 0.123 m,
the maximum flow velocity is $v = (1/0.02) \cdot 0.123^{\frac{2}{3}} \cdot 0.5^{\frac{1}{2}}$ = 0.87 m/s.

The maximum carrying discharge capacity is now Qmx = v * Amx = 0.87 * 0.667 = 0.583m³/s

It can be concluded that Qmx > Qact and the cross section is large enough during stage 1.

Stage 1 is the phase with bare soil. Loamy silt has a critical flow velocity ranging from **0.1 to 0.2** m/s. In order to compare the critical flow velocity with the actual flow velocity, the actual flow cross section must be computed. This requires iteration with the flow depth h as h determines the cross-section.

The underlying formulas are:
$w2 = h/0.75$ (depth/slope of riser) and $w1 = h/0.05$ (depth/traverse slope) from which A can be calculated as $A = (0.5 * w1 * h) + (0.5 * w2 * h)$ and $P = (w1^2+h^2)^{0.5} + (w2^2+h^2)^{0.5}$ and $r_{hy} = A/P$.

The result is a depth h of 0.054 m. This results in $v_{act} = 0.32$ m/s and $v_{act} > v_{crit}$. Erosion would occur during stage 1 with a storm with 50 mm.

In **stage 2** is the terrace developed with grass. The following parameters change:

CN value = 70, Manning's roughness n = 0.035, Runoff coefficient = 0.05, critical v = 1.5 m/s

The SCS method yields $0.002 m^3/s$ and the rational method $0.005 m^3/s$. The resulting actual depth is 0.05 m and gives an actual flow velocity of 0.17 m/s which is less than the critical 1.5 m/s velocity.

Once the terrace is fully developed the grass can withstand a rainfall event of 50mm within one hour.

1.8 Check Dams

In regions with heavy rains, watershed management alone will not suffice to control erosion, gullies and torrents. Additional slope stabilization, torrent and gully control measures, such as check dams, ground sills, bed ramps are needed. Check dams are typically sited in steep tributaries with high sediment loads.

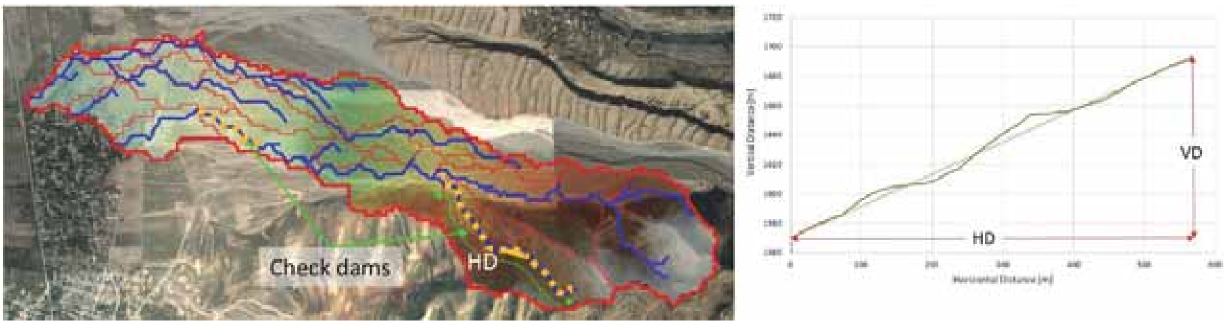


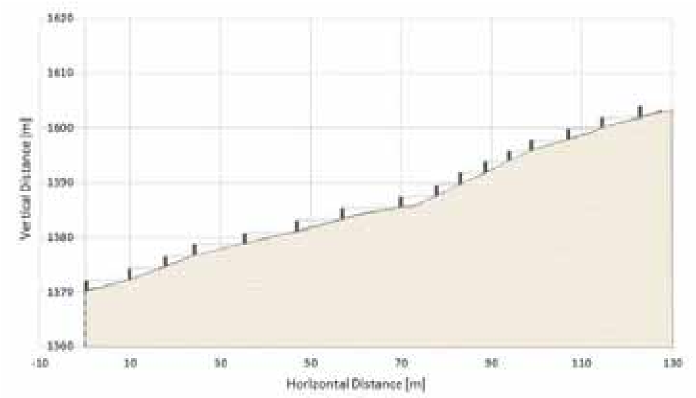
Figure 25: Transport reaches suitable for check dams

After the identification of suitable sections, the survey of the longitudinal profile starts. For developing this example, the reach indicated with HD is used.

A practical instruction regarding check dams is given in (FAO, Gully Control, 1986) from which basic concepts are adopted.

Spacing of check dams can be determined according to the compensation gradient and the effective height of the check dams. The compensation gradient between two adjacent check dams is the slope measured from the top of the lower check dam to the bottom of the adjacent upper one. This is considered as a slope which is formed when material carried by flowing water fills the check dams to spillway level and keeps a balance between erosion and sedimentation. Formulas have been developed to compute the compensation gradient. However, field experience has demonstrated that the compensation gradient of gullies is usually not more than 3 percent. For practical reasons, 3 percent are used for estimating the number of check dams along a gully (FAO, Gully Control, 1986).

The average gradient is calculated with $g_{avg} = VD / HD$. The number of check dams is then estimated by $N = \frac{HD \cdot g_{avg} - VD \cdot 0.03}{H}$ where H as is the effective height (excluding foundation) of the check dams. The taller the effective height is, the less is the number of check dams. A decision has to be made regarding more and smaller check dams, which are easier to be built, or less and taller check dams, which require more effort for construction.



The average gradient of the stretch is 22%, the compensation gradient is chosen to 3% and with an effective height of 1.5 m, the whole stretch of 570 m horizontal distance (HD) with 123 m vertical distance (VD) would require approximately 80 check dams. A section of 130 m is illustrated with the compensation gradient from which the number of check dams was estimated.

The first check dam should be constructed on a stable point in the gully such as a rock outcrop, the junction point of the gully to a road, the main stream or river. If there is no such stable point, a counter-dam must be constructed. The distance between the first dam and the counter-dam must be at least two times the effective height of the first check dam (FAO, Gully Control, 1986).

Example:

The hydrological parameters in the reach are derived from the sub-basin 21 A and B. The peak discharge is given to:

Sub-basin	ID	Area ha	Rational Qp m³/s	SCS Qp m³/s	Model Qp m³/s
Caritas site	21A	28.2	1.34	0.01	0.04
not cultivated hill side	21B	28.2	1.54	0.43	0.26
Peak discharge Qp			2.84	0.44	0.3

A cross section is selected for which the check dam is calculated.

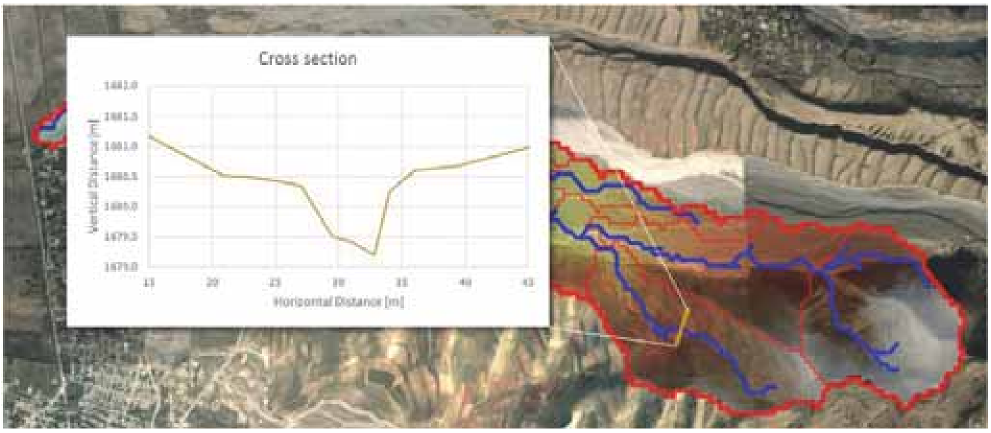


Figure 26: Cross-section in a river reach for developing check dams

Applying the criteria for check dams given in Part I, a cross-section with a check-dam could look like this:

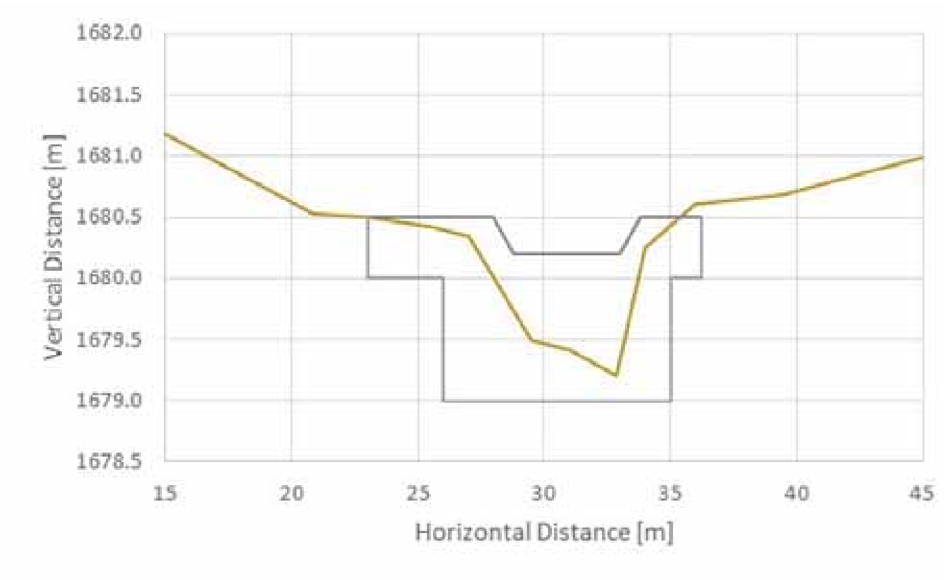


Figure 27: Cross-section of the check dams

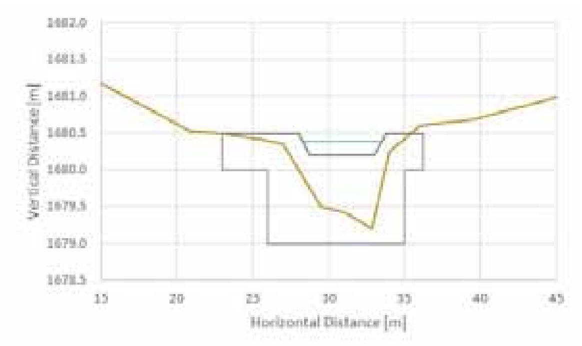
A gabion dam with one layer of 0.5 m height with three layers (1.5 m height) is chosen. The wings reach into the banks and the foundation is anchored one gabion deep into the stream bed. The spillway is considered as broad crested weir. With a peak discharge Qp of approximately 0.45 m³/s (= SCS approach), the necessary height of the spillway is calculated by using:

$$Q = \frac{2}{3} \cdot \mu \cdot c \cdot w \cdot \sqrt{2 \cdot g} \cdot h^{1.5}$$

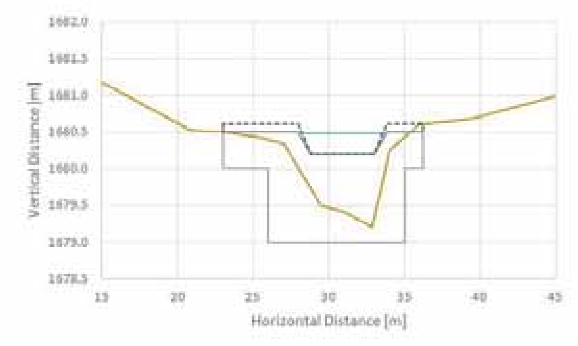
where:

μ:	coefficient [-]
c:	factor for broad crested weir [-]
w:	width of the spillway (here assumed as rectangle) = 4.2 [m] (results as constraint due to the width of the cross-section)
g:	gravity [m/s²]
h:	overflow height [m]

With Q = 0.45 and w = 4.2 m the height results in 0.18 m. This gives enough freeboard for the selected design event. About 50% of the sub-basin was re-vegetated, terraced and developed due to the watershed management measures developed by Caritas Switzerland. What if no watershed management were in place? The resulting overflow height rises 10 cm to 0.28 m and is shown in the right picture below. No freeboard is left and the check dam had to be build higher to achieve the same freeboard. It is possible that elevating the crest level requires a new gabion layer as no standard size fits the change in height.



With the watershed management due to Caritas



Without watershed management

Figure 28: Cross-section of the check dam with/without watershed management upstream

The positive effects of watershed management affects all check dams which are to be developed. In other words, without watershed management, all check dams, gabions or boulder check dams, had to be higher causing more material to be used for the structure, more effort for construction, more labour force and higher costs.

Many examples can be found demonstrating positive effects of watershed management. A lesson learnt is that watershed management measures always have to be developed, no matter which hard or soft measure is chosen downstream.

More than one check-dam needs to be developed but not all are gabion dams. The first check dam downstream will be developed as a gabion dam together with the counter check dam. Most of the other check dams upstream can be developed as boulder dams, ideally fortified with logs or other sturdy material.

1.9 Longitudinal structures and streambed stabilisation

Part of the settlement was erected in the direction of flow paths coming down from the catchments in the south of the example site. The flow paths are usually dry, but with heavy rain, flash floods can occur which come down the flow paths exerting destructive forces on buildings and other infrastructure.

The situation calls for the development of a diversion channel with longitudinal protection structure and stream bed stabilisation diverting a flash flood into the main channel to the right in direction of flow but mainly provides a protection against high sediment loads. The slope in the alluvial fan offers options for erecting an embankment. However, the measure may interfere with some paths used as access roads to get into the headwater area. This must be considered and dirt roads need adjustment.

This example measure was chosen to demonstrate both ramps for reducing gradients and embankments.

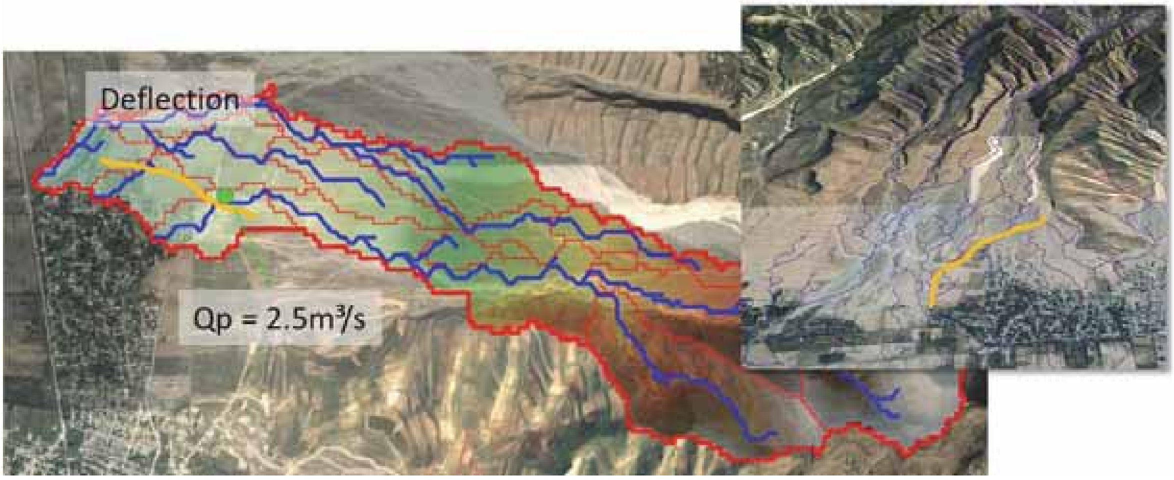
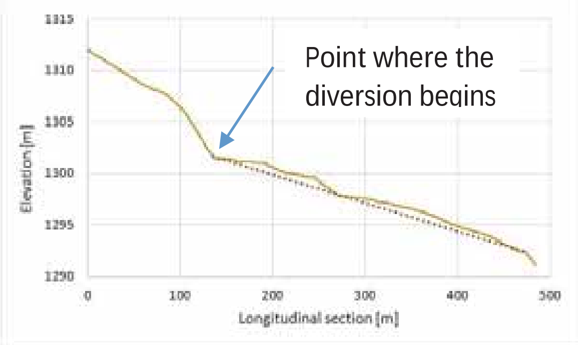


Figure 29: Area for developing a diversion channel

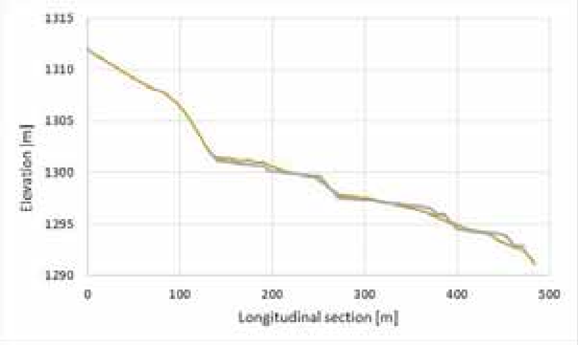
At the impact point, indicated with a green dot, the peak discharge of a 50a / 1hr rain results in 2.5 m³/s derived from the hydrological model. The task is to develop a suitable longitudinal section with an adequate gradient and suitable cross-section for facilitating the peak discharge without erosion.

The natural soil characteristic along the suggested diversion channel is fine to coarse sand mixed with coarse gravel.

Diversion profile according to the terrain with an average slope of 2.7%



Diversion profile developed with ramps and 1% slope



Given the material of the underground, the terrain with an average slope of 2.7 % would result in erosion incising the diversion channel and destabilising the banks. A reduction in slope is needed by developing the new profile with ramps. Only the ramps require stone packages while the rest of the profile could be developed according to Figure 30.

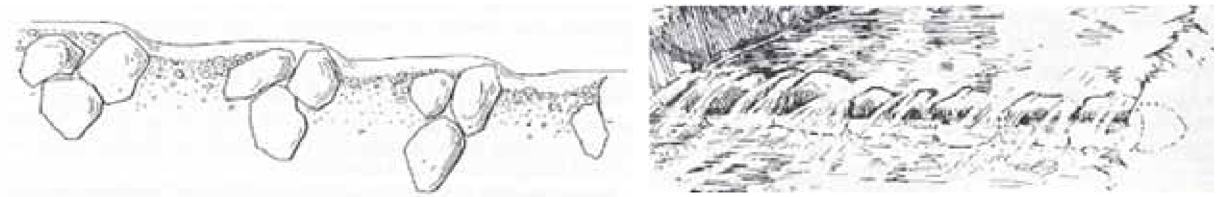


Figure 30: Natural river bed developed with cascade of boulders according to (Patt, 1998)

The water level should be developed with less than 1% with a boulder cascade resembling the diversion channel as a natural mountainous riverbed. In addition, seven ramps are necessary to bridge the vertical difference to the target riverbed north of the settlement. The profile of one ramp is illustrated as an example.

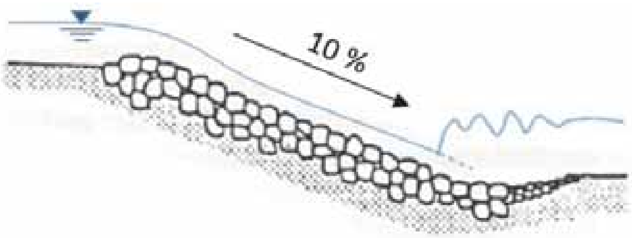


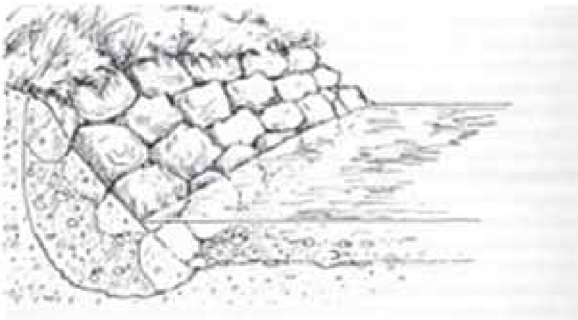
Figure 31: Profile of a streambed ramp given as an example taken from (Patt, 1998)

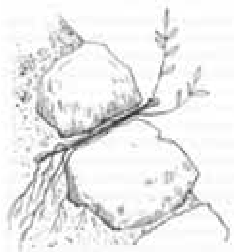
Alternatively, the implementation of ramps could be avoided with a longer diversion channel that meanders from A to B. However, the diversion must reach more than 1000 m length to result in a slope less than 1%, thus, this option is not further developed or illustrated in this example.

Measure:
Diversion channel with embankment left river bank.
Length: 336 m
Average slope: 2.7%
Developed with boulder cascade and 7 ramps
Water level < 1% gradient,
Ramps = 10%

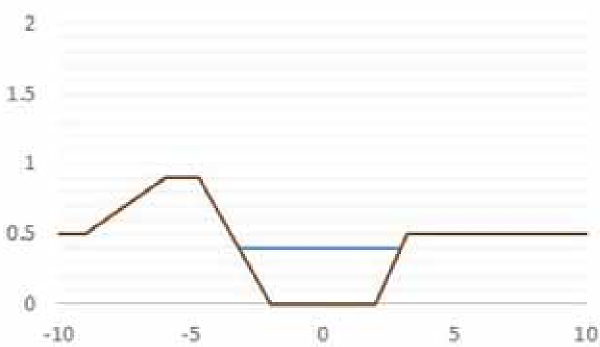
Figure 32: Diversion channel with embankment on the left bank

The cross-section of the diversion channel





Riverbank protection according to (Patt, 1998)



Cross-section:

- Bed material:
  medium to coarse sand and gravel,
- boulders d>25 cm
- bottom width: 4 m
- bank slope: 1:3,
  Developed with stone packages d>25 cm

Figure 33: Cross-section of the diversion channel

The hydraulic calculations are as follows:

The calculation uses the Manning Equation (Section 2.6) and computes sheer stress according to Section 2.7. Critical sheer stress and critical flow velocity is taken from the tables in Section 2.7.

The discharge used to derive the geometry is 2.5 m^3/s (50 a return period, 30mm rain in 1 hour). The results require adaption if a larger return period or other rain events are applied.

1. Stability of the bed material and size of the boulders in the cascade

The bed material is assumed to consist of medium to coarse sand and gravel. According to Table 12 critical sheer stress is 1 (medium sand) to 45 (coarse gravel) and critical velocity ranges from 0.35 to 1.6 m/s.

With a longitudinal slope of 1%, a cross-section with a bottom width of 4m, slopes 1:3, manning roughness 0.03, which represents a mountain stream with gravel, cobbles and few boulders at the bottom, and a discharge of 2.5 m^3/s results in a flow depth of 0.37 m and a flow velocity of 1.3 m/s. This means that sand is eroded and gradually washed out while gravel remains stable. The boulder cascade would be stable with stones of 10cm diameter reducing the energy line to less than 1% and increasing flow depth to 0.45 m. The boulders have a specific density of approx. 2650 kg/m^3 and should be hard with a lower coefficient of abrasion. Placing them into the stream bed will cause small scours downstream the stones. The stones will dig into the bottom until the underground provides enough support. From a practical viewpoint, the diameter of the cascade boulders should be 5-times the diameter of the surrounding natural bed material. Therefore, the boulders are chosen to have a minimum diameter of 25 cm.

2. Stone package of the ramps

The ramp will be developed with a slope of 10%. A diameter of 20 cm should be chosen according to the equation in Section 2.8. To be prepared for larger discharges, a minimum diameter of 30 cm is suggested. All recommendation in Section 2.8 must be regarded.

3. River bank stone package

The left river bank in direction of flow is developed as an embankment with enough freeboard to protect the settlement. The right river bank, however, is open for flooding. As such, higher discharges can be facilitated without overtopping the embankment.

Along the sections with 1% slope with boulder cascades, riprap 63/90 would suffice according to the equation for tractive force on bank material in Section 2.8. Along the ramps riprap with the same diameter like the stones for the ramp itself should be chosen.

1.10 Summary of the step by step example

The aim of this step-by-step example is to enable the reader to identify the steps required, to become aware of the different tools and hydrological and hydraulic concepts and – most importantly – to realise to which extent experts with experience should be asked for advice.

To understand the example completely requires at least basic knowledge about hydrology and hydraulics. The explanations in Section 2 help and provide some useful background knowledge but, of course, they do not replace training and experience.

It must be beard in mind that the example with the measures shown were chosen to go through all steps and to demonstrate them rather than providing a detailed solution for the particular site.

As such, selecting another return period, rainfall event or bringing up different measure and to develop them at other locations is truly possible.

2 HANDS-ON HYDROLOGY AND FLOOD MANAGEMENT

This section provides simple hydrological knowledge, approaches and formulas to enable readers to make their own calculations.

There is a need to understand underlying hydrological and hydraulic principles to identify root causes, to select adequate short-, medium- and long-term measures and to design them. The principles of torrent control and streambed stabilisation plays a crucial role. This is why a set of approaches is provided to support considerations with respect to risk assessment, planning, designing and siting of flood mitigation measures.

2.1 Runoff process and flood formation in a watershed

Hydrologic features in a watershed are interconnected and changing one usually impacts on others. To understand the formation of floods in a watershed, it is important to comprehend the runoff process and to know how human-activities affect flood volume and peak.

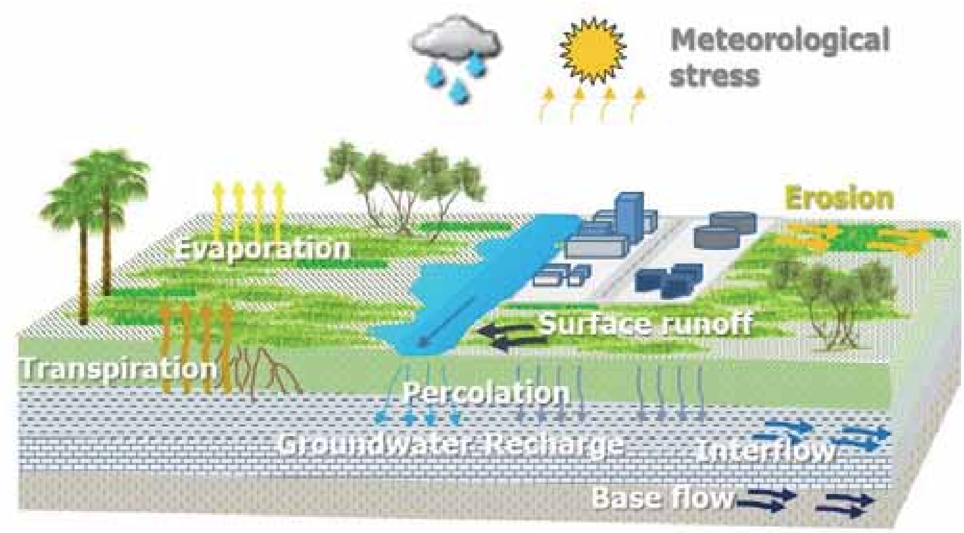
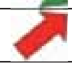


Figure 34: Hydrological processes related to runoff

The following table links hydrological features to runoff generation.

Table 6: Hydrological features impacting on runoff formation (adopted from (Maidment, 1998))

Feature	Characteristic	Runoff
Natural factors		
Topography	Steep slopes > 10°	
	Gradients > 1° and < 10°	
	Plain	
Soil	Texture with large pores and less adhesion are permeable (gravel, coarse to fine sand, silty sand)	
	Texture with small pores and medium adhesion are less permeable (silt)	
	Texture with small pores and high adhesion are nearly impermeable (loam, clay)	
	Deep soil or soil without a horizon with loam or clay	
	Shallow soil depth or soil with a horizon with loam or clay	

Feature	Characteristic	Runoff
Natural factors		
Land cover	Dense vegetation canopy with a deep root structure	
	Ground covered with vegetation	
	Ground sparsely covered with vegetation	
	Bare soil	
Human-made factors		
Urban areas	Paved surfaces (roads with tarmac or concrete, roofs)	
	Stones, bricks with impermeable joints	
	Compacted surfaces (dirt roads with car traffic)	
	Stones, bricks with permeable joints	
	Planted surfaces	
Road drainage	No road drainage	
	Roads drainage with check dams	
	Road drainage diverted into vegetated and permeable areas	

Apart from natural factors, land-use changes are often major drivers for an increase of runoff. Land use alterations can be understood as a root cause for increasing flood peaks, erosion, landslides and mudflows, if infiltration is impaired,. Table 7 provides a summary of hydrological impacts associated with land-use changes.

Table 7: Hydrological effects of land-use changes (adopted from (Maidment, 1998))

Land-use change	Component affected	Hydrological processes involved	Geographical scale and likely magnitude of effect
Afforestation (Deforestation has converse effects)	Annual flow	Increased interception in wet periods	Basin scale; magnitude proportional to forest cover
		Increased transpiration in dry periods through increased water availability to deep root systems	
	Seasonal flow	Increased interception and increased dry period transpiration will increase soil moisture deficit and reduce dry season flow	Basin scale; can be of significant magnitude to reduce dry season flow
		Drainage activities associated with planting my increase dry season flow	Basin scale; drainage activities my increase dry season flow
	Floods	Interception reduces floods by removing a proportion of the storm rainfall; build up of moisture storage	Basin scale; effect is generally small but greatest for small storm events
	Erosion	High infiltration rates in natural, mixed forests reduce surface runoff and erosion	Basin scale; reduces erosion
		Slope stability is enhanced by reducing soil pore water pressure and binding of forest roots	Basin scale; reduces erosion
		Windthrow of trees and weight of tree crop reduces slope stability	Basin scale; increases erosion
		Soil erosion through splash detachment is	Basin scale; increases erosion

Land-use change	Component affected	Hydrological processes involved	Geographical scale and likely magnitude of effect
		increased without understory of shrubs or grass	
		Management activities: cultivation, drainage, road construction, felling, all increase erosion	Basin scale; management activities are often more important than the direct effect of the forest
	Climate	Increased evaporation	Micro and meso scale
Agricultural intensification	Water quantity	Alteration of transpiration rates affects runoff	Basin scale; effect is marginal
		Timing of storm runoff altered through land drainage	Basin scale; significant effect
	Erosion	Cultivation without proper soil conservation measures and uncontrolled grazing on steep slopes increases erosion	Basin scale; effects are site-dependent
Draining wetlands	Floods	Drainage method, soil type, channel improvement, all effects flood response	Basin scale; open drains increase flood peak
Urbanisation	Flood volume	Impervious surfaces such as paved roads, parking lots, roofs prevent rainfall from infiltrating into the ground	Basin scale; increase of flood volume is proportional to impervious areas
	Flood peak	Surface runoff in urban areas has a higher flow velocity	Basin scale; increase in velocity, along with the increase of runoff volume and the concentration of the runoff in pipes and channels increases flood peaks significantly

The table indicates both positive and negative effects on water availability due to afforestation. This should not guide the reader into a wrong direction. It is worth noting that positive effects outstrip negative by far.

2.2 Intensity-Duration-Frequency curves (IDF curve)

An IDF curve illustrates the combination of rainfall Intensity in (mm/hr), rainfall duration and rainfall frequency. These three parameters make up the axes of the graph of an IDF curve. An IDF curve is ideally derived from long term rainfall records.

Rainfall is the driver for all discharge and design flood computations. The difficulty is to overcome the gap with respect to available rainfall records. Ground observation stations are sparse and often lack data, especially the availability of high temporal resolution less than one day is a problem. Another challenge in Tajikistan is that extreme events of rainfall often coincide with snowmelt.

A feasible way to achieve precipitation relevant to flood management are time series provided by satellite observations verified with data from ground stations. Except for TRMM or GPM data (see Part I), time series come as daily values. Even though daily values bear the risk to underestimate rain events with shorter durations than one day, they can be used for a statistical analysis from which IDF or Depth-Duration-Frequency (DDF) curves are extrapolated. However, results should be taken with care as long as no verification with observed records could be carried out.

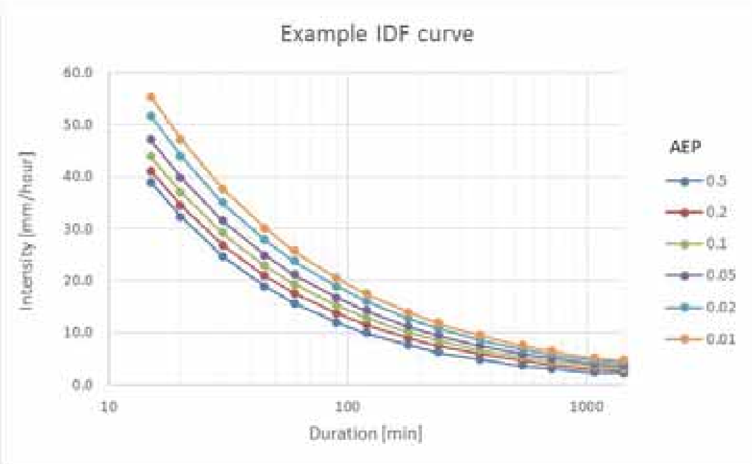
According to (Maidment, 1998), IDF curves can be described mathematically to facilitate calculations in the form:

$$i = \frac{c}{t^{c} + f}$$

where:

i:	design rainfall intensity [mm/hour]
t:	duration in minutes
c:	coefficient which depends on the exceedance probability
e, f:	coefficients depending on the location

It is recommended that coefficients for Tajikistan for various locations are developed homogeneously and to make them available for the public so that flood managers are able to apply them. The distinct advantage of a generalised approach covering the whole country is that the basis for design purposes is harmonised according to a standardised approach.



The curve is most likely underestimating the situation for durations less than 1 day due to the data base.

Figure 35: Example of an IDF-curve, developed with daily values from Khaburabad

Generally, IDF curves plotted on logarithmic scales show a strong linearity so that values equal and larger than one day can give an orientation for extrapolation towards shorter rainfall durations.

Applying an IDF curve without considering snowmelt results in an underestimation so that a safety factor should come on top. From Figure 35 a rainfall intensity of 20 mm/hr for a 60 min rainfall and a 10 year return period can be derived.

The values from Khaburabad were taken from (WB, 2017). Rainfall data can also be downloaded up to 1991 at: https://geographic.org/global_weather/tajikistan/khaburabad_853.html

2.3 Calculating runoff

Calculating runoff and deriving flood peaks and hydrographs are the first features needed to design flood mitigation measures. There are a number of approaches many of which entail sophisticated calculations and data requirements. Two widely used methods are introduced. Both need only a few parameters and are supported by a vast amount of literature and sources from where coefficients can be taken.

2.3.1 Rational Method

The simplest approach is the Rational Method which was originally developed for urban hydrology. It is a widely used approach and applies a relationship between the drainage area, rainfall intensity and a runoff coefficient representing land cover, soil types and sub-catchment slope. Its application is simple and data needs are low. The accuracy is inferior to more sophisticated and physically-based approaches and underlying assumptions and limitations must be observed.

The rational method is appropriate for estimating peak discharges for small drainage areas. The method provides the designer with a peak discharge value, but does neither provide a time series of flow nor flow volume.

The Rational method predicts the peak runoff according to the formula:

$$Q = c \cdot i \cdot A \cdot 0.00268$$

where:

Q: peak flow [m³/s]

C: runoff coefficient [-] (c is a function of the land cover, soil type and sub-catchment slope)

I: rainfall intensity [mm/hr] (the rainfall intensity is the average rainfall rate in mm/hr for a specific rainfall duration and a selected frequency. The duration is assumed to be equal to the time of concentration.)

A: sub-catchment area [ha]

Units must be taken with care and require conversion factors. The equation above calculates the peak discharge with i in [mm/hr] and area in [ha] and the factor reflects the conversion into m³/s. The runoff coefficient changes if applied to rural and mixed-use watersheds and is calculated based on four runoff components

Table 8: Runoff Coefficients for Rural Watersheds (adopted from (TxDOT, 2016)

Watershed characteristic	Extreme	High	Normal	Low
Relief - C_r	0.28-0.35	0.20-0.28	0.14-0.20	0.08-0.14
	Steep, rugged terrain with average slopes above 30%	Hilly, with average slopes of 10-30%	Rolling, with average slopes of 5-10%	Relatively flat land, with average slopes of 0-5%
Soil infiltration - C_i	0.12-0.16	0.08-0.12	0.06-0.08	0.04-0.06
	No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	Normal; well drained light or medium textured soils, sandy loams	Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal cover - C_v	0.12-0.16	0.08-0.12	0.06-0.08	0.04-0.06
	No effective plant cover, bare or very sparse cover	Poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Storage - C_s	0.10-0.12	0.08-0.10	0.06-0.08	0.04-0.06

	Negligible; surface depressions few and shallow, drainageways steep and small, no marshes	Well-defined system of small drainageways, no ponds or marshes	Normal; considerable surface depression, e.g., storage lakes and ponds and marshes	Much surface storage, drainage system not sharply defined; large floodplain storage, large number of ponds or marshes

The final coefficient is: $C = Cr + Ci + Cv + Cs$

For areas with a mixture of land uses, a composite runoff coefficient should be used. The composite runoff coefficient is weighted based on the area of each respective land use and can be calculated as:

$$C = \frac{\sum_{i=1}^{n} Ci \cdot Ai}{\sum_{i=1}^{n} Ai}$$

Assumptions and limitations are:

- The method is applicable if time of concentration for the drainage area is less than the duration of peak rainfall intensity.
- The calculated runoff is directly proportional to the rainfall intensity.
- Rainfall intensity is uniform throughout the duration of the storm.
- The frequency of occurrence for the peak discharge is the same as the frequency of the rainfall producing that event.
- Rainfall is distributed uniformly over the drainage area.
- The minimum duration to be used for computation of rainfall intensity is 10 minutes. If the time of concentration computed for the drainage area is less than 10 minutes, then 10 minutes should be adopted for rainfall intensity computations.
- The rational method does not account for storage in the drainage area. Available storage is assumed to be filled.

The table and the calculation of coefficients for rural and mixture of land use stems from the Hydraulic Manual – Texas Department of Transportation (see (TxDOT, 2016)).

The major drawback of this method is the poor physical representation of catchment characteristics and the absence of hydrographs.

2.3.2 SCS-Method

The SCS-Method was developed by the National Resources Conservation Service, Department of Agriculture, USA. The approach utilises physical parameters of a catchment area like soil type, land use, slope from which a so-called Curve Number (CN) is deduced. The CN-value represents the runoff characteristic and ranges from 20 (very high retention characteristic, almost no runoff) to 100 (no retention, no losses, precipitation results in runoff). It was developed as an event-based approach using accumulated rainfall from which the flood volume is calculated. The peak discharge is derived with the lag time, this is the time to rise to the peak of the hydrograph. A triangular hydrograph is assumed.

The approach requires more effort than the Rational method but considers physical characteristics. This makes the approach more transparent. In addition, the data base of CN-values is large, countless publications supply tables with CN-values. Derivatives of the approach include event-based losses and allow for antecedent soil moisture prior to an event. This is important as soil moisture conditions have a major effect. Without introducing antecedent soil moisture, best results can be expected for bare soil or sparse vegetation.

A list of CN-values for different hydrological soil groups and land cover can be found here: https://en.wikipedia.org/wiki/Runoff_curve_number.

The potential retention S in [mm] is calculated by: $S = 25.4 \cdot \left(\frac{1000}{CN} - 10 \right)$

where:

S: potential retention [mm]

CN: curve number [-]

The runoff volume Q is given by: $Qv = \frac{(P - 0.2 \cdot S)^2}{(P + 0.8 \cdot S)}$

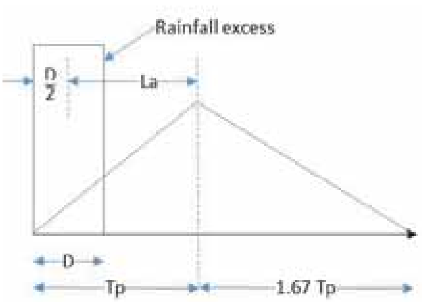
where:

Qv: runoff volume or depth of runoff [mm]

P: accumulated rainfall [mm]

The peak discharge is derived with the assumption of a triangular hydrograph given by:

$$Qp = \frac{0.208 \cdot A \cdot Qv}{0.5 \cdot D + 0.6 \cdot tc}$$



where:

Qp: peak discharge [m³/s]
A: catchment area [km²]
D: rainfall duration [hr]
Tc: time of concentration [hr]
Tp: time of rise [h]

2.3.3 Time of Concentration

The time of concentration tc is the time after commencement of rainfall excess when all portions of drainage basin are contributing simultaneously to flow at the outlet. It is also referred to a longest length of overland flow from the remotest point of the drainage area to the outlet while remoteness relates to travel time rather than distance. There are many formulas describing tc. Three are given:

Kirpich:

tc*: time of concentration [min]
tc: tc*/60 [hour]
L: L` [m]/0.3048, where L` is length of overland flow
So: slope [-]

$$tc^* = 0.0078 \cdot L^{0.77} \cdot So^{-0.385}$$

Kerby:

tc*: time of concentration [min]
tc: tc*/60 [hour]
L: L` [m]/0.3048, where L` is length of overland flow
n: manning coefficient [s/m$^{1/3}$]
So: slope [-]

$$tc^* = 0.83 \cdot \left(L \cdot n \cdot So^{-0.5}\right)^{0.467}$$

SCS lag:

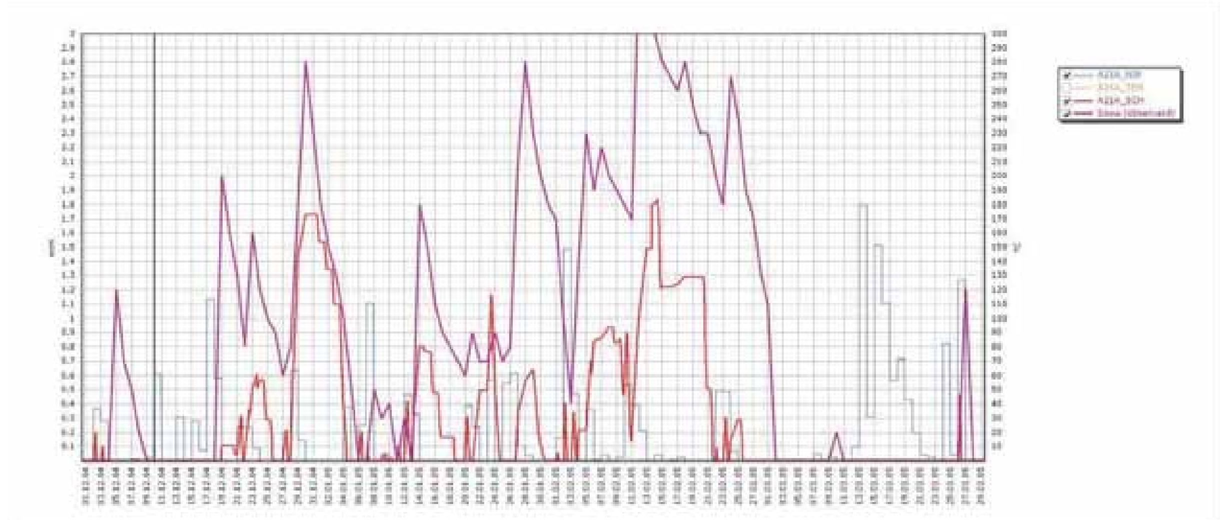
tc*: time of concentration [min]
tc: tc*/60 [hour]
L: L` [m]/0.3048, where L` is length of overland flow
S: potential retention S = 1000/CN – 10
CN: curve number
So: slope [%]

$$tc^* = L^{0.8} \cdot \frac{(S+1)^{0.7}}{1900 \cdot So^{0.5}}$$

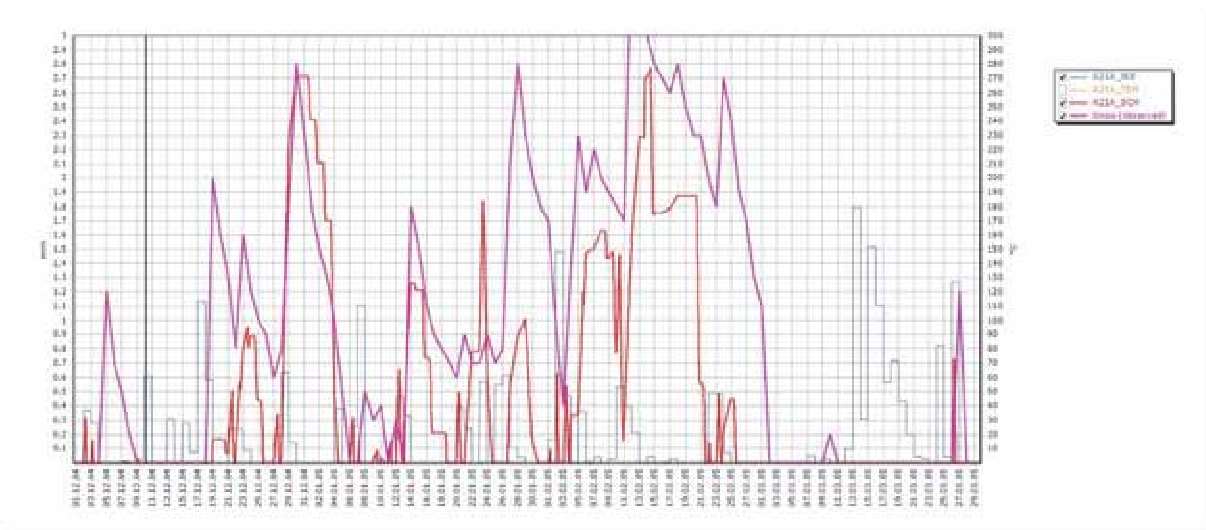
Kirpich considers slope and overland flow length but does not account for land cover. The disadvantage of the Kirpich formula is that tc would not change even if land use changes occurred in the drainage basin. Kerby introduces the manning coefficient reflecting land cover and is able to cope with land use alterations. The SCS lag formula uses the CN-value and yields longer tc compared to Kirpich and Kerby. Applying the SCS lag formula gives better results compared to model applications considering losses and sophisticated approaches like isochrones of travel time, cascades with different travel times and different flow components.

2.4 Snow computation

Computing snow accumulation, compaction and water equivalent is crucial in Tajikistan for any hydrological question. A short example is demonstrated with data from Khaburabad computed with the Snow Compaction approach according to (Bertle, 1966) and (Knauf, 1980). The method is based on field tests conducted by the US-Bureau of Reclamation.



(without any calibration)



(with only one calibration step)

The pink line indicates the observed snow, the red thin line shows the computed values. The model used was Talsim-NG (www.sydro.de). The model applies the Snow-Compaction approach as described in (Knauf, 1980), (Bertle, 1966). Input parameters are:

Table 9: Parameter of snow compaction method adopted from (Knauf, 1980), (Bertle, 1966)

Key	Parameter	Default
Tsnow	Temperature threshold when snow is accumulated [°C]	0
Mp	Rate of snowmelt [mm/(day Kelvin)]	4 - 5
Dmax	Threshold pack density at which compaction ceases and drainage from the snowpack begins [%]	40 - 45
Dfr	Initial dry snow density of snow pack in [%]	10

The approach is rather simple and data requirements are low compared to other methods. Calibration can be conducted based on observed snow depths.

2.5 Estimating erosion

Land erosion is an important parameter to identify adverse conditions which might come along with flood events, e.g. mudflows. Erosion is a very complex process and estimating it requires parameters which are difficult to assess. The universal soil loss equation (USLE) is one of the mostly used approaches. The equation is:

$$A = R \cdot K \cdot K \cdot S \cdot C \cdot P$$

Parameters and their dimensions are:

A	long-term average annual soil loss	$ML^{-2}T^{-1}$ (ML^{-2})*
R	rainfall erosivity factor	MLT^{-4} (MLT^{-3})*
K	soil erodibility factor	$L^{-3}T^{3}$
L	topographic factor of length	M L T
S	topographic factor of slope	M L T
C	Land management factor (C = C1 · C2)	
	C1: cropping management factor of vegetal cover	M L T
	C2: cropping management factor of tillage	M L T
P	conservation practices factor	M L T

M = mass, L = length,T = time

Each of the parameters has its own set of assumptions and coefficients which are often unknown and require a guess. Still, USLE is an accepted approach and provides a good overview to establish a map about erosion-prone areas. A disadvantage of the equation is the result as annual soil loss. This means it is not event-based. Event-based approaches have been developed known as modified USLE (MUSLE) replacing the rainfall erosivity factor by an event-based erosivity factor.

2.5.1 Rainfall erosivity factor R

The rainfall runoff erosivity is calculated as a product of storm kinetic energy (E) and the maximum 30-minute storm depth (I30) summed for storms in a year. Rainfall erosivity is calculated based on annual rainfall or monthly rainfall.

Formula based on monthly and annual rainfall

An approach which considers inner-annual rainfall uses:

$$MFI = \sum_{i=1}^{12} \frac{PM_i^{\;2}}{P}$$

PM: Monthly rainfall

P: Annual rainfall

Each month is weighed with its long-term average. To obtain the factor R two equations are applied:

$$R = [0.07397 \cdot MFI^{1.847} / 1.72], \text{ when } MFI < 55 \text{ mm}$$

$$R = [95.77 - 6.081 \cdot MFI + 0.4770 \cdot MFI^2 / 17.2], \text{ when } MFI > 55 \text{ mm}$$

2.5.2 Event-based soil erosion

The modified USLE (MUSLE) replaces the rainfall erosivity factor R with the product of rainfall amount and runoff amount with the aim to predict soil erosion for a single water erosion events.

Examples of formulas are:

$$S' = 95\left(Qp_p\right)^{0.56} \cdot K \cdot L \cdot S \cdot C \cdot P$$

where:

S': sediment yield for a single event in tons [t]

Q: total event runoff in [ft^3]

p_p: event peak discharge [ft^3/s]

The parameters K, L, S, C and P are identical to the USLE.

A transformation into metric units requires a factor for converting $feet^3$ into m^3 so that the result is S = S' 0.0283168.

2.5.3 Soil erodibility (K factor)

K reflects the susceptibility of soils to erosion. According to a study conducted Faizabad in Tajikistan, K factors ranged from 0.37 to 0.42 (Bühlmann, et al., 2010). This study applied the nomograph derived by (Wischmeier & Smith, 1978).

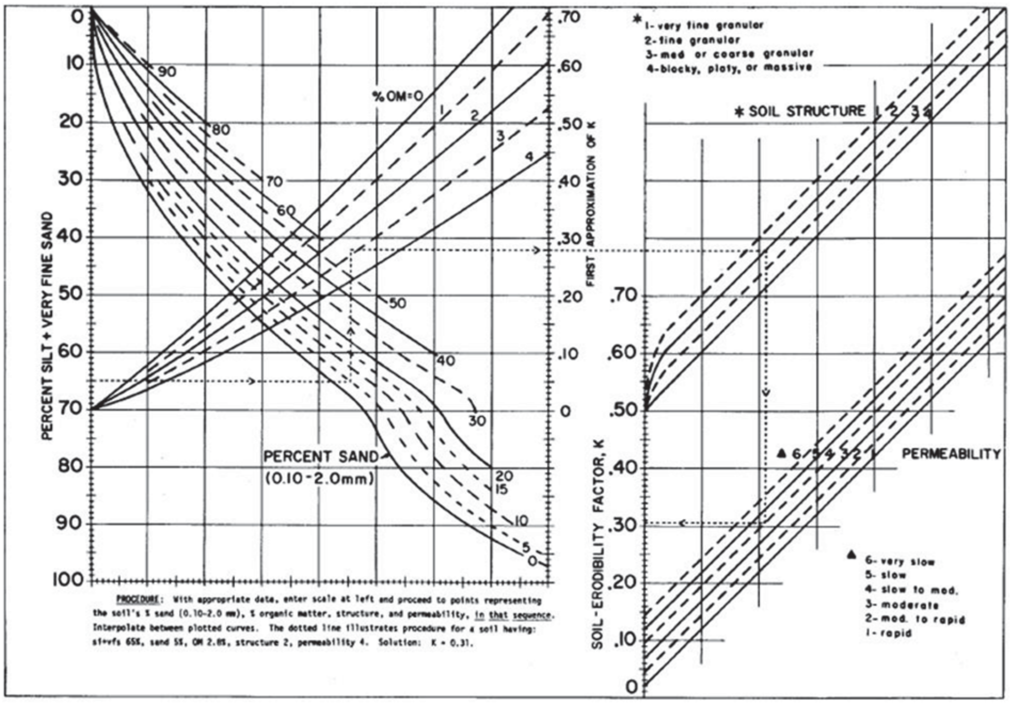


Figure 36: Nomograph for estimating K-factor (Wischmeier & Smith, 1978)

2.5.4 Slope length (L factor)

The L factor in the USLE is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or to where the flow connects to a river system.

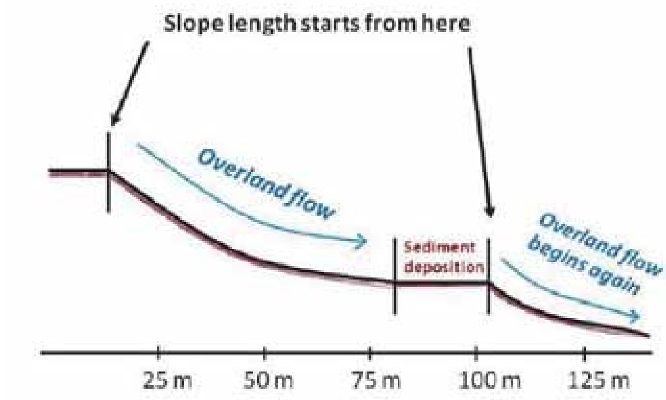
$$L = (\lambda / 22.13)^m$$

where

λ: Average slope length of single fields in [m]

m: variable slope length exponent that depends on slope steepness

- m = 0.5 for slopes greater than 5%,
- m = 0.4 for slopes between 3% and 5%,
- m = 0.3 for slopes less than 3%



(all adopted from (Wischmeier & Smith, 1978))

For practical use, average values can be determined by means of a GIS or by using a map and estimating mean conditions. This factor is linearly connected with the annual erosion losses. That means that an error of 10% in estimating this parameter results in a 10% change of the result.

2.5.5 Slope steepness (S factor)

Calculating slope, which is required to calculate the S-factor, is a standard procedure in GIS applications with a digital elevation model. The approach to estimate the S factor is according to (Renard, Foster, Weesies, McCool, & Yoder, 1997):

$$S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.065$$

Θ = mean slope angle in degrees

or

$S = 10.8 \sin\theta + 0.03$, gradient < 9%

$S = (\sin\theta / 0.0896)^{0.6}$, gradient ≥ 9%

2.5.6 Cover management or land cover (C factor)

The C factor is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding soil loss from a continuously tilled fallow area.

Example values of C

Land Cover Class	C-Factor	Location	Author/Source
Dense forest	0.001	Sumatra	KOOIMAN (1987)
Open forest	0.001	Sumatra	KOOIMAN (1987)
Shrubs and bush vegetation	0.1	Java	HAMER (1981), quoted in KOOIMAN (1987)
Low cover vegetation (fallow)	0.2	Java	HAMER (1981), quoted in KOOIMAN (1987)
Bare soil	1	Sumatra	KOOIMAN (1987)
Residential areas and home gardens	0.14	Sumatra	KOOIMAN (1987)

More information on how to assess the parameter in detail provides (Renard, Foster, Weesies, McCool, & Yoder, 1997).

Literature about C and P values in Tajikistan is sparse. (Bühlmann, et al., 2010) has obtained a C value of 0.2 for vegetable which is in the range of mixed agriculture in the table below.

2.5.7 Conservation support practice (P factor)

P factor is the soil loss ratio with a specific support practice to the corresponding soil loss with up and down slope tillage.

The P factor value will reduce when there are more effective supporting mechanical practices such as contouring, strip cropping, terracing and retention ditches. When there are no conservation support practices in the area of interest, maximum values of 1 will be assigned, meaning no land use influence.

2.6 Hydraulic calculations

Hydraulic calculations are needed for transforming discharge from hydrological considerations into flow velocity, flow depth and to calculate tractive forces exerting on movable bed particles.

Given a flow cross-section, the mean velocity can be derived by using the continuity equation: $v = Q / A$ where Q = discharge [m^3/s] and A is the flow cross-sectional area [m^2].

Assessing a channels capacity, the use of the Manning Equation for uniform flow is commonly applied.

$$v = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

where:

v: velocity in m³/s
n: Manning's roughness coefficient (= 1/kst where kst=Strickler coefficient)
R: hydraulic radius [m] = A / WP
A: flow cross-sectional area [m²]
WP: wetted perimeter of flow [m]
S: slope of the energy gradeline [m/m]. For uniform, steady flow, S is the channel slope.

Iteration is required because the water level is needed to compute WP and A. With A and the resulting flow velocity the discharge must be checked with v = Q/A. A result is achieved when the estimated water level results in a flow cross section from which v = Q/A and v from Manning Equation give the same flow velocity.

It is common practice to assume stationary, uniform flow and to use the channel bed slope. It is necessary to bear in mind that during a flood event, flow is neither stationary nor uniform so that the result incorporates uncertainties. This must be reflected with safety factors during design. Suggested Manning roughness coefficients are given in Table 10. These coefficients are subject to change in steep terrain.

Table 10: Manning roughness coefficients (adopted from (TxDOT, 2016))

Natural Channels	Minimum	Normal	Maximum
Minor Streams (top width at flood stage <30 meters)			
Streams on plain:			
Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
Same as above, but more stones and weeds	0.030	0.035	0.040
Clean, winding, some pools and shoals	0.033	0.040	0.045
Same as above, but some stones and weeds	0.035	0.045	0.050
Same as above, but lower stages, more ineffective slopes and sections	0.040	0.048	0.055
Clean, winding, some pools and shoals, some weeds and many stones	0.045	0.050	0.060
Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages:			
Bottom: gravel, cobbles, and few boulders	0.030	0.040	0.050
Bottom: cobbles with large boulders	0.040	0.050	0.070
Flood Plains			
Pasture, no brush:			
Short grass	0.025	0.030	0.035

Natural Channels	Minimum	Normal	Maximum
High grass	0.030	0.035	0.050
Cultivated areas:			
No crop	0.020	0.030	0.040
Mature row crops	0.025	0.035	0.045
Mature field crops	0.030	0.040	0.050
Brush:			
Scattered brush, heavy weeds	0.035	0.050	0.070
Light brush and trees, in winter	0.035	0.050	0.060
Light brush and trees, in summer	0.040	0.060	0.080
Medium to dense brush, in winter	0.045	0.070	0.110
Medium to dense brush, in summer	0.070	0.100	0.160
Trees:			
Dense willows, summer, straight	0.110	0.150	0.200
Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
Same as above, but flood stage reaching branches	0.100	0.120	0.160
Major Streams (top width at flood stage >30 meters)			
Regular section with no boulders or brush	0.025	--	0.060
Irregular and rough section	0.035	--	0.100
Lined Channels			
Concrete-lined	0.012	--	0.018
Concrete rubble	0.017	--	0.030
Unlined Channels			
Earth, straight and uniform	0.017	--	0.025
Winding and sluggish	0.022	--	0.030
Rocky beds, weeds on bank	0.025	--	0.040
Earth bottom, rubble sides	0.028	--	0.035
Rock cuts	0.025	--	0.045

An alternative to Manning's equation provides the formula of Darcy-Weisbach.

$$v = \sqrt{\frac{1}{\lambda} \cdot 8 \cdot g \cdot r_{hy} \cdot I_E}$$

where:

v: average velocity [m/s]

λ: Coefficient of resistance [-]

r_{hy}: hydraulic radius [m] = A / WP

IE: slope of the energy gradeline [m/m]. For uniform, steady flow, S is the channel slope.

The coefficient of resistance can be expressed as:

$$\frac{1}{\sqrt{\lambda}} = -2.03 \cdot \lg\left(12.27 \cdot \frac{r_{hy}}{k_s}\right)$$

where k is the equivalent sand roughness. The approach is more complex than Manning's formula but gains wide acceptance due to a better approximation of flow processes. However, applying the formula requires iteration.

Table 11: Equivalent sand roughness coefficients (adopted from (Patt, 1998))

River bed structure	Ks [mm]
Rock:	
Machined, smoothed	220 – 350
coarse	450 – 700
Earth channels:	
regular	15 – 60
Good conditions, no vegetation	6 – 10
Bed and banks muddy, regular	25 – 50
Gravel bed, sparse vegetation	80 – 140
Medium vegetation	190 – 270
Poorly maintained	300 – 500
With bed load	100 – 200
Flow strongly impaired by weeds	500 – 1500
Stones and gravel (not transport):	
Coarse gravel	50 – 54
Coarse gravel mixed with sand and mud	30 – 40
Sand and gravel (< 6 cm)	20 – 55
Regular machined stones (10-20 cm) in bulk, plain river bed	16 - 18

2.7 Sediment transport

Measures for torrent control aim at reducing typical effects of torrential flows, erosion and transport/deposition of eroded material. In contrast to Section 2.5 where erosion is understood as land erosion and loss of soil, this section deals with erosion, deposition and stabilisation processes in open channels, river beds and stream banks. Streamflow causes the tractive force that detaches and transports materials either as bed load or suspended solids. This document concentrates on bed load. The tractive force follows the equation:

$$\tau = \rho_w \cdot g \cdot r_{hy} \cdot I_E$$

where:

τ: tractive force or sheer stress [N/m²]

ρ_w: density of water [kg/m³], ρ_w =1000 km/m³

g: gravity [m/s²]

r_{hy}: hydraulic radius [m] = A / WP

I_E: slope of the energy gradeline [m/m]. For uniform, steady flow, S is the channel slope.

The tractive force is countered by the resistance of materials to detachment and transport through weight, inertia and friction. The threshold when mass movement begins is called the critical sheer stress, boundary sheer stress or critical tractive force τ_{crit}. The torrentiality of a stream may be assessed by comparing τ with τ_{crit} to see whether t > τ_{crit}. If so, there will be erosion and/or sediment transport.

The tractive force on bank material can be calculated with:

$$\tau_{bank} = \tau_{bed} \cdot \left(\cos\theta \sqrt{1 - \frac{\tan^2\theta}{\tan^2\varphi}} \right)$$

where:

τ_{bed}:	tractive force or sheer stress stream bed (see above) [N/m²]
Θ:	angle of bank slope above the horizontal
φ :	angle of internal friction of bank material

Values for angle of internal friction are:

Rock	30
Sand	30 - 40
Gravel	35
Silt	34
Clay	20
Loose sand	30 – 35
Medium sand	40
Dense sand	35 - 45
Gravel with some sand	34 - 48
Silt	26 - 35

Because the angle of internal friction, is typically around 25 to 35, the coefficient of internal friction (tan) is 0.5 to 0.7.

The core of torrent control is the identification of the balance between actual sheer stress caused by streamflow and critical sheer stress due to the material's properties. Any form of hydrological intervention in the watershed that reduces the drivers for tractive force or increases boundary sheer stress contributes to improving torrential control. There are structural, engineered and nature-based measures as well as biological methods like watershed improvement, land conservation and soil stabilisation. All three components must complement each other to obtain a sustainable solution. Doing nothing in the watershed management but engaging in structural measures is like combating symptoms only without curing root causes. For example, fixing soil erosion will reduce the quantity of suspended sediments and decreases turbidity and density which, in turn, reduces the specific gravity γ and weakens the tractive force.

Table 12: Critical sheer stress for different material

Soil	d mm	Tau-crit	v crit	kst
Silt	0.02 ... 0.063	-	0.1 ... 0.2	40 .. 50
fine sand	0.063 ... 0.2	0.5 .. 1.0	0.2 ... 0.35	40 ... 50
medium sand	0.2 ... 0.63	1.0 ... 2.0	0.35 ... 0.45	40 ... 50
coarse sand	0.63 ... 2.0	3.0 ... 6.0	0.45 ... 0.6	40 ... 50
fine gravel	2.0 ... 6.3	8.0 .. 12.0	0.6 ... 0.8	40 ... 50
medium gravel	6.3 ... 20	15	0.8 ... 1.25	40 ... 60

coarse gravel	20 ... 63	45	1.25 ... 1.6	35
stones, boulders 50 ... 75	50 ... 75	-	1.7 ... 1.8	30
stones, boulders 75 ... 100	75 ... 100	-	1.9 ... 2.0	28

Table 13: Critical sheer stress for bank revetments

Stabilization	d mm	Tau-crit	v crit	kst
riprap 32/63	32/63	30 ... 58	-	20 ... 30
riprap 63/90	63/90	40 ... 75	-	20 ... 30
riprap 63/125	63/125	75 ... 100	-	20 ... 30
riprap 100 ... 150	100 ... 150	-	1.9 ... 3.4	20 ... 30
stone packing	150 ... 200	53 ... 73	2.6 ... 3.8	-
cobble-stone pavement	200 ... 300	73 ... 160	-	-
grass (short, well-rooted), average	-	15 ... 18	1.5	-
grass (short, well-rooted), peak	-	20 ... 30	1.8	-
concrete grid panels with grass	-	108	-	40 ... 50
concrete grid panels with sand	-	40 ... 50	-	40 ... 50
concrete grid panels with gravel	-	50 ... 100	-	40 ... 50
concrete without sediment	-	-	4	-
concrete with sediment	-	-	2.5	-
vegetated gabions	-	30 ... 40	-	-
well-rooted shrubs	-	100 ... 140	-	-
quarrystone, fortified	-	-	5	-

(Schillinger, 2001) has evaluated field tests and laboratory tests to compile critical sheer stress of bioengineering measures.

Table 14: Critical sheer stress (adopted from (Schillinger, 2001)

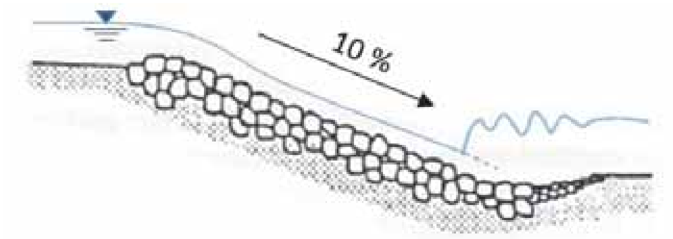
Measure	Literature / Author	Age [Month]	vm [m/s]	ISo [‰]	h [m]	bSo [m]	Bank slope	τ_{crit} [N/m²]	Comments
willow brush mattress	FLORINETH (1982)	15	-	30,0	1,20	16,0	4:5	218	Zangenbach
		15	-	30,0	1,15	8,0	4:5	195	Lasankenbach
	FLORINETH (1995)	7	-	18,0	3,00	36,0	2:3	309	Passer
		7	-	30,0	1,20	16,0	4:5	312	Zangenbach
		7	-	30,0	1,15	8,0	4:5	292	Lasankenbach
		7	-	18,0	3,00	36,0	2:3	480	Passer
	LACHAT (1994)							300	
	ZEH (1990)		3,5						
	BEGEMANN/SCHIECHTL (1994)							50 bis >300	
	GERSTGRASER (2000)	3 bzw. 7	3,2 - 3,5					200 - 300	
wattle fence	STEIGER (1918)			2,0			1:2	50	
	BORKENSTEIN (1976)							50	
	ZEH (1990)		3,5						
	RÖSSERT (1994)							50	
	GERSTGRASER (2000)	15	3,2 - 3,5					100 - 120	

Measure	Literature / Author	Age [Month]	vm [m/s]	ISo [‰]	h [m]	bSo [m]	Bank slope	τ_{crit} [N/m²]	Comments
fascine	BEGEMANN/SCHIECHTL (1994)							60	
	RÖSSERT (1994)							70	
	LACHAT (1994)							250	
	LfU (1996)		2,5 - 3,0	0,6 - 0,9				70 - 100	dead wood fascine
			3,0 - 3,5	0,6 - 0,9				100 - 150	Live fascine
	ZEH (1990)		3,5						
	GERSTGRASER (2000)	15	3,5 - 4,0					180 - 240	with planting stakes
		15	2,0 - 2,5					120 - 150	on brushlayer
		15	3,3 - 3,8					150 - 200	array of fascines
	STEIGER (1918)			7,0				180	Piles with fascines
	SCHOKLITSCH (1930)							70	
willow cuttings	WITZIG (1970)			5,5	3,00	28,0	2:3	165	Joint planting with concrete blocls
	EVED (1982)							> 140	Joint planting with bolder reventments
	BEGEMANN/SCHIECHTL (1994)	0 - 3 Jahre						50 - 250	With piles and stone packing
		0 - 3 Jahre						75 bis > 350	with array of blocks
	LfU (1996)		3,0 - 3,5	0,6 - 0,9				100 - 150	with riprap
	GERSTGRASER (2000)	15	2,2 - 2,8					80 - 120	Coconut fibre rolls
willow shrubs	WITZIG (1970)						2:3	100	elastic
	EASF (1973)							100 - 140	
	ANSELM (1976)	1-2 Jahre						50 - 70	
		> 2 Jahre						100 - 140	
		20 Jahre						800	
riprap	GERSTGRASER (2000)	15	3,0 - 3,5					120 - 160	Geotextile with brushlayers
	STEIGER (1918)			7,0				170	
	LfU (1996)		3,5 - 4,0					bis 150	
	ZEH (1990)		3,5						
	BEGEMANN/SCHIECHTL (1994)	0 - 3 Jahre						100 bis > 300	With joint planing
Reeds /	ZEH (1990)		2,0						
brush mattress construction with reeds	LfU (1996)		2,0 - 2,5					55 - 65	
grass	WITZIG (1970)						1:2 bis 2:3	50 - 100	
	EASF (1973)						1:2 bis 2:3	50 - 80	
	RÖSSERT (1988)							15 - 18	Long-term
								20 - 30	Short-term
	BEGEMANN/SCHIECHTL (1994)							15 - 18	Long-term
								20 - 30	Short-term
	LfU (1996)		1,5					30	With crushed stones
			1,8					40	seedings
			> 3,5					> 60	strip of turf
	ZEH (1990)		1,8						Dry seeds
			1,8					30	Seedings with geotextiles

Measure	Literature / Author	Age [Month]	vm [m/s]	ISo [‰]	h [m]	bSo [m]	Bank slope	τ_{crit} [N/m²]	Comments
			3,7						Strip of turf
Revetments	LfU (1996)		2,5 - 3,2					70 - 100	gravel (0 - 40mm)
			3,5 - 4,0					100 - 150	boulders
			> 4,0					> 150	Large boulders
	BOLLRICH (1992)		1,9 - 3,4						riprap
			2,6 - 3,8					53 - 73	bouldars (15 - 20 cm)
								73 - 160	boulders (20 - 30 cm)

2.8 Development of streambed stabilisation

Ramps are often used to bridge large slopes so that the rest of a longitudinal profile can be developed with less slope and as such with less tractive forces.



A formula to estimate the diameter needed for implementing a ramp was developed by (Whittaker, 1986):

$$d_{crit} = 1.225 \cdot \left(\frac{\rho_s - \rho_w}{\rho_w} \right)^{-\frac{1}{3}} \cdot I^{\frac{7}{9}} \cdot q_{crit}$$ or asking for q_{crit}: $$q_{crit} = 0.235 \cdot \sqrt{\frac{\rho_s - \rho_w}{\rho_w}} \cdot \sqrt{g} \cdot I^{-\frac{7}{6}} \cdot d_s^{\frac{3}{2}}$$

where:

g:	Gravity [m/s²]
ρ_s:	Density of the stones used for the ramp [kg/m³]
ρ_w:	Density of water [kg/m³]
I:	Slope of the ramp [m/m]
q_{crit}:	critical discharge per m width at which movement of the ramp would start [m³/(s m)]

With a given discharge, the minimum diameter can be estimated or with given stones the critical discharge at which movement of the stones would begin. The stones used for developing a ramp should be very hard to resist abrasion. The stones need to be tightly placed or ideally fixed with cement or mortar. It is obvious that larger diameter of the stones provide more robustness.

Developing a ramp with diameter less than 40 cm, it is possible to raise the ramp still as a loose stone package saving time and labour force. Larger diameters require an excavator with a gripper arm to place each stone carefully. The development of a plain underground can be combined when an excavator is used. The material beneath the ramp should fulfil a rule of thumb in the way that

d_{85} (substrate) · 5 < d_{stones}

Is the substrate smaller, a filter must be laid. Generally, a ramp should be developed as a plain along the whole the cross-section to avoid flow concentration in the middle. The stone package is to continue into the river banks.

2.9 Advanced methods

2.9.1 Hydrological modelling

A hydrologic model is a simplification of the real world and distinguishes between different hydrological processes like precipitation-runoff, soil water and soil moisture, overland flow, flow in open channels or pipes, lakes and reservoirs, groundwater, etc. It depends on the model which methods are implemented and how complex they are. As a rule of thumb, more complex methods usually require more parameters and thus more data and observations for calibration. Hydraulic methods for weirs, spillways and diversion are often incorporated. A watershed can be modelled by composing the processes to a hydrological system.

The model approach starts with the delineation of sub-basins and river reaches,, followed by acquiring the parameters needed for each sub-basin and river reach. All elements are then combined to represent the flow network. The comparison of the GIS sub-basins and a screenshot of Talsim-NG (www.sydro.de) as hydrological model is shown in

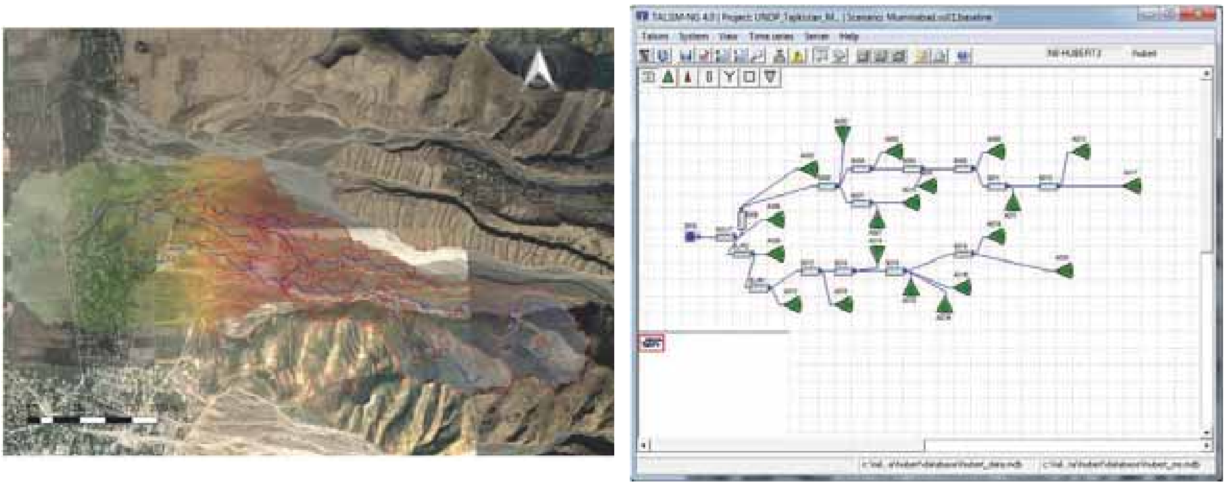
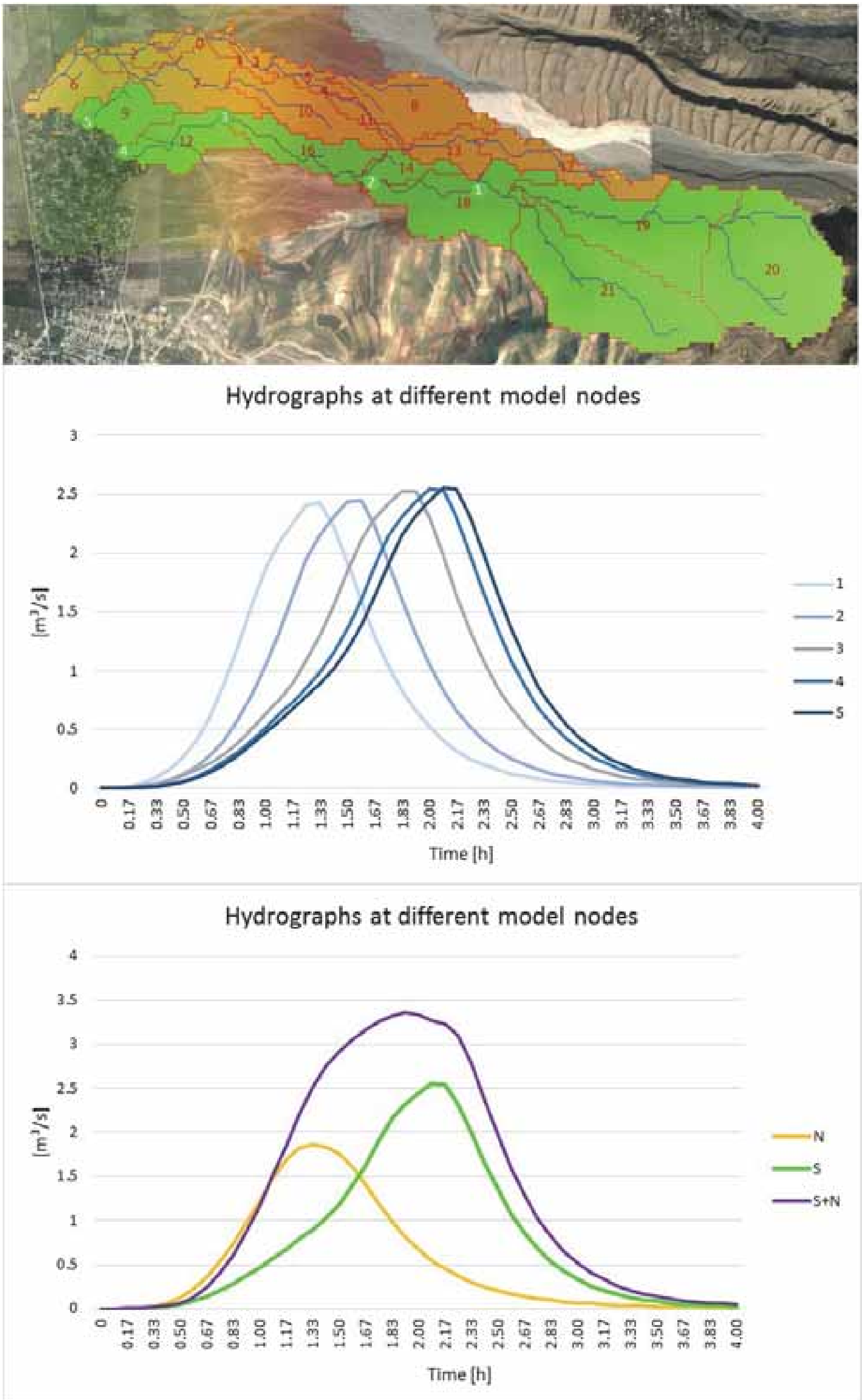


Figure 37: Hydrological model – from GIS to flow network (QGIS and Talsim-NG)

Hydrological models usually embed sub-basins, river reaches, diversions, weirs, reservoirs, consumers, point-discharge elements and sometime groundwater elements. Additionally, the Talsim-NG model allows for incorporating operating rules for controllable structures like reservoirs, gates, pumps and turbines.

Basically, hydrological models are state-of-the-art in computing runoff, propagating water through rivers and generating hydrographs at given points in a watershed. The capacity to allow for losses in the runoff generation, to consider time of concentration according to the topography and land use parameters and above all, the ability to overlay flow from different sub-basins and to transport water in a stream network are the major advantages.

The propagation of flow is demonstrated through the model nodes indicated as green as shown in the figure below.



The flow along the green area shows the time lag water needs to flow from one node to the next.

Figure 38: Overlay of flow for different catchments

Due to the different travel time in the watershed, the resulting maximum peak flow is not a simple addition of peak discharge from the green and orange area.

It is recommended to use hydrological models while assessing a watershed for flood management. Free models are available here:

http://www.hec.usace.army.mil/software/hec-hms/ (for beginners) http://www.bluemodel.org/ (for advanced users)

www.sydro.de (upon request) (for beginners up to experts)

http://swat.tamu.edu/software/ (for experts)

2.9.2 Hydraulic modelling

Flood modelling comprises of two components, hydrological simulation, which quantifies the size, duration and probability of a flood event and hydraulic simulation providing the means to compute water depth from which inundated areas can be derived.

Hydraulic modelling comes in two ways: 1D and 2D modelling. 3D is not considered here. 1D employs the longitudinal direction along the channel. A stream network composed by a 1D model is a linear system of river reaches where traverse flow is more or less ignored and vertical differences in a cross section are averaged. In contrast, a 2D model serves the longitudinal and lateral directions and consists of a regular or irregular mesh of cells, connected to each other and flow can cross the edges of all cells.

The preferred field of work for 1D and 2D are:

1D	Narrow valleys Steep gradients Modelling of hydraulic structure like gates, weirs, pipes, etc. No retention areas Steady or unsteady flow possible	2D	Floodplains River with large river banks Unclear and changing flow paths Flow with distinct traverse flow components Flow direction less predictable

Figure 39: Typical 1D and 2D hydraulic schemes

The question needs to be answered whether more advanced modelling like a fully developed 2D approach supported by detailed spatial information is actually more advantageous than simplified 1D modelling. In fact, the more sophisticated approaches become extremely demanding in terms of data and computational resources. This imposes substantial barriers on the utilisation of 2D models.

As a rule of thumb, the use of 1D models will suffice the requirements in a typical terrain with steep and narrow valleys. There is no need to apply 2D models, unless urban settlements are affected in an area where multiple possible flow paths exist which changing channels from flood event to flood events. Typical examples are large deposition areas and alluvial debris cones.

Figure 40: A case for a 2D hydraulic application

2.10 Flow in steep terrain and estimation of sediment load

The Manning roughness is not a constant value. It decreases with a smaller wetted perimeter while the cross section remains constant. In other words, the decrease in roughness is not only expressed in a smaller hydraulic radius but also in a decrease of the Manning roughness (Bergmeister K. S.-M., 2009). The range of validity for the Manning roughness is considered to be not more than 4% slope. A correction factor for n is given as (Bergmeister K. S.-M., 2009):

$$\frac{1}{n} = \frac{26}{d_{90}^{1.6}}$$

where:

n: Manning roughness

d90: 90% of the grading curve of the river bed material

Alternatively, the flow velocity for steep torrential streams was evaluated by (Rickenmann, 1996) as:

$$v = \frac{0.37 \cdot I^{0.2} Q^{0.34} \div g^{0.33}}{d_{90}^{0.35}}$$

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

Table 15: Increase of discharge due to sediment load (Bergmeister K. S.-M., 2009)

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

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

$M = 27000 \cdot A^{0.78}$	Zeller [219], Rickenmann [174]
$M = L_c \cdot (110 - 250 \cdot J_f - 3)$	Rickenmann/Zimmermann [178]

All empirical formulas stem from field investigation in the Alpine region.

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Part III: Best Management Practice Examples

Document Information

Project	Strengthening disaster risk redaction and response capacity
Project Countries	Tajikistan
Document	Flood Disaster Risk Reduction Manual for Tajikistan
Date	28.03.2018
Consultant	Dr.-Ing. Hubert Lohr
Financing Organisation	Government of Japan, UNDP Tajikistan

Organisation	Best Practice Example
ACTED	Integrated Flood Mitigation Measures and Awareness Raising - Devashtich, Village Bobuchak River bank stabilisation - Kuhistoni Mastchoh, Village Gas
CAMP tabiat Public Foundation for sustainable mountain development	Climate adaptation through Sustainable forestry
cesvi	Disaster risk reduction (DRR) and resilience building in education sector Reduction of Land Degradation and Prevention of Desertification through the Development of Natural Resources Management
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	Watershed management: Ecosystem-based adaptation to Climate Change Watershed management – Forest Management River training: Gabion walls and flood protection
welt hunger hilfe	Geo-hazard Capacity building and monitoring; Early Warning System
cesvi	Technical Leaflets –Soil Bio-Engineering 1 Palisades 2 brush layering 3 contour line fascines 4 drainage fascines 5 wattling 6 gabion walls 7 tripodes for river works 8 check dams

Flood Management Guideline Tajikistan

Best Practice Example:
Integrated Flood Mitigation Measures and Awareness Raising - Devashtich, Village Bobuchak

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

<table>
<tr><td>Project name</td><td colspan="2">The Consortium HELVETAS, ACTED and GIZ is implementing the project "National Water Resources Management" (NWRM) funded by Swiss Agency for Development and Cooperation (SDC).</td><td>Organisation</td><td>ACTED

French International NGO “ACTED” (Agency for Technical Cooperation and Development).</td></tr>
<tr><td></td><td colspan="4">As part of the project, ACTED is responsible for the implementation of Result 6 “Watershed Management and Disaster Risk Reduction”, which aims to reduce the impact of water related disasters in the Ak-Suu watershed.</td></tr>
<tr><td>Location</td><td colspan="4">Devashtich, jamoat Rosrovut, village Bobuchak</td></tr>
<tr><td>Project Period (start-end)</td><td colspan="4">August 2016</td></tr>
<tr><td>Contact</td><td colspan="4">Nargiz Mirbozkhonova- Senior Project Officer , 92 770 21 43
nargiz.mirbozkhonova@acted.org</td></tr>
<tr><td>Beneficiaries / Number of Female</td><td>the village population 513 people (117 households), schools, a medical center, as well as tea house and a mosque.</td><td>Stakeholder</td><td colspan="2">CoES of Devashtich, jamoat Rosrovut, District Hukumat</td></tr>
<tr><td>Budget (Costs)</td><td colspan="4">estimate of total costs of the measure: 12 500 USD</td></tr>
<tr><td>Purposes and Background</td><td colspan="4">Bobuchak is a small rural mountainous village, located in the middle part of the Ak-Suu watershed (altitude-1799m) in Rosrovut Jamoat of Devashtich district. According to the results of the natural disaster risk assessment conducted in the village, Bobuchak can be consider as at high risk of disaster. In fact, it is highly vulnerable to mudflows, which every year cause damage to households, social facilities, and livestock. All in all, the village houses 513 people (117 households).


Figure 1. Bobuchak village of Devashtich district

ACTED holistic approach aims to reduce the risk of disasters and build community preparedness through the integrated management of natural resources within the watershed. To this end, ACTED provided a series of training sessions to Community Members, involving them in restoration works as demonstration models, so that they could apply in practice the skills and knowledge received during the trainings. This allowed them to execute the mitigation activities planned for reducing the risk of disasters, using improvised inexpensive means.

In April 2016, the Bobuchak’s population decided to set-up a living palisade by planting native seedlings and shrubs such as tree elms and dog rose as a fence and by placing water tanks for their irrigation, due to the limited water available in the village. All the required works were executed by community members, using the means readily available in the village (stones, seedlings, shrubs, wire). Moreover, CBOs member set up a series of activities to involve school children in the gardening and watering of the seedlings. In this way children can observe the restoration process, and through the direct observation they can understand the root causes of mudflows and the irrational use of natural resources. In fact, due to the ongoing economic crisis in Tajikistan, the adult male population is often into labor migration and women are fully engaged in domestic work. As a result, teenagers are now the segment of the population which is more often responsible for cutting shrubs and trees, throwing away the garbage in the sai, leading grazing animal on pastures, without realizing the severe consequences of their actions.

Nonetheless, the measures implemented are still not sufficient to reduce the risk of mudflows in the village. Moreover, such interventions should be carried out on a year basis, because after mudflows rubbles tend to cover everything. There is more and more the need to restore and clean up the environment, without losing heart and without despair.</td></tr>
</table>

Measures and Methodologies of this project	Taking into account the wealth of data collected from the in-depth disaster risk assessment, ACTED decided to implement in August 2016 two additional mitigation projects in this village: “Bank protection” and “Rehabilitation of mud channel”. These have significantly reduced the risk of natural disasters for 117 households, schools, a medical center, as well as tea house and a mosque. The activities of the population of this small mountain village were taken into consideration by ACTED’s experts when selecting the sites for the implementation of mitigation projects. It is extremely important to directly involve the local population in the process so that they can understand by doing the meaning of what is happening. Why do mudflows become worse every year in the village? What are the main reasons for their occurrence? What should be done to reduce disaster risk? Directly involving local population in the project implementation was pivotal for building the capacity of the community members in disaster risk reduction. So, women, the elderly, teenagers participate in the work. Given the mountainous relief in the Ak-Suu River watershed, it is very difficult to divert a mudflow in the upper reaches of the village, which is particularly recommended for the implementation of mitigation sites. Here the technical possibilities are limited to the mountain area, where there are pastures. Members of the Pasture Committee discussed the issue for preserving the pasture areas where mudflows originate. Through preserving the pasture areas and other additional measures grass cover land can be restored and roots strengthened, consequently increasing water filtration and reducing runoffs of water, which will ultimately lead to a significant decrease of the frequency and intensity of mudflows.		
Complementary measures			
Replicability	By implementing integrated mitigation projects with restoration components in Bobuchak, ACTED not only aims to reduce the vulnerability of the people that live in Bobuchak, but also to provide an example and inspiration for the conduction of restoration activities in neighboring villages with similar or high risk of disaster.		
Sustainability / Maintenance	With the aim of providing the sustainability for the realized mitigation measure, there was used the approach on both structural and non structural works i.e both technical and non technical measures. Community itself was involved from the beginning in order to feel ownership and take a role of leader for the process of projects implementation and maintenance.		
Expected and/or proven effects	on-site	Upstream	downstream
Activities of Stakeholders	Local authority- jamoat and CoeS supported community with some type of machines and techniques.		
Challenges			
Illustrations	Photo documentation at the end of this document.		
Data and Requirements			
Work plan	• Bank protection • Rehabilitation of mud channel.		

Pros and Cons of the Project

Pros	Cons

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood mitigation	
	Measure:	Effectiveness
1	Technical infrastructure	High
2	“green” activities (tree planting)	High
3	Community’s awareness about the ways for disaster risk reduction	Very high
4	Cooperation between stakeholders on preparation of joint plan for DRR	Very high
5		
Self-evaluation	The evaluation of the mitigation work was conducted by the team of AMEU (Appraisal Monitoring and Evaluation Unit) where the team was collecting data based on specified criterias and adapted to rural situation methodology.	

Figure 2. Conduction of restoration activities by population of Bobuchak village

Figure 3. Re

Figure 3. Bank protection in Bobuchak village

Flood Management Guideline Tajikistan

Best Practice:
River bank stabilisation - Kuhistoni Mastchoh, Village Gas

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

Project name	Improving Livelihood and Food Security through sustainable Natural Resources Management, 2016-2021 (in consortium of AKF in partnership with MSDSP, Sarob, CAMP Kuhiston).	Organisation	ACTED French International NGO “ACTED” (Agency for Technical Cooperation and Development).
	ACTED responsible for the realization of activities under Result 1 and Result 3 for improvement of natural resources: pasture improvement, reforestation measures, structural and non structural measures, soil erosion control, promotion of energy efficient components, Watershed management plans.		
Location	Kuhistoni Mastchoh, jamoat Ivan tojik, village Gas		
Project Period (start-end)	19/07/2017-31/08/2017 (implementation)		
Contact	**Robiya Nabieva, Project Manager, 92 770 21 47, zaravshan.cmd@acted.org**		
Beneficiaries / Number of Female	Population of village Gas -150 people, 77 female, 9 has of agricultural lands	Stakeholder	CoES of Kuhistoni Mastchoh, jamoat Ivan tojik, District Hukumat
Budget (Costs)	estimate of total costs of the measure: 12 000 USD		
Purposes and Background	The mudflow 2016 which was added into the exisiting water of river Gusn on the bank of which is situated village Gas, became the reason for getting the level of the water high nad washed away the irrigative channel, transformer and raised the risk to the households. Due to the fact that the irrigation channel was washed away the whole population of the village GAS did not have enough water for their lands. People by themselves were trying to dig small irrigation channel which water was not enough and for the last harvest season farmers of the village could not get good harvest for covering the expenses of their livelihood. The high level of snow fall in winter 2017 and then sudden non expected high temperature in spring and summer raised the level of risk for mudflow and avalanches in upper part of Zerafshan valley for that villages which were situated on the bank of the rivers in water catchments. Population of the villages were worrying about this situation and were trying to address the problem by every possible way i.e making some mitigation measures locally, applying for help to CoES, local authorities, NGOs. Village Gas was selected as one of the riskiest ones by the side of CoES,local authorities and experts team of ACTED.		
Measures and Methodologies of this project	The scheme and estimation of the project’s cost was done by engineer of ACTED in close cooperation with engineer who was provided by District Hukumat. During the preparation of scheme the main focus was given to the sustainability of the mitigation work and its adaptation to the situation. Instead of metal mesh for gabions it was decided to use metal rebar which showed itself more sustainable for a big mudflows even. Plus to the technical prevention there was added the part on making “green mitigation works” also, i.e community took for its contribution planting of trees which demonstrated themselves as one of the sustainable one for bank protection works. Mainly they were the type of osier which were promoted under the previous projects in the region for bank protection measures. One of the main approach which should be taken into account in the process of making any mitigation measure it was the involvement of the community from the beginning. Community itself by facilitating of ACTED conducted Hazard Vulnerabiltiy Assessment in their village with the aim of identifying the most riskiest places for disasters. Members of Community Based Organization- Mahalla Committee, passed two days training on “Disaster Risk Reduction based on Natural Resources Management”, preparation of Village Disaster Preparedness Plans. After the receiving of the training Mahalla Committee members prepared together with all other members of the community their Village Disaster Preparedness Plan in which they have indicated the measures for decreasing the level of disaster and build preparedness of the community. “Now we know that better to solve the problem in the root rather than working on its symptoms. By controlling the measures on stabilising the degradation level of natural resources we can decrease the level of disaster in our village. We are working on improving the situation of pasture, reforestation and soil erosion control around of our village”- said the head of Mahalla Committee- Homidov Nozim.		

<table>
<tr><td>Complementary measures</td><td colspan="3"></td></tr>
<tr><td>Replicability</td><td colspan="3">Neighboring villages Ruvosk and Gusn which population are in close cooperation with population of GAS, as they are also situated on the bank of the same river and they understand that if disaster happens in one of the their village it will impact the neighboring villages too. Looking at the measure which now population are taking for decreasing the level of disaster, population of Ruvosk and Guzn also started the process of taking measures for disaster risk reduction by organizing hashars, tree planting on the bank of the river, making plans for Natural Resources Management and Improvement.</td></tr>
<tr><td>Sustainability / Maintenance</td><td colspan="3">With the aim of providing the sustainability for the realized mitigation measure, there was used the approach on both structural and non structural works i.e both technical and non technical measures.
Community itself was involved from the beginning in order to feed ownership and take a role of leader for the process of projects implementation and maintenance.</td></tr>
<tr><td rowspan="2">Expected and/or proven effects</td><td>on-site</td><td>Upstream</td><td>downstream</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Activities of Stakeholders</td><td colspan="3">District Hukumat and CoeS supported with machines and techniques, District Hukumat also provided its engineer in the process of project design and cost estimation.</td></tr>
<tr><td>Challenges</td><td colspan="3">{challenges during the project implementation, e.g. land ownership, responsibility with respect to maintenance, involvement of local authorities and communities, protection of the sites, etc.}
Some times the level of the water which was getting higher day after the day was raising the challenge in implementation of technical works. Some type of techniques which were initially planned for using were changed for another type which were demanding time for finding.</td></tr>
<tr><td>Illustrations</td><td colspan="3">Photo documentation at the end of this document.</td></tr>
<tr><td>Data and Requirements</td><td colspan="3">By the side of ACTED there was used the subcontractor for implementation that type of activities which were identified as an ACTED contribution according to the cost of estimation of the mitigation project. This subcontractor was LLC “DSM 41”.</td></tr>
<tr><td>Work plan</td><td colspan="3">• Digging, concreting of irrigation channel for 170 ms
• Bank strengthening works by rebar gabion for 170 ms
• Tree planting works for 170 m</td></tr>
</table>

Pros and Cons of the Project

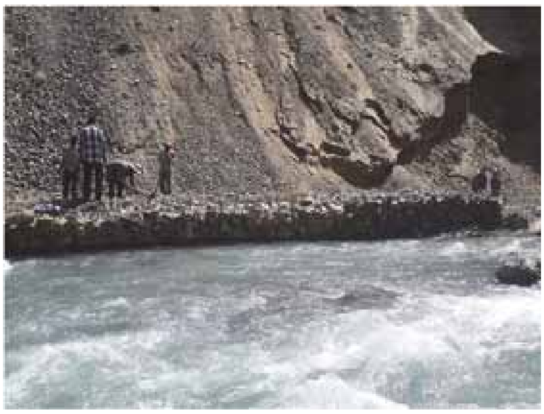
Pros	Cons
{list of advantages} • Community’s high level of contribution • Timely realization of the technical works • Good coordination between all stakeholders	{list of disadvantages} • Challenges with realization of technical works due to the changing level of water in the river

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood mitigation	
	Measure:	Effectiveness
1	Technical infrastructure	High
2	“green” activities (tree planting)	High
3	Community’s awareness about the ways for disaster risk reduction	Very high
4	Cooperation between stakeholders on preparation of joint plan for DRR	Very high
5		
Self-evaluation	The evaluation of the mitigation work was conducted by the team of AMEU (Appraisal Monitoring and Evaluation Unit) where the team was collecting data based on specified criterias and adapted to rural situation methodology.	








Flood Management Guideline Tajikistan

Best Practice:
Climate adaptation through Sustainable forestry

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

Project name	Climate adaptation through Sustainable forestry in Important River Catchment Areas Tajikistan	Organisation	CAMP Tabiat
Location	Tajikistan, GBAO.		
Project Period (start-end)	2016-2019		
Contact	**forest@camptabiat.org, +99293444527, Haqrizo Nurmamadov**		
Beneficiaries / Number of Female	150/23	Stakeholders	Forest users, Forestry of districts, State Forest Enterprises, Community organization, local people, Land committee, Nature protection committee
Budget (Costs)			
Purposes and Background	Adaptation to climate change and biodiversity conservation, as well as to improve the living standards of the local population in the project areas through the restoration of forests, conservation and sustainable use of forests.		
Measures and Methodologies of this project	The state forest agency, forest enterprises and forest users are working together to protect and rehabilitate forests and ensure that they are used sustainably. Progress is being made in the adaptation to climate change and the conservation of biodiversity in the project areas, and living conditions are improving.		
Complementary measures	Fencing the area for protecting reforestation activities from livestock To strengthen the capacities of forest authorities and forest users Give the legal right for the forest users on using of timber and non-timber forest products. Riverbank stabilization with grey infrastructure.		
Replicability	JFM has been successfully introduced and adapted to the needs of six communities with different forest types. The forest agency, forest enterprises and forest users have gained a comprehensive understanding of JFM and are now able to share this approach more widely within and beyond the target areas.		
Sustainability / Maintenance	The forest user group was set up and included under the local management structure-Community organization.		
Expected and/or proven effects	on-site	upstream	downstream
	Income generation Forest rehabilitation Improved access to forest resources		
Activities of Stakeholders	Fencing the area, planting the trees, irrigation the plots, protection from illegal cutting and grazing.		
Challenges	• Communication with the target group, incentives • Ownership and integration of State Forest Agency • Grazing in forest plots • Processing and increase of income from forest products		
Illustrations			
Data and Requirements			
Work plan	First field visit and collection of the base information, site selection, Informational seminar, listing and selection of forest users, distributing the forest plots, mapping of plots, contract with the forest users, elaborating the annual plan and management plan with the forest users, monitoring of the plots.		

Pros and Cons of the Project

Pros	Cons
The degraded forest area was afforested, Additional Income for forest user, Sustainable management and use of the forest resources.	Some people couldn't give the plots due to shortage of the forest plots. Conflict between the forest users and local people.

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood mitigation	
	Measure:	Effectiveness
1	Planting the trees and bushes with the strong roots on the river bank	High
2	Riverbank stabilization with grey infrastructure	Very High

Empowered lives.
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Flood Management Guideline Tajikistan

cesvi

Best Practice:
Disaster risk reduction (DRR) and resilience building in education sector

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

<table>
<tr><td>Project name</td><td colspan="2">Supporting education authorities and stakeholders in mainstreaming disaster risk reduction (DRR) and resilience building in education sector</td><td>Organisation</td><td>CESVI</td></tr>
<tr><td>Location</td><td colspan="4">School #40 Kulob district
School #11Rudaki district</td></tr>
<tr><td>Project Period (start-end)</td><td colspan="4">16/09/2016 – 15/07/2017 (10 months)</td></tr>
<tr><td>Contact</td><td colspan="4">Simone Balboni; mail: cesvi_taj@cesvioverseas.org; tel: +992909551693.</td></tr>
<tr><td>Beneficiaries / Number of Female</td><td colspan="2">Schools: targeted 2 - reached 2
Students: targeted 250 - reached 335 of which 193 boys and 142 girls
Teachers and PTA* members: targeted 20+25 - reached 117 teachers, 19 parents and 4 other school staff
Youth Groups to be established: targeted 2 – reached 2
*PTA = parents and teachers association</td><td>Stakeholders</td><td>UNICEF
School population (students, teachers, PTA members, other staff)
MoES
MoES and CoES authorities both at national and local level
Fire Brigades at local level
SANIIOSP
RCST</td></tr>
<tr><td>Budget (Costs)</td><td colspan="4">TJS 679,033.29</td></tr>
<tr><td>Purposes and Background</td><td colspan="4">Output 1. Successful DRR educational models are piloted for future replication to increase resilience of children and families
Output 2. Capacity of schools in comprehensive disaster risk management is enhanced</td></tr>
<tr><td>Measures and Methodologies of this project</td><td colspan="4">Develop and mainstream DRR/DRM into school curriculum and DRR educational models (UNICEF International expert)
Promotion of participation of children
Study Tour in Armenia
Review, adopt and develop school safety assessment/school-based disaster management methodologies
Capacity building of schools actors in comprehensive disaster risk management through trainings on DRM planning and simulation exercises/drills
Provide regular mentoring support and monitoring visits (include joint monitoring of schools with MoES on implementation of DRR curriculum in pilot schools)
Provision of EPR/safety tools and emergency signage</td></tr>
<tr><td>Complementary measures</td><td colspan="4"></td></tr>
<tr><td>Replicability</td><td colspan="4">The action is easily replicable: a standard approach, methodology, training and other working materials are already developed and ready to be reused.</td></tr>
<tr><td>Sustainability / Maintenance</td><td colspan="4">The sustainability of the action is linked to the level of engagement with beneficiaries achieved during the implementation, as most of activities necessary to keep in place the established DRM system doesn't require economic effort (periodic meetings for DRM groups, trainings for new students and teachers, periodic drills planned and performed by the schools by themselves).
Schools were provided with a tool (SANIIOSP report) that helps them drafting appropriate fund requests to local authorities focusing on the real necessities and problems of the school buildings.
Schools were also provided information on a small grants program supported by the Japanese Government to apply for funds for bigger retrofitting works.
Students were very eager in participating in the activities, spreading information within their families and will become adults aware of DRR/DRM contributing to the creation of better prepared communities, with a long-term result.</td></tr>
<tr><td rowspan="2">Expected and/or proven effects</td><td>on-site</td><td colspan="2">Upstream</td><td>Downstream</td></tr>
<tr><td>Students and teachers are</td><td colspan="2">Local authorities (at district,</td><td>Students (and teachers)</td></tr>
</table>

	aware about potential risks related to disasters, know how to be prepared and how to respond School DRM plans developed, responsibilities and tasks are clear, DRM groups are in place A DRM school curriculum is developed	jamoat and village level) involved and sensitized	spread awareness and knowledge on DRR/DRM in their families and thus in their communities
Activities of Stakeholders	UNICEF established a working group with MoES to provide with results of the project and evaluate the possibility to adopt the developed DRM curriculum at national level UNICEF organized a study tour in Armenia to exchange experiences UNICEF provided an international consultancy to develop the teaching methodology and test the DRM curriculum Local DoES and CoES assisted to conducted trainings and drills and provided their feedback SANIIOSP conducted a visual structural assessment of the schools and provided official reports RCST conducted 1st aid trainings for 1st aid group members		
Challenges	Planning of activities must take in consideration school courses timing (especially in schools with double courses shift) and teachers' and students' school engagement Clearly specify objectives and purposes of the project to avoid wrong expectations among the school population (the project doesn't structurally retrofit school buildings)		
Illustrations			
Data and Requirements	Data used: Statistics of pilot schools population Existing laws and norms on school safety standards Existing training and working materials on DRR/DRM Data produced: Manual on DRM planning for schools Training materials on DRM planning for schools Teaching methodology and materials for DRR school curriculum Training materials for Youth Groups Emergency maps, emergency signage, EPR and safety tools		
Work plan	Collection, review and selection of existing training materials, laws and norms in force Meetings with stakeholders Drafting of the manual on school DRM planning Assessments of schools (available capacities and means, exposure to risks and disasters) Trainings on DRM planning to test the manual Specific trainings for DRM groups established (SOPs, 1st aid, etc) Trainings for all the teachers Performance of simulation exercises/drills Development of a DRM curriculum and teaching methodology and its test with teachers and students Specific meetings and trainings to establish Youth Groups Theatre performances Development of emergency maps and installation of emergency signage and EPR tools Performance of public drills for representatives from all the schools and local authorities at district level		

Pros and Cons of the Project

Pros	Cons
School population is very willing and eager in participate in activities Beneficiaries are aware on DRR School of intervention are safer places thanks to instructions and tools provided	Turnover of teachers and students during the project implementation Short term duration doesn't allow proper follow up and monitoring of activities performed by schools by themselves after the end of the project

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood mitigation	
	Measure:	Effectiveness
1	Creation of a SOP adopted by the school to be followed in case of flood	High
2	Performance of drills simulating emergency situations	Very High
3	Provision of bags to be filled in with sand and other working tools to be used to prevent flood in school building	Very High
4	Identification of safe heaven	High
5	Identification of risks related to flood within the school premises and in the surroundings	High
Self-evaluation	Thanks to the trainings on DRM planning and practical simulation exercises, now the school population is aware of risks, consequences and knows how to respond in case of emergency	

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Flood Management Guideline Tajikistan

Best Practice:
Reduction of Land Degradation and Prevention of Desertification through the Development of Natural Resources Management

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

<table>
<tr><td>Project name</td><td>Reduction of Land Degradation and Prevention of Desertification through the Development of Natural Resources Management inTajikistan, financed by European Union- (DCI-ENV/2010/220-558)</td><td>Organisation</td><td>CESVI</td></tr>
<tr><td>Location</td><td colspan="3">7 Watershed in Kovaling District and 11 Watershed in Termumalik District.
Cesvi was operating mainly in Kovaling District, in 18 target villages.</td></tr>
<tr><td>Project Period (start-end)</td><td colspan="3">November 2010 - November 2013:</td></tr>
<tr><td>Contact</td><td colspan="3">Head of Mission: FIlippo Crivellaro; mail: filippocrivellaro@cesvioverseas.org;
tel: +992938042090</td></tr>
<tr><td>Beneficiaries / Number of Female</td><td>3721 person, approx..30% women
(Civil Society representatives, Extension Service Providers, Farming households)</td><td>Stakeholders</td><td>- Local Hukumats (and related departments: Agricultural, Economic, Ecology), Vodkhoz of Kovaling district, Kovaling district forestry entity; Emergency Situation Department; Education Departments; Jamoats within target Watershed Area;
- Community Based Organizations;
- Extension service providers (ATAK);
- Local and International NGOs (UNDP; Bunyodimilly; MISSION EST;DFID; ACTED; OXFAM; GIZ; MSDSP;Geres; SDC; ADB; WFP).</td></tr>
<tr><td>Budget (Costs)</td><td colspan="3"></td></tr>
<tr><td>Purposes and Background</td><td colspan="3">The combination of climate changes effects with past degradation of forest and land use changes have affected Kovaling watersheds in term of increase flood dangerous events.
From an hydrological point of view, the results of these changes are higher values of peak discharge and lower lag time associated to less infiltration of water in the soil. In the same time, from a geological vision, these changes are affecting the slope stability of the medium and high steep land in the target district.</td></tr>
<tr><td>Measures and Methodologies of this project</td><td colspan="3">As Disaster Risk Reduction the field intervention were based on Soil Bio-engineering techniques:
- Living Fascines for slope stability
- Living Fascines for drainage
- Wattling
-Brush layering
- Pile wall
- Palisides
- Gabions for river bank protection, erosion control & land slide stabilization and erosion prevention.
These kind of techniques are oriented to prevent erosion, slope instability, and floods in punctual site. These interventions are done with plants and the effects are not only sustainable but also increasing with the time.

The project has been promoting awareness and knowledge on erosion, desertification prevention and natural resources management, reduction of land degradation through the application of sustainable soil management techniques; energy efficiency techniques, conservation and efficient use of water resources.</td></tr>
<tr><td>Complementary measures</td><td colspan="3">2 Natural Resources Management Boards have been established and 18 NRM watershed plans have been implemented , working in continuous contact with local authorizes and civil society organizations;

The overall project was performing several activities related with environment and population livelihood. Activities were related to capacity building for government staff and technical specialist on NRM and desertification, exchange of information on water management and bio-engineering;
Other themes of the project are related to agriculture, irrigation system and technology for save water, agroforestry, energy efficiency and pasture management.</td></tr>
</table>

<table>
<tr><td>Replicability</td><td colspan="3">Soil bio-engineering intervention could be very low cost intervention if done with local materials: main materials needed are stones, sand and seedlings that can be easily found close the location of the intervention.</td></tr>
<tr><td>Sustainability / Maintenance</td><td colspan="3">The strong process of awareness campaign knowledge on erosion, desertification prevention and natural resources management, reduction of land degradation through the application of sustainable soil management techniques was conducted in order to develop skill in population about long period management of the intervention done.</td></tr>
<tr><td rowspan="2">Expected and/or proven effects</td><td>on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td>People improve their practices and apply SLM and soil bio-engineering techniques</td><td>Increased permeability of the soil
Reduction of sediments in water flows
Reduction of gully erosion
Slope stabilization</td><td>Runoff decreased
Decreased sediments inside the water</td></tr>
<tr><td>Activities of Stakeholders</td><td colspan="3">- Population of the villages was involved in construction of soil Bio-engineering interventions
- Natural Resource Management Boards, involving all district level stakeholders were assessing existing resources, risks, planning and implementing necessary rehabilitation and prevention measures
- Extension service providers were building capacities of the target population in SLM and soil bio-engineering techniques</td></tr>
<tr><td>Challenges</td><td colspan="3">The watershed approach implies involvement of a wide variety of stakeholders with different priorities that are sometimes challenging to coordinate.
The rehabilitation sites are usually far from the settlements, therefore a strong community mobilization is vital to ensure participation of the community members in practical on-site rehabilitation and prevention works
The promoted techniques must be low-cost and based on locally available materials</td></tr>
</table>

Illustrations	 FIgure 1. Participation of population to contribute to find critical risky sites.  Figure 2. Slope stabilization interventions down and up to the main road.

	 Figure 3. River bank/Slope protection.  Figure 4. Palisade for gully protection
Data and Requirements	Situations of intervention were evaluated by CESVI engineers, geologists and agronomists. During the period of the project some guidelines leaflets and manuals were developed for improve the communication with local population and the collaboration with others organizations. All the soil bio-engineering techniques promoted by the project are based on use of locally available material. Except for the gabions, there special double twisted net is required.
Work plan	The soil bio-engineering techniques, given their specificity, provide most effect if applied throughout autumn-spring period.

Pros and Cons of the Project

Pros	Cons
Very effective intervention with low budget and local material used Environmental friendly interventions High autonomous replicability of the intervention for local inhabitants Involvement of population for construction steps	

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood mitigation	
	Measure:	Effectiveness
1	Live palisides	Very High
2	Brush layering	Very High
3	Contour lines fascines	Very High
4	Drainage fascines	High
5	Live wattling	Very High
6	Vegetated gabions gravity retaining wall	Very High
7	Check dams	Very High
Self-evaluation	The evaluation is based on practical efficient results achieved by the project and reported/confirmed by the target beneficiaries and local authorities.	

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Flood Management Guideline Tajikistan

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Best Practice:
Watershed management: Ecosystem-based adaptation to Climate Change

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

<table>
<tr><td>Project name</td><td>Regional project on Ecosystem-based adaptation to Climate Change in the Mountainous Regions of Central Asia</td><td>Organisation</td><td>GIZ

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH</td></tr>
<tr><td>Location</td><td colspan="3">Tajikistan: Gorno-Badakhshan Autonomous Region, Rushon District, Siponj and Darjomj (Bartang)
Kyrgyzstan
Kazakhstan</td></tr>
<tr><td>Project Period (start-end)</td><td colspan="3">June 2015- May 2019</td></tr>
<tr><td>Contact</td><td colspan="3">Claudia Haller, Country Coordinator. Email: claudia.haller@giz.de
Marhabo Yodalieva, Project Advisor. Email: marhabo.yodalieva@giz.de</td></tr>
<tr><td>Beneficiaries / Number of Female</td><td>Primary beneficiaries are communities in the pilot watersheds
Total in TJK: 456 /Male: 237/Female: 219</td><td>Stakeholders</td><td>TJK:
Political project partner:
Committee of Environmental Protection under the RT
Other implementing partners:
- Mountain Societies Research Centre, the University of Central Asia (UCA),
- Michael Succow Foundation (MSS),
- German Research Centre for Earth Sciences (GFZ),
- Consultancy Company UNIQUE-Forestry & Land Use GmbH,
- Public Foundation CAMP Tabiat
- Center for Climate Systems Research (CCSR),
- World Wildlife Fund US.</td></tr>
<tr><td>Budget (Costs)</td><td colspan="3"></td></tr>
<tr><td>Purposes and Background</td><td colspan="3">“Ecosystem-based Adaptation to Climate Change in High Mountainous Regions of Central Asia” is a regional project and is carried out in three countries: Tajikistan, Kyrgyzstan and Kazakhstan. In Tajikistan, the project is implemented in Rushan district, Bartang valley in Siponj and Darjomj villages. The project is commissioned by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) of Germany, funded by the International Climate Initiative (ICI) and implemented by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH).
The ecosystems of the high mountain regions of Central Asia are rich in biodiversity and provide essential services, such as the regulation and provision of water for the population of the entire region. However, inappropriate land management of these fragile ecosystems combined with their vulnerability to climate change threats (e.g. melting glaciers, changes in water flow regime, droughts) decrease their resilience and thus, the ability to provide continued services to people.
The principal aim of the project is to develop a methodology and to ensure the availability of innovative and cost-effective interventions and strategies for implementing the ecosystem-based approach for climate change adaptation at the level of the state policy, strategic planning of countries and the relevant international development partners.
The pilot area in Tajikistan, Bartang valley, is located in Rushan district and is one of the remotest and the most hard-to-reach valleys in GBAO, with the harshest climatic conditions. It is 250 km far from GBAO administrative center Khorog and 180km far from Rushan District Center. The area is isolated and impoverished with poor infrastructure and livelihoods. Two pilot villages, Siponj and Darjomj, where it is planned to realize the Ecosystem based Adaptation to Climate Change in High Mountainous Regions of Central Asia project are one of the most vulnerable villages due to lack of agricultural lands and water shortages. Both villages are prone to water erosion. In the case of Siponj, the most affected area by erosion and flood is land along the River Bartang, especially during high water level in summer.</td></tr>
<tr><td>Measures and</td><td colspan="3">A BMUB (Federal Ministry for the Environment, Nature Protection, Building and Nuclear</td></tr>
</table>

<table>
<tr><td>Methodologies of this project</td><td colspan="3">Safety) IKI (International Climate Initiative) funded and GIZ-led (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH) consortium explores the use of an ecosystem-based adaptation approach to help people adapt to the adverse impacts of climate change. It aims to strengthen the provision of ecosystem services and thereby enhance the livelihoods of the population depending on them. Although the application of potential ecosystem-based measures in Central Asia is not new, typically relevant climate risk information on people and ecosystems is not considered and thus, has a higher risk of introducing maladaptive interventions. This project used a modified form of the Open Standards for the Practice of Conservation to systematically develop and test an integrated planning framework that used climate risk information to identify key vulnerabilities of people and ecosystem services under several plausible climate change scenarios and developed potential adaptation options.

The framework's guidance can contribute to a paradigm shift: moving away from business as usual approaches to climate informed adaptation processes. More information on the developed framework can be found on the Panorama Solutions Platform under http://www.panorama.solutions/en/solution/open-standards-based-framework-planning-and-implementing-ecosystem-based-adaptation and soon published as book chapter in the following book http://www.springer.com/series/8740 .

The modified, climate-informed EbA framework uses scientific projections about climate change in a participatory scenario-planning approach for adaptation with the community stakeholders. The steps of the "Climate-informed Open Standards Ecosystem-based Adaptation" framework that emerged are:
1. Define the social, thematic and geographic scope of the EbA planning process
2. Understand current and desired state of ecosystems1
3. Analyse conventional vulnerabilities of people and ecosystems (those not related to climate change)
4. Identify climate change-related threats
5. Develop a general model of the socioeconomic-ecological system (including climate impacts)
6. Re-evaluate project objectives
7. Identify and select strategies measures based on general model
8. Implement and monitor selected adaptation measures, learn, adapt

As an outcome an overall adaptation strategy together with local communities is elaborated consisting of different adaptation measures.</td></tr>
<tr><td>Complementary measures</td><td colspan="3">The EbA planning framework is used to define an overall adaptation strategy for local communities in high mountainous regions in CA with a clear priority (but not limited to) measures using ecosystems and their goods and services. These measures are currently implemented.
In TJK this comprises the following ecosystem-based measures:
Siponj: Re/afforestation in river banks, re/afforestation in landslide areas, improved pasture management through trainings and the setup of a Pasture User Union,
Darjomj: Re/afforestation in landslide areas, re/afforestation in river banks</td></tr>
<tr><td>Replicability</td><td colspan="3">Developed methodology is replicated in the 2 villages of Voru Jamoat: Ghazza and Voru villages in Penjikent district. Further uptaking is planned in cooperation with other development partners.
Capacity development of national experts: A 3 module based training of trainers for facilitators for the implementation of the EbA planning framework and the facilitation in the communities has been conducted. 15 facilitators can be approached for further replication.</td></tr>
<tr><td>Sustainability / Maintenance</td><td colspan="3">It is planned that the developed EbA strategies are systematically integrated into local development plans and the organisations in charge have the mandate and capacities necessary to implement and monitor the, then climate change informed, development plans. Combining the efforts of capacity building, institutionalizing of the EbA approach and making available and accessible scientific information to local development planners, paves the way to come from a project to a process, because adaptation is a process and not a project.</td></tr>
<tr><td rowspan="2">Expected and/or proven effects</td><td>on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td>-The participatory application of the framework provided clarity to local stakeholders on the</td><td>Expected: As EbA measure afforestation on the slopes was identified. This is directed to prevent from soil</td><td>Expected: Better access to water for irrigational and drinking
Expected: Protection of river</td></tr>
</table>

	potential conventional and climate change related threats as well as adaptive capacities of local communities and ecosystems towards current and long-term climate change trends. -It allowed to identify the most promising adaptation options robust to different climate scenarios, primarily focusing on improved pasture and forest management as well as water conservation measures. -Additionally, households have been introduced to alternative income opportunities, such as tourism and fruit processing. -The level of knowledge of local authorities, specialists of public sector institutions, and the local population about climate change issues and the need to adapt with nature-based solutions has been improved through communication and environmental education. -The capacity of village institutions has been strengthened to flexibly plan the management of natural resources and make decisions on conservation and restoration of biodiversity. -Local authorities and village institutions are now familiar with the features of decision-making under a changing climate (scenario planning). -These joint measures will enable residents of high mountainous regions to better adapt to climate change.	erosion and protect villages from avalanches and mudflow	bank and close to river plants from flooding.
Activities of Stakeholders			
Challenge	- Discuss climate information with community: There is the danger that climate change can be misunderstood as the source of all environmental problems. Therefore, this process must be facilitated with deliberate consideration of this situation.		
Illustrations			
Data and Requirements	- A viability assessment for size, landscape context and conditions of ecosystems is conducted; - Climate projections downscaled for the pilot areas, which were derived from a suite of 21 general circulation models (GCMs); - Information about predominant livelihood strategies is used to locally adapt seasonal and annual climate projections for the near future.		

Work plan	A full guidance for community facilitation guidance incl. work plan of the EbA planning framework implementation will soon be elaborated and can be shared.

Pros and Cons of the Project

Pros	Cons
- Practitioners often select EbA measures based on conservation priorities and do not consider climate risk affecting ecosystems meant to help people adapt to climate change. This is tackled by the EbA planning framework. - Vulnerability Assessment included in the planning framework (steps 1-5) directly linked to the ecosystems, the services they provide to the people and their livelihoods strategies and not stand alone. - The climate-informed EbA framework proved to be a useful framework for the development and implementation of an EbA strategy in high-mountainous regions of Central Asia. In particular the consistent logical chain from climate stimuli, provided by locally adapted climate projections, to the adaptation measure identified, is considered a strength of the approach, clearly distinguishing it from 'business-as-usual-adaptation'. - Furthermore, the framework is designed to be applied in a participatory manner, involving the local population in the whole process. This is considered a particular advantage for creating ownership of the adaptation process by those that need to adapt to the adverse effects of climate change on the ground.	

Effectiveness and Evaluation

Self-evaluation	Too early to evaluate the result, since the implementation phase is ongoing. Currently, a comparison analysis is elaborated comparing the integrated EbA planning framework that uses climate risk information to identify key vulnerabilities of people and ecosystem services with other planning frameworks like participatory rural appraisals. Results can be shared at a later stage.







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Flood Management Guideline Tajikistan

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

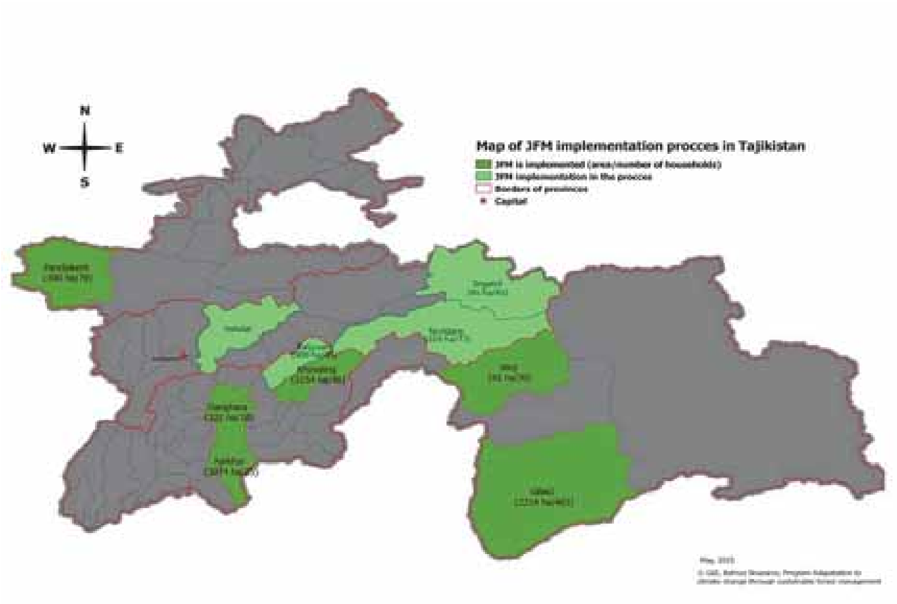
Best Practice: Watershed management – Forest management

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

<table>
<tr><td>Project name</td><td colspan="2">a) Regional Programme for Sustainable and Climate Sensitive Land Use for Economic Development in Central Asia (KAZ, KGZ, TJK, TKM, UZB) and its predecessor projects
b) Project on Adaptation to climate change through sustainable forest management (TJK)
c) Regional project Ecosystem-based adaptation to climate change in high mountainous regions of Central Asia (KAZ, KGZ, TJK)</td><td>Organisation</td><td>GIZ

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH</td></tr>
<tr><td>Location</td><td colspan="4">Farkhor, Khovaling, GBAO (incl. Vanj), Penjikent, Dangara, Jirgatol, Tavildarra, Baldjuan</td></tr>
<tr><td>Project Period (start-end)</td><td colspan="4">Parts of ongoing programmes / projects starting from 2006 till now.</td></tr>
<tr><td>Contact</td><td colspan="4">Stéphane Henriod, Advisor. Email: stephane.henriod@giz.de
Nicole Pfefferle, Adviser. Email: nicole.pfefferle@giz.de
Alsam Munakov, Adviser. Email aslam.munakov@giz.de</td></tr>
<tr><td>Beneficiaries / Number of Female</td><td>Forest users: 1016
(64 female forest users)</td><td>Stakeholders</td><td colspan="2">Forest users, forest user groups, local state forest enterprises</td></tr>
<tr><td>Budget (Costs)</td><td colspan="4">Separate costs for implementing the measure have not been analysed.</td></tr>
<tr><td>Purposes and Background</td><td colspan="4">Forests provide essential ecosystem services such as regulating the water balance to reduce risk from floods and droughts. Restoration and management of forests is therefore of vital importance in the process of adapting to climate change and disaster risk reduction. Afforestation and reforestation are often long lasting and economically viable methods for local communities to prevent or reduce the impact of various hazards, such as soil erosion, landslides, floods, and droughts.
In Tajikistan where climate change contributes to the increase in the frequency and intensity of extreme events and tree cover has been reduced due to deforestation during the civil war, responsible forest management can make a significant contribution to disaster risk management. Simple forest management techniques can contribute to comprehensive disaster risk reduction strategies. Additionally, forests play a key role in the lives of Tajikistan's rural population. Firewood, fodder, medicinal plants, fruit and nuts can be sold locally at a profit and represent an important source of income.</td></tr>
<tr><td>Measures and Methodologies of this project</td><td colspan="4">JFM - Joint forest management (JFM) essentially involves leasing forest land to local people over the long term. The tenants rehabilitate and use their forest plots according to management plans. Local forest enterprises advise them on forest rehabilitation. The project sets out to demonstrate the applicability and impact of joint forest management in different forest ecosystems, paving the way for wider use of the approach throughout the country.
Forest cover as part of an EcoDRR strategy can bring the following benefits:
<table>
<tr><th>Benefits of forest cover</th><th colspan="2">Forest management techniques</th></tr>
<tr><td>1. Stabilization of soil
2. Preservation of soil moisture
3. Water regulation and flood protection
4. Preservation of nutrients
5. Climate change mitigation</td><td>• Increase of forest cover through afforestation and reforestation
• Sustainable use of wood
• Shrub laying
• Drip-irrigation (e.g. with plastic bottles)</td><td>• Protection of tree seedlings
• Avoid grazing on forest areas
• Live fence (palisade)
• Conservation of forest biodiversity
• Local and climate resilient tree species</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>Complementary measures</td><td colspan="3">Climate change adaptation and disaster risk reduction strategies should always be implemented as a component of an overall adaptation strategy for a watershed. The JFM approach and the forest management for DRR techniques can for example be part of the measures identified within the EbA approach (see other GIZ input).
“[e]cosystem-based adaptation uses the range of opportunities for the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change” - Convention on Biological Diversity (CBD)</td></tr>
<tr><td>Replicability</td><td colspan="3">JFM is very successful and popular among the forest users. Crucial for its success are the long term land use rights that the contract with the local state forest enterprise (SFE) provides.
The JFM approach has been successfully introduced in Tajikistan and is reflected in current laws and by-laws. Consequently, JFM can be applied in all districts of Tajikistan.
Forest management as DRR strategy, is due to its cost effectiveness easily replicable. However, in the short term some grey infrastructure might be needed if the risk is very prominent.</td></tr>
<tr><td>Sustainability / Maintenance</td><td colspan="3">JFM-forest users are agreeing on an annual basis with the SFE which activities should be done during the year. As the income of the forest plot is shared between forest users and SFE, the forest users are mostly taking very well care of their land.
According to the Forest Code (2011, Article 45-49) and the provisions on Joint Forest Management, a JFM contract can be issued for 20 years. Long-term management and annual activity plans, indicating the forest management activities that need to be undertaken by the forest user and the State Forestry Enterprise (SFE), as well as the amount of forest products that can be sustainably taken from the forest, are mandatory elements under the JFM contract.
DRR – Forest management can serve as EcoDRR strategy which is long lasting and requires minimal maintenance by the stakeholders.</td></tr>
<tr><td rowspan="2">Expected and/or proven effects</td><td>on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td>1. Stabilization of soil
2. Preservation of soil moisture
3. Water regulation and flood protection
4. Preservation of nutrients
5. Climate change mitigation</td><td>-</td><td>- water regulation and flood protection</td></tr>
<tr><td>Activities of Stakeholders</td><td colspan="3">Stakeholders (forest users) usually support the activities with in-kind contributions</td></tr>
<tr><td>Challenges</td><td colspan="3">- Grazing on forest plots (especially where seedlings are planned)
- Financing of seedlings, fences, etc.</td></tr>
</table>

Illustrations	
Data and Requirements	See JFM manual.
Work plan	Listed are approaches within projects, therefore a description of the whole work plan would be too detailed, more information can be found in the JFM manual.

Pros and Cons of the Project

Pros	Cons
- Long term involvement of local people through long term leasing contracts of forest land - As a result of the JFM approach, forests are rehabilitated to their natural composition and the proportion of local and climate resilient tree species will increase.	

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood mitigation	
	Measure:	Effectiveness
1	Increased forest cover	After full maturity of plants: Erosion: very high Flood reduction: medium to high
Self-evaluation	In the beginning the effectiveness is rather low, however, as soon as the trees have grown to their full size, increased forest cover can be a very effective flood management tool, depending on the flood type.	









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Flood Management Guideline Tajikistan

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Best Practice:
Gully control and River training: Check dams, gully rehabilitation, gabion walls

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

Project name	Support to Regional Cooperation for Disaster Response and Risk Reduction Programe in Central Asia	Organisation	GIZ
Location	Sughd oblast, Devashtich district, community Kurush. 40,07,44,90 N 69,14,40,40 E		
Project Period (start-end)	Jan 2012 – December 2014		
Contact	**Nodir Muhidinov, +992 987330379, nodir.muhidinov@giz.de**		
Beneficiaries / Number of Female	Approx. 20 to 30 households	Stakeholders	
Budget (Costs)			
Purposes and Background	For years Hoji Numonjon Aslonov, a resident of Kurush village in Spitamen district, has seen his land washed away by debris flows originating in the mountains of neighboring Kyrgyzstan. Due to extreme rainfall events and unusually high temperatures in summer the risk was further exacerbated in recent years. His and his neighbors' houses had already become under direct threat when CoES together with GIZ supported the local population with technical advice and construction materials to build a protection wall for their houses.		
Measures and Methodologies of this project	Within approximately 30 days the community members, led by Hoji Numonjon Aslonov, constructed a 300 meters-long gabion protection wall. In addition the community was provided with willow seedlings which they planted along the wall, creating additional long term protection which grows stronger over time. The protection wall has already been withstanding heavy mudflows several times since, showing its strength and effectiveness.		
Complementary measures			
Replicability			
Sustainability / Maintenance	Hoji Numonjon Aslonov takes good care of the trees, and by now they have already grown to a respectable size and prevent the foundation of the wall from being washed out. Feeling safe and secure again, he even started to use the area behind the wall by planting fruit trees for an additional contribution to his livelihoods.		








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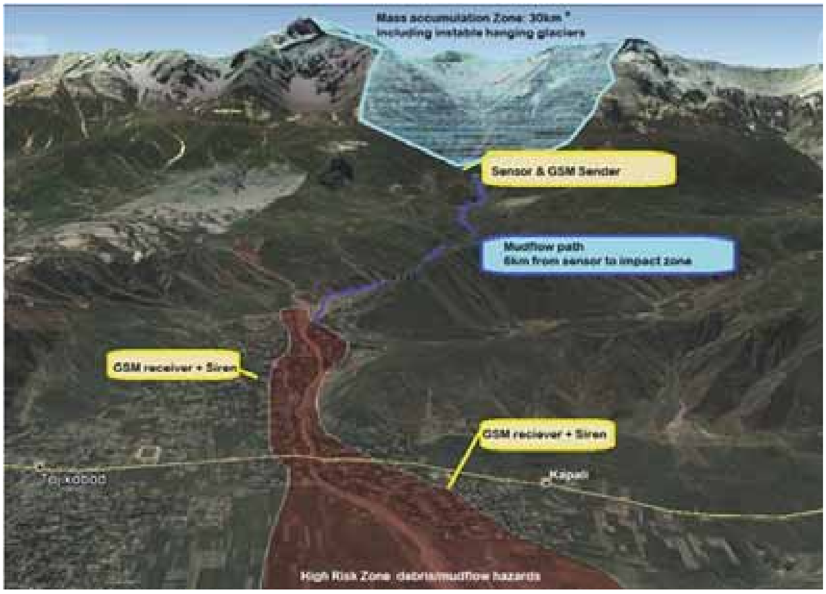
Resilient nations.

Flood Management Guideline Tajikistan



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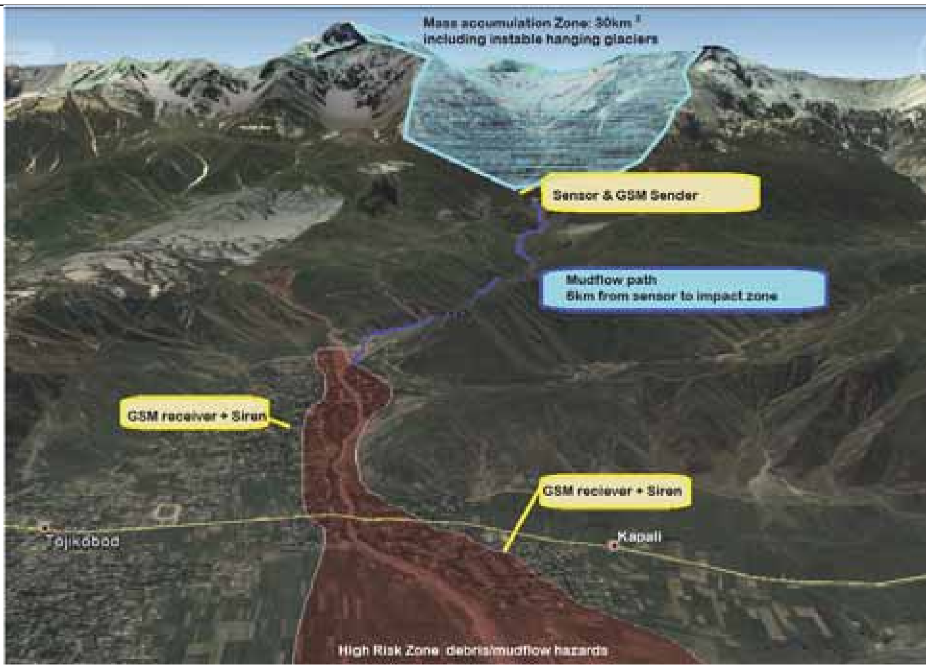
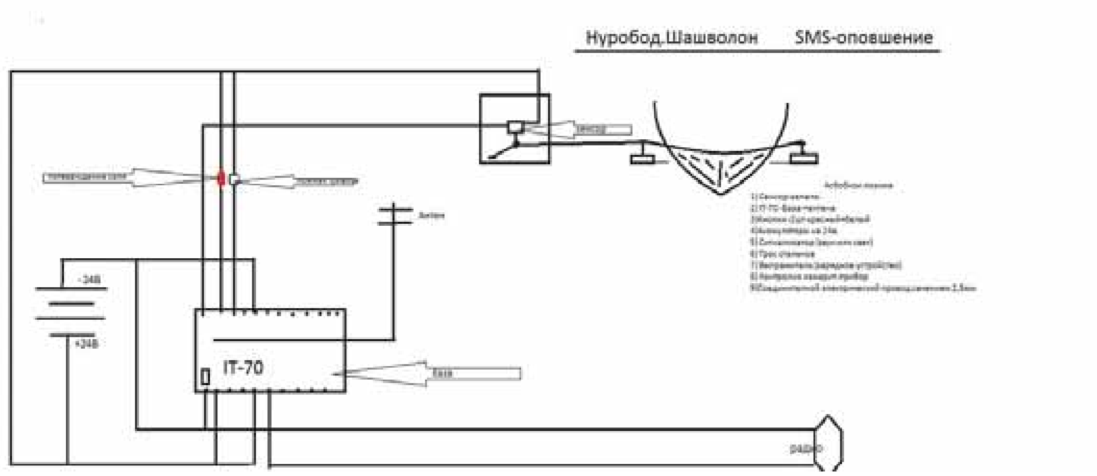
Best Practice:
Geo-hazard capacity building and monitoring;
Early Warning System

Document	Flood Management Guideline Tajikistan
Date	06.02.2018

<table>
<tr><td>Project name</td><td>SDC/FOCUS project:
“Remote Geo-hazard Capacity building and monitoring (TJK 1075-11)
DIPECHO projects:
DIPECHO 8: “A Watershed - Based Approach To Integrated Disaster Risk Management” (TJK 1087-14)
DIPECHO 9: “Enhancing Integrated Institutional Disaster Risk Management and Community Resilience in Vulnerable Rural and Peri-Urban Areas of Rasht Valley” (TJK 1099-16)
DIPECHO 10: “Streamlining collaborative institutional and community disaster risk management, capacities and resilience in vulnerable rural and peri-urban areas of Rasht Valley” (TJK 1104-17)</td><td>Organisation</td><td>Deutsche Welthungerhilfe e.V.</td></tr>
<tr><td>Location</td><td colspan="3">Location of Early Warning Systems installed.
Zeravshan and Rasht valley:
<table>
<tr><th>Location</th><th>Type of EWS</th><th colspan="2">Coordinates</th></tr>
<tr><td>Ayni district, Urmetan jamoat, Vashan village.</td><td>Siren</td><td>N 39.3491°</td><td>E68.0569°</td></tr>
<tr><td>Penjikent district, Rudaki jamoat, Panjrud village.</td><td>SMS + Siren</td><td>N 39°24′5″</td><td>E 68°15′50″</td></tr>
<tr><td>Nurobod district.jamoat Komsomolobod. Shahvolon vilage</td><td>SMS + Siren</td><td>N395430.58</td><td>E695610.38</td></tr>
<tr><td>Rasht jamoat. Rahimnzoda \. Ruvoz vilage</td><td>Siren</td><td>N390641.84</td><td>E701259.85</td></tr>
<tr><td>Rasht.N. Maxsum. Sharisabs vil.</td><td>Siren</td><td>N390104.3</td><td>E701504.3</td></tr>
<tr><td>Rasht. N. Maxsum. Shul village</td><td>SMS + Siren</td><td>N390159.5</td><td>E701803.1</td></tr>
<tr><td>Rasht, Hoit jamoat, Hoit village</td><td>Siren</td><td>N391207.5</td><td>E705235.9</td></tr>
<tr><td>Tojikobod jamoat, Langari SHoh, Mazori bolo village</td><td>SMS + Siren</td><td>N390231.25</td><td>E703748.64</td></tr>
<tr><td>Laksh, Jirgatol jamoat, Maidonterak village.</td><td>Siren</td><td>N391333.7</td><td>E710922.0</td></tr>
</table></td></tr>
<tr><td>Project Period
(start-end)</td><td colspan="3">SDC/FOCUS: April 2011-March 2013
DIPECHO 8:May 2014 – September 2015
DIPECHO 9: February 2016 – March 2017
DIPECHO 10: May 2017 – July 2018</td></tr>
<tr><td>Contact</td><td colspan="3">1. Abdujabbor Hakimov, Director of PO “Innovation and Participation for Development” for Zeravshan valley, e- mail: ngo_ipd@mail.ru
2. Dominik Zwicky, Technical Adviser WHH, e -mail: Dominik.Zwicky@welthungerhilfe.de
3. Valijon Muzafarov, Technical expert/Meteorologist in Rasht, phone:988509387</td></tr>
<tr><td>Beneficiaries / Number of Female</td><td></td><td>Stakeholders</td><td>Committee of Emergency situation (CoES)
Local Hukumats,
Partner organizations; Mercy Corps.</td></tr>
<tr><td>Budget (Costs)</td><td colspan="3">Estimation price of EWS installation - 4,500 Euro per one system for installation (1,500 Euro –IT 70 transmitter; 3,000 Euro-construction materials and accessories)</td></tr>
<tr><td>Purposes and</td><td colspan="3">Tajikistan is prone to natural disasters, e.g. floods, earthquakes, landslides, mudflows, avalanches,</td></tr>
</table>

Background	droughts, and heavy snowfalls. Its mountainous terrain, coupled with the specific geological and hydrological conditions predispose to floods and mudflows during rainy session and intensive snow melting mostly provoked by climate change. During rainy session and intensive snow melting, small mountain streams frequently transforming to threatening mud or debris flows destroying infrastructures (households, bridges, roads) and frequently causing life casualties. The EWS envisages to saving lives and some movable assets but does not prevent damage to infrastructures and fields. The EWS installed are in high risk zones with different levels of vulnerability, particularly in remote mountain villages. The majority of the risks in Rasht and Zeravshan Valley are of the high frequency/middle impact natural hazard type. Mudflows, landslides and flash floods are the most prominent, followed by earthquakes, avalanches, and rock falls. Such events take place every year on multiple occasions. Excessive rains in July 2015 produced two severe mudflows Mazori Bolo and the peri-urban center of Rasht District (Gharm), resulting in 1 fatality, over 50 houses destroyed, 1,500 displaced, hundreds of dead livestock and more than 20 hectares of destroyed farmland. In addition, vital public infrastructure such as roads, bridges, electricity lines and water pipes were damaged. Natural disasters like these mudflows further negatively affected the coping mechanisms of these remote communities and also demonstrated the sustained need for DRR and DRM interventions in the target area. Whenever a disaster strikes, poor communities suffer the most - especially those far from urban centres. The early warning system (EWS) is one of the option timely to inform population for upcoming disasters after hard rainfall or intensive melting of glaciers causing to catastrophic floods/mudflow. The system recommended to install over the mountain watershed upper about 1 km from last household of settlement in order to have time to evacuate population to save place.
Measures and Methodologies of this project	Main Features • Automated early warning against mudflows, debris flows and other localized, rapid-onset hazards in areas where technical mitigation is not possible. • Warning of population and first responders through sirens, SMS messages and pre-recorded voice-calls on registered mobile phones. • Designed to give a 10-40min warning time in order to save lives and movable assets. • Combined with establishment and training of Disaster Management Groups in villages at risk. • Combined with training of national Committee of Emergency Situations to plan, install, operate and maintain similar systems. General Layout Two types of EWS installed in the project target areas. These two types included a village-based alert systems (bells, sirens) and GSM-based system implemented by WHH under DIPECHO cycles. As a GSM-based system requires the availability of a mobile connection, in some of the newly selected watersheds this connection might be an issue and thus necessitate the installation of a simplified EWS that would still provide warning to the population. Meanwhile, in other watersheds where the mobile connectivity is secure, a real-time hazard monitoring and warning system installed. It provide long-range warnings to populations at risk from flash floods and mud- or debris-flows. Depending on the location and type of hazard monitored, the warning time for these systems is between 10 minutes and two hours. In case of a disaster, the entire population living in the impact zone will immediately receive warning messages via SMS. In addition, people with key functions (police, response groups, village leaders, CoES) will receive automated calls (voice) with instructions what to do. Technically, the GSM based early warning systems consist of three elements: a) A real time monitoring system (sensor) at the source of the hazard. In the case of a flash-flood warning system, this electro-mechanical sensor would be placed in a suitable location several kilometers above the risk zone. It triggers an alarm if a predefined water level is exceeded. The sensor is protected from animals, climatic influence and vandalism. b) A GSM transmitter to forward the alarm via SMS and pre-recorded voice messages to alarm groups one (first level responders like CoES, emergency teams, authorities, Megafon duty etc) and two (the population at large). The transmitter (the size of a mobile phone) is set in a safe location close to the sensor. It is solar powered, with a 100 day back-up battery to guarantee 24/7 operation all year round. Automated weekly status reports to alarm group 1 ensure that the system is functional at all times. c) Alert systems (bells, sirens) in the communities at risk, where these do not already exist. These sound alarms serve as a back-up to alert people which may have overlooked a warning SMS. They may be triggered automatically or manually by the leaders of response teams.

<table>
<tr><td></td><td colspan="3">

Location profile of Kapali EWS, Rasht Valley, Tajikistan</td></tr>
<tr><td>Complementary measures</td><td colspan="3">The system requires building complementary infrastructure like small room to keep in safe the EWS transformer (IT70) and other accessories (battery, metal boxes, wires). It is also important to train local responsible for operating of the system</td></tr>
<tr><td>Replicability</td><td colspan="3">Easily possibly</td></tr>
<tr><td>Sustainability / Maintenance</td><td colspan="3">The partners such as the Tajik Committee for Emergency Situations (CoES) and a national telecommunications company (Megafon,) will continue to pursue innovative approaches automated EWS that has the potential to protect thousands of people living in vulnerable watersheds. For this aim in order to transfer knowledge and skills of how to build and maintain GSM alarm systems WHH provided trainings to relevant staff. Further WHH has handed over ceremony of installed/maintained EWS to local authorities (CoES, Hukumat, community leaders) for taking over the ownership and future maintenance.</td></tr>
<tr><td rowspan="2">Expected and/or proven effects</td><td>on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Activities of Stakeholders</td><td colspan="3"></td></tr>
<tr><td>Challenges</td><td colspan="3">- Ensuring responsibility of CoES and community members for further maintenance and proper operation.
- Need for continued support of mobile communication providers to keep activate sim cards</td></tr>
<tr><td>Illustrations</td><td colspan="3">

Graph: Scheme of SMS+siren base EWS function in Shahvolon village, Nurobod district.</td></tr>
</table>

Picture: Mechanical Sensor for Mud/Debris flows. If a mud or debris flow hits the sensor construction, the pull switch is activated.

Picture: The steel ropes from sensor connected to a pull switch.

Picture: The signal thorough connection wire reach programmable GSM Alert Devicce Eviateg IT 70

Picture: Programmable GSM Alert Devicce Eviateg IT 70 installed in safety room.

Picture: IT 70 and supporting Accessoires put in box.

Picture: Programmable GSM Alert Devicce Eviateg IT 70

Multifunctional Alert Modem with:

- Quadband GSM modem
- 4 digital, 4 analog, 2 temperature inputs
- 2 programmable relais outputs to switch sirens etc.
- Integrated back-up battery recharging unit
- Internal storage for 256 telephone numbers
- Internal storage for 20 text messages
- Internal storage for prerecorded voice messages
- Email, GSM, ISDN and VDSN2465 protocols

Picture: Installed IT 70 with alarm reaction buttons

<table>
<tr><td></td><td>
Electronic High Output Siren
- Piezo technology for maximum output at minimum power consumption.
- 126 dB @1m sound output = effective range 400m
- 24V DC powered, 1,1A , 2x50Ah Back-up Battery
- 45 selectable alarm tones
- Marine grade protection for permanent outdoor installation
- In off-grid locations, sirens can be solar powered</td></tr>
<tr><td>Data and Requirements</td><td></td></tr>
<tr><td>Work plan</td><td></td></tr>
</table>

Pros and Cons of the Project

Pros	Cons
{list of advantages} Fully automated, excludes the „human factor“ as source of malfunctioning Applicable in high-risk areas where technical mitigation is unaffordable. Much cheaper than technical mitigation (ca. 4,500 Euro for full system)	{list of disadvantages} Stable GSM signal at sensor location and impact zone is required. Requires expert know-how in programming of IT 70 device. Regular update of Phone numbers required (new arrivals/people changing numbers)

Effectiveness and Evaluation

Flood mitigation	Effectiveness in terms of flood alleviation and awareness	
	Measure:	Effectiveness
1	Early Warning System	Very High

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