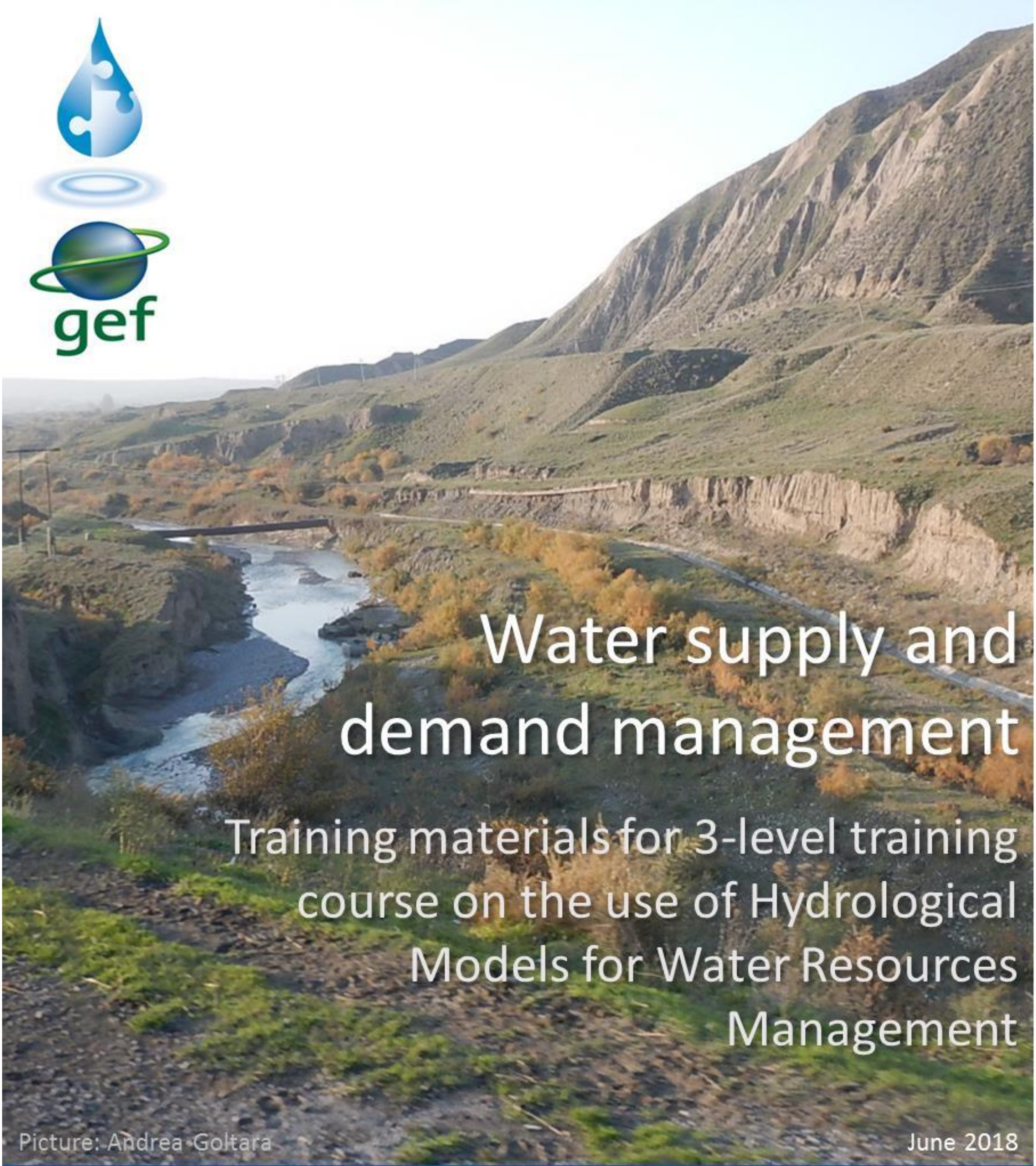


Water supply and demand management

Training materials for 3-level training course on the use of Hydrological Models for Water Resources Management

Picture: Andrea Goltara

June 2018

United Nations Development Program

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

Acknowledgements

This document was prepared in order to support the Kura River Basin Project within the framework of the project:

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

The author wishes to thank the UNDP Kura River Basin Project teams Azerbaijan and Georgia for their support, contribution, flexibility and commitment. The discussions and meetings in Baku and Tiflis and during the field trips were invaluable for preparing this document.

June, 2018

Dr. Hubert Lohr

Contents

Figures

Tables

Training material hydrological modelling for water resources management

Document Information

Project	Advancing Integrated Water Resource Management (IWRM) across the Kura river basin through implementation of the transboundary agreed actions and national plans
Project Countries	Azerbaijan and Georgia
Document	Training material hydrological modelling for water resources management
Date	21.06.2018
Consultant	Dr.-Ing. Hubert Lohr
Client	UNDP Kura II Project
Client Representative	Mary Matthews, Ahmed Elseoud
Financing Organisation	UNDP

1 STRUCTURE OF THE TRAINING MATERIAL

The training material is structured in presentations, simple Excel-based exercises and practical sessions with models. The structure is illustrated below.

Table 1: Structure of the training material

No	Form	Topic	Objective	Duration	Prerequisite
1	Presentation	Introduction into modelling	Understand why modelling is important Learn different type of models Understand principle course of action	1 - 2 hr +	Projector
2	Presentation	Modelling principles, basic concepts	Learn about components of models Gridded vs. sub-basin oriented models Understand the node – element concept Conceive precipitation – runoff transformation Learn Atmosphere – Vegetation – Soil interaction	2 hr +	Projector
3	Exercise (Excel)	Single sub-basin with precipitation – runoff and runoff concentration methods	Identify parameters and their effect and sensitivity Practical application of what has been shown in 2	2 hr +	Projector Computers
4	Exercise (Excel)	Simple Water Balance Model of the Kura River Basin in Excel	Learn how Excel can help set up simple modelling techniques Understand relationship between water abstraction, losses and water scarcity in a transboundary context	2 hr +	Projector Computers
5	Presentation, River basin modelling	Simple Water Balance Model of the Kura River Basin with a river basin model (Talsim-NG)	Understand the use of a river basin model Learn how to interpret reality and a model Learn how to assess and interpret results	1 – 2 day	Projector Computers (intranet for interaction between participants)
6	Presentation and modelling (EToCalculator)	Calculation of Evapotranspiration for irrigation	Understand how to calculate evapotranspiration Learn which data is necessary	1 day	Projector Computers
7	Presentation and modelling	Irrigation requirements and relationship to losses	Learn how water losses affect irrigation requirements in a simple way	2 – 4 hr	Projector Computers

No	Form	Topic	Objective	Duration	Prerequisite
	(Excel)				
Optional					
8	Presentation and modelling (AquaCrop, CropWat)	Irrigation water management and water scarcity	Understand how water management affects crops See how this can help water managers and farmers to better use water	1 – 2 day	Projector Computers
9	Presentation and water supply network (EPANET)	Water distribution network modelling, model set up and application for loss control	Learn EPANET as a powerful tool for modelling water supply distribution systems	1 – 2 day	Projector Computers

Sessions 5, 6, 8 and 9 are based on model documentations and tutorials, which are compiled from the model repositories. No special presentation or documents needs to be written except for short introductory presentations. The sources are available and will be distributed when the training takes place. All models are available free of charge.

Some basic background knowledge is provided in Section 2, 3 and 4 that complements the training modules and do have an overarching function.

Generally, the duration of each module is estimated but is of course flexible. The training assumes that basic understanding of hydrology and hydraulics is available, even though the hands-on chapter has beginner level. The modules 1 to 7 follow a structure in which topics are introduced and explained that are prerequisites in subsequent modules.

All 9 topics exceed a 3-level training course. This is why topic 8 and 9 are presented as option as both require modelling experience to fully understand the concept and handling of the models. It might be less effective from the viewpoint of sustainability to present both programs and have the training attendees applied the models by simply copying what the trainer shows. The concern is that without guidance, any further application will fail.

It is suggested to consider the models in the ongoing activities but to exclude them in the 3-level training course.

2 GIS ANALYSIS

The GIS analysis contains six steps from which parameters for modelling can be derived. GIS is the most important tool for preparing hydrologic models.

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

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

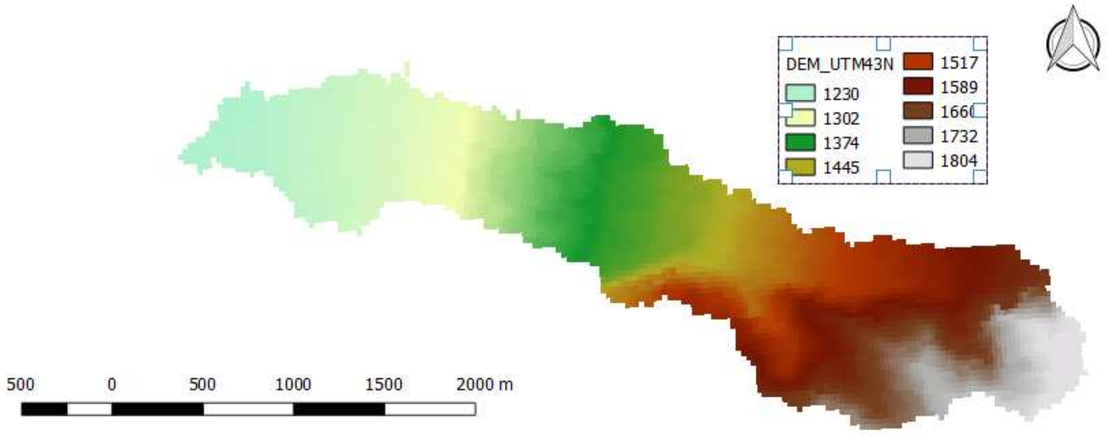


Figure 1: SRTM30 DEM for an example site

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.

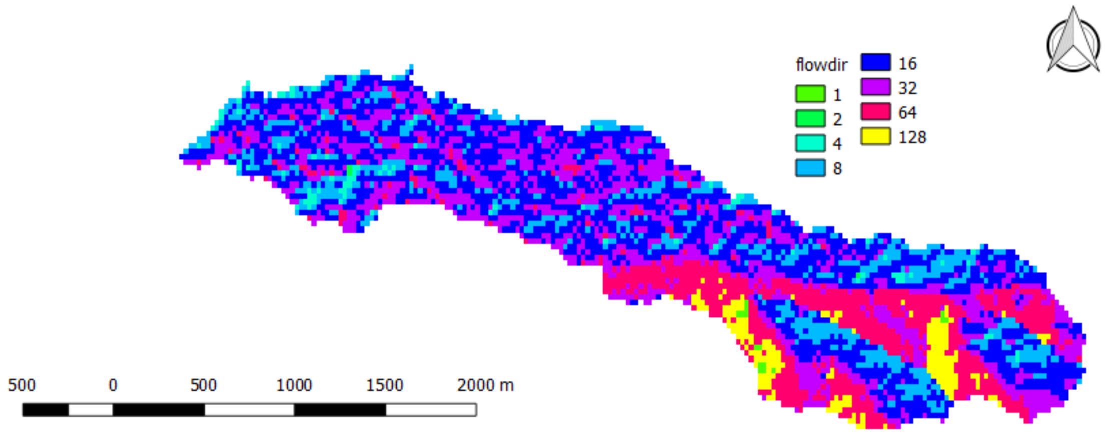
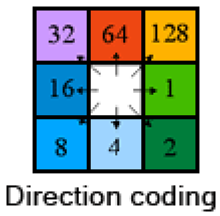


Figure 2: Flow directions

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.

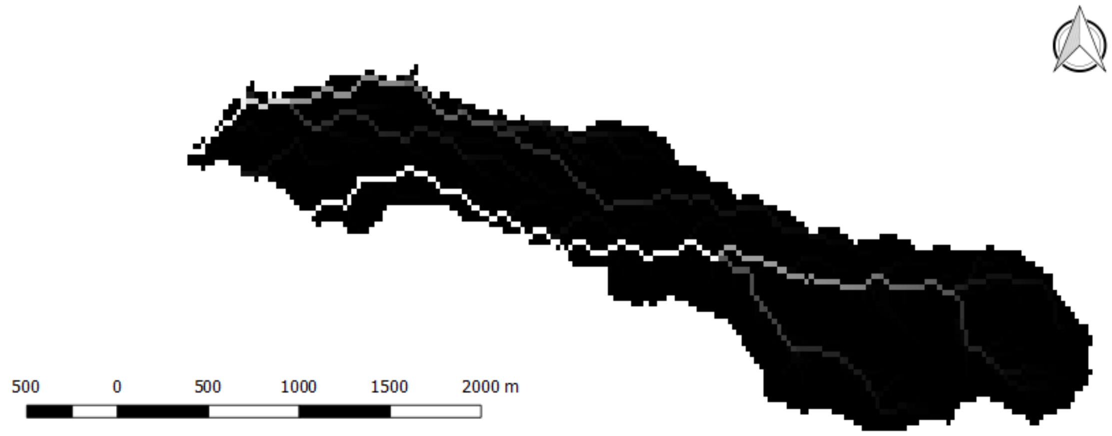


Figure 3: Flow accumulation

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.

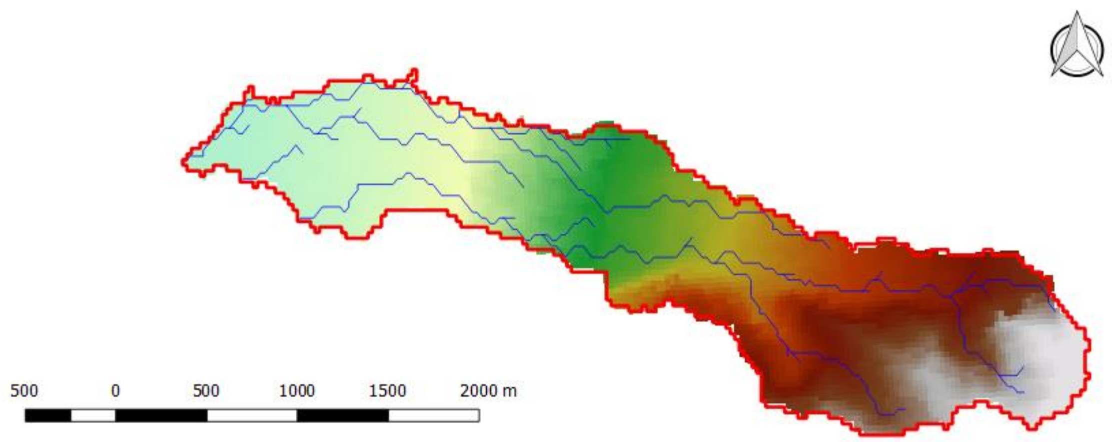


Figure 4: Stream network calculated

The stream network provides the means to identify possible flow paths and gives a direction for setting up a model. 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.

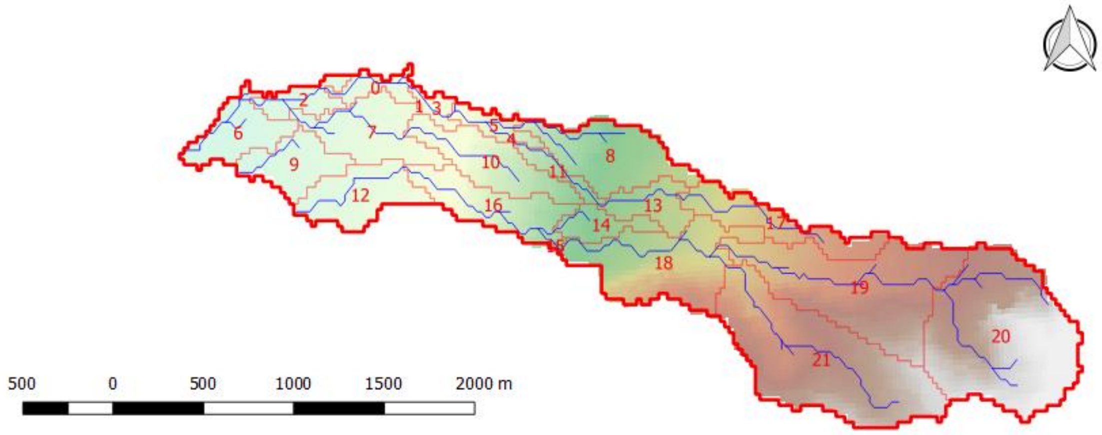


Figure 5: Sub-basins

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 runoff generation or erosion proneness and is used in many applications, e.g. estimation of erosion, time of concentration, runoff. Slope is also required to derive parameters for calculating discharge at a certain point.

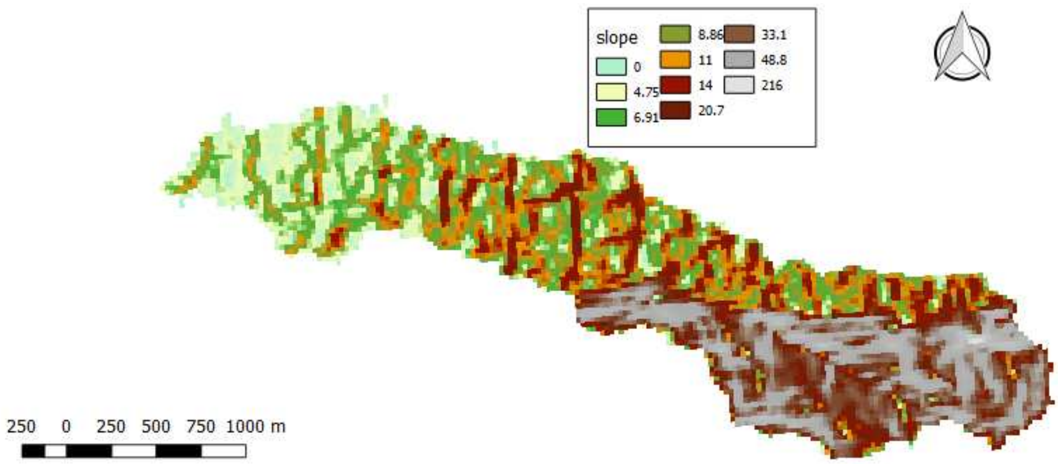


Figure 6: Slope calculated from SRTM30 DEM

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

3 HANDS-ON HYDROLOGY

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.

3.1 Runoff processes 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.

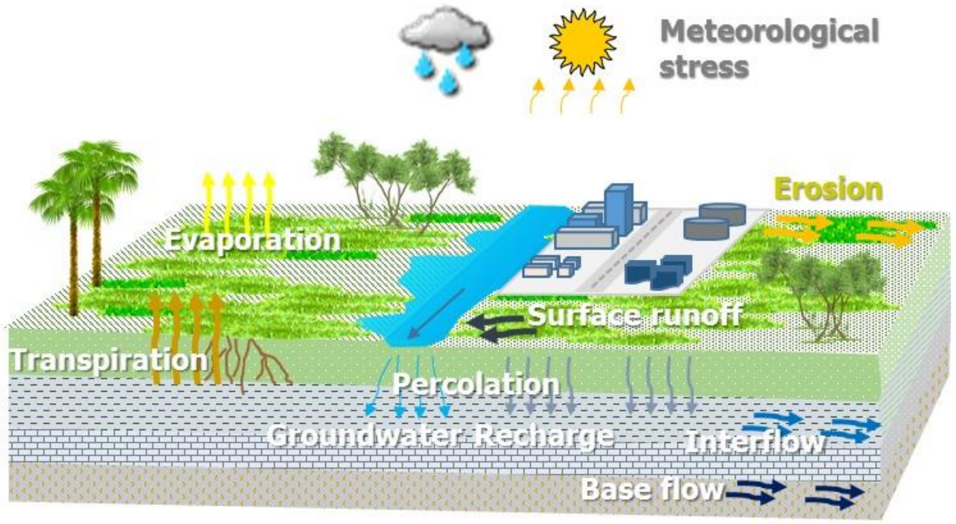
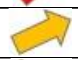
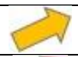
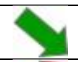
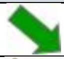
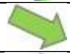
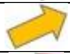
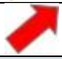
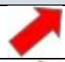
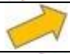
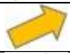
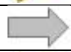
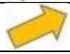


Figure 7: Hydrological processes related to runoff

The following table links hydrological features to runoff generation.

Table 2: 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 3 provides a summary of hydrological impacts associated with land-use changes.

Table 3: 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.

3.2 Calculating runoff

Calculating runoff and deriving hydrographs are the first and easiest way to understand principles of hydrological modelling. There are a number of approaches many of which entail sophisticated calculations and data requirements. Two widely used methods are introduced before more complex methods are eloborated. Both need only a few parameters and are supported by a vast amount of literature and sources from where coefficients can be taken.

3.2.1 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 4: 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.

3.2.2 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: $Qv = \frac{(P - 0.2 \cdot S)^2}{(P + 0.8 \cdot S)}$

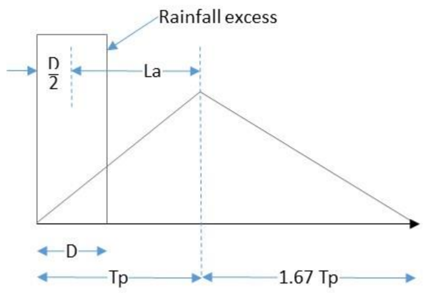
where:

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]

3.2.3 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.

3.3 Snow computation

Computing snow accumulation, compaction and water equivalent is crucial for any hydrological question in mountainous areas.

Under construction.

Table 5: 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.

3.4 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. Hydraulic methods are often used in hydrological models for flood routing.

Given a flow cross-section, the mean velocity can be derived by using the continuity equation: v = Q / A where Q = discharge [m³/s] and A is the flow cross-sectional area [m²].

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 6. These coefficients are subject to change in steep terrain.

Table 6: Manning roughness coefficients (adopted from (TxDOT, 2016))

Natural Channels	Minimum	Normal	Maximum

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
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

Natural Channels	Minimum	Normal	Maximum
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 7: 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

River bed structure	Ks [mm]
Sand and gravel (< 6 cm)	20 – 55
Regular machined stones (10-20 cm) in bulk, plain river bed	16 - 18

3.5 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 a GIS example wth sub-basins and a screenshot of Talsim-NG (www.sydro.de) as hydrological model is shown.

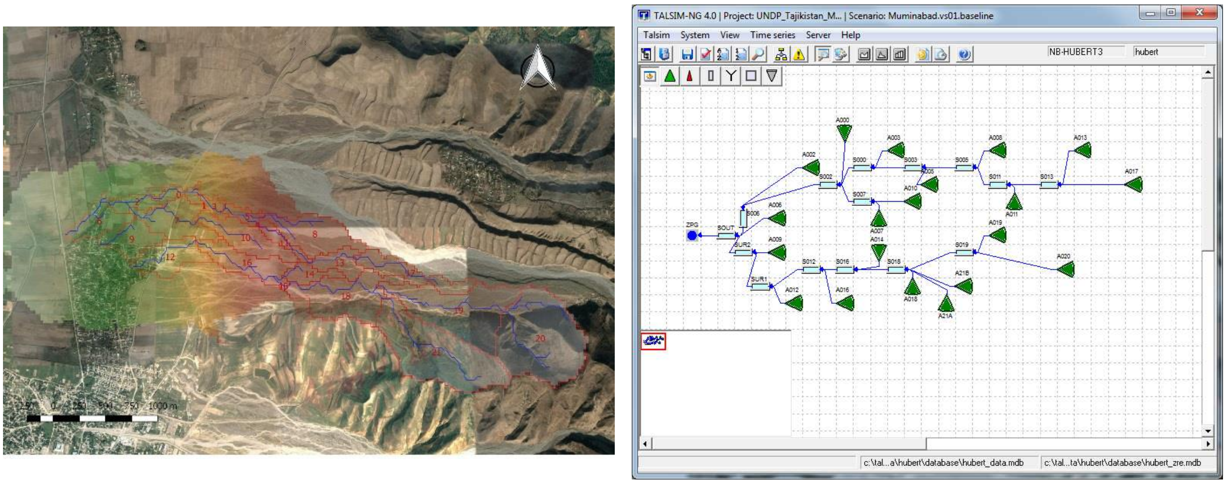


Figure 8: Hydrological model – from GIS to flow network (QGIS and Talsim-NG)

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 operation rules for controllable structures like reservoirs, gates, pumps and turbines. This is particularly important for water management.

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. Some models can also incorporate simplified groundwater aquifers and groundwater movement.

Generally, modelling has become the state-of-the-art approach in hydrology, in flood management and water resources management. 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, results can achieve high accuracy. A high accuracy is also a very relevant economic factor. The rational method and to a lesser extent the SCS approach (introduced below) incorporate safety factors to address the simplifications embedded in the approaches, which, of course, result in lager runoff and thus larger dimensions when it comes to designing measures or overestimates with respect to available water. A better understanding of processes and their interplay in combination with a higher accuracy foster viability and risk-informed decision-making.

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.

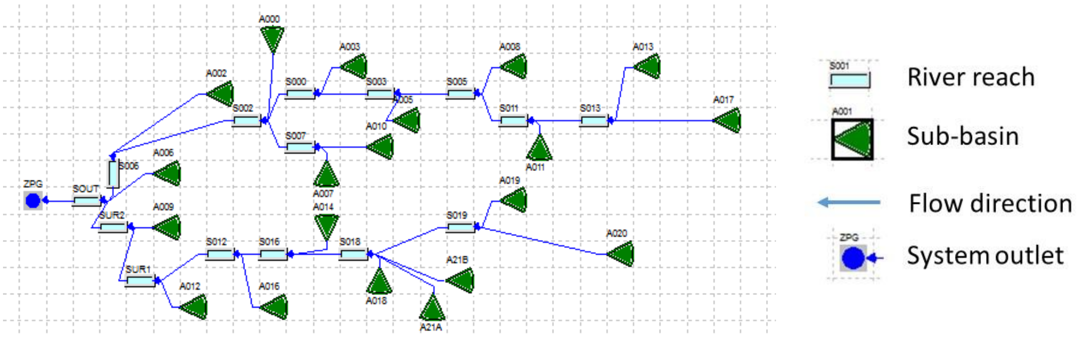
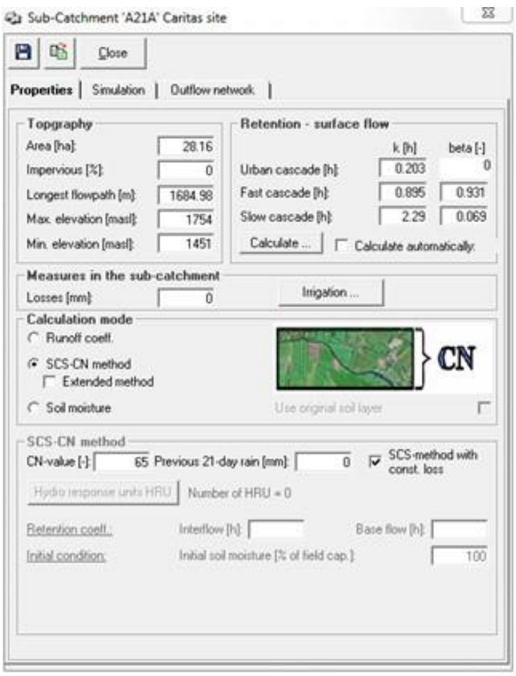
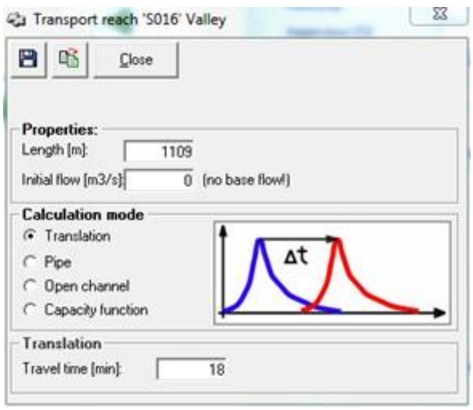


Figure 9: Flow network of the example site based on Talsim-NG

Step 2: Parameters

The user must enter the parameters for all elements. The Talsim-NG model is used for demonstration. It 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 10: 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. Flood simulation require storm profiles with intensity distributions while long-term simulation for deriving water balances require long time series of precipitation.

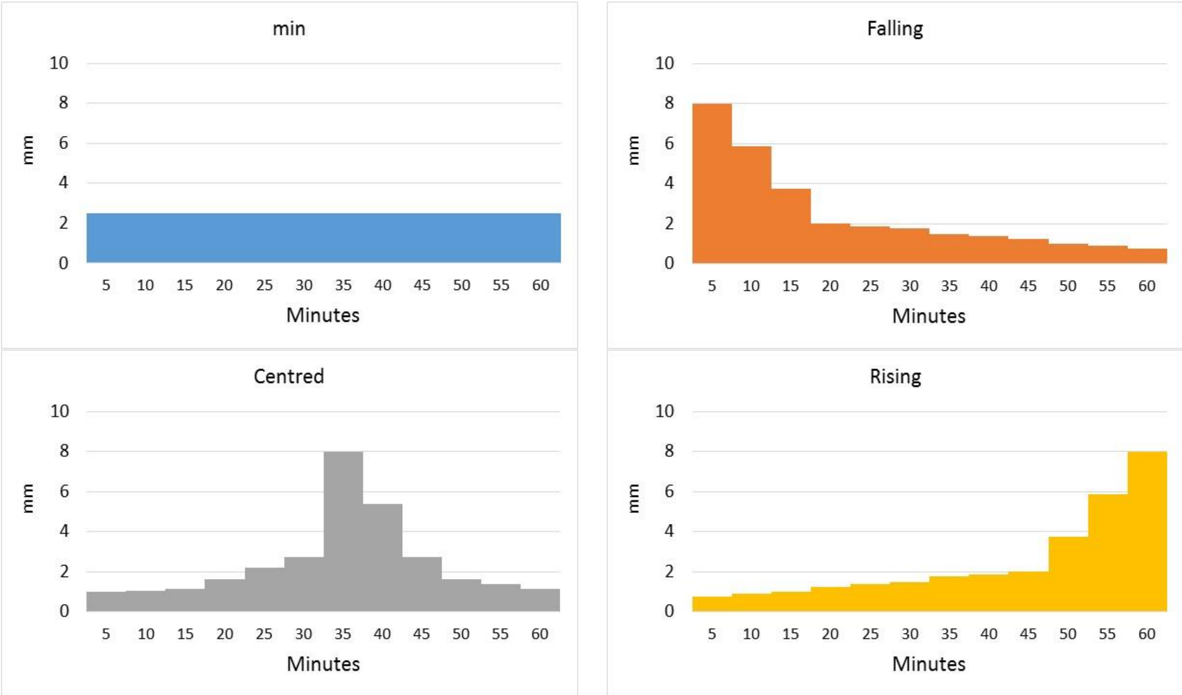


Figure 11: Examples of storm profile of rainfall each with a 60 min rainfall duration

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

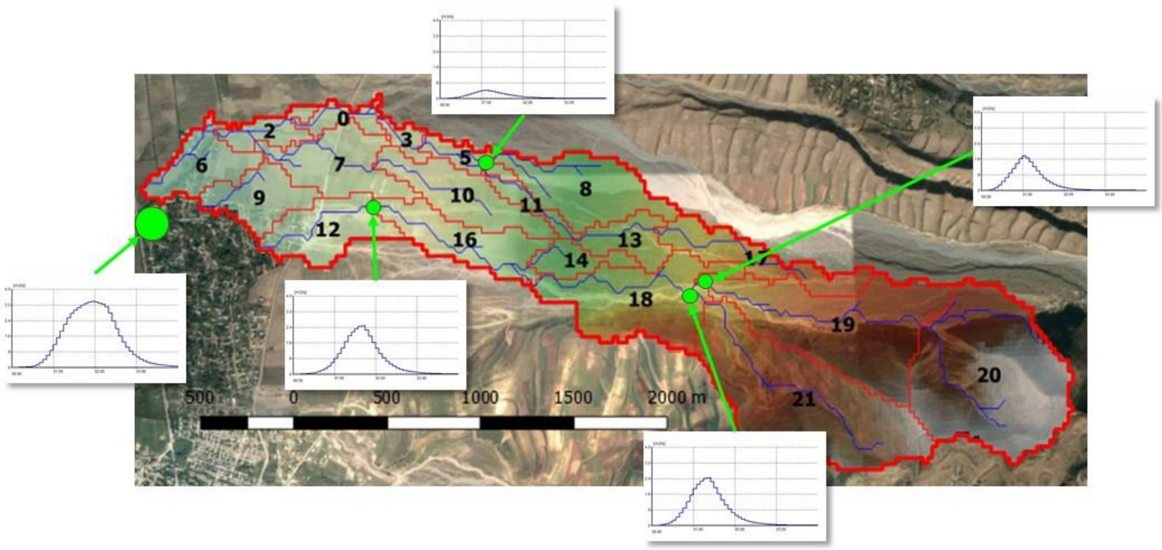
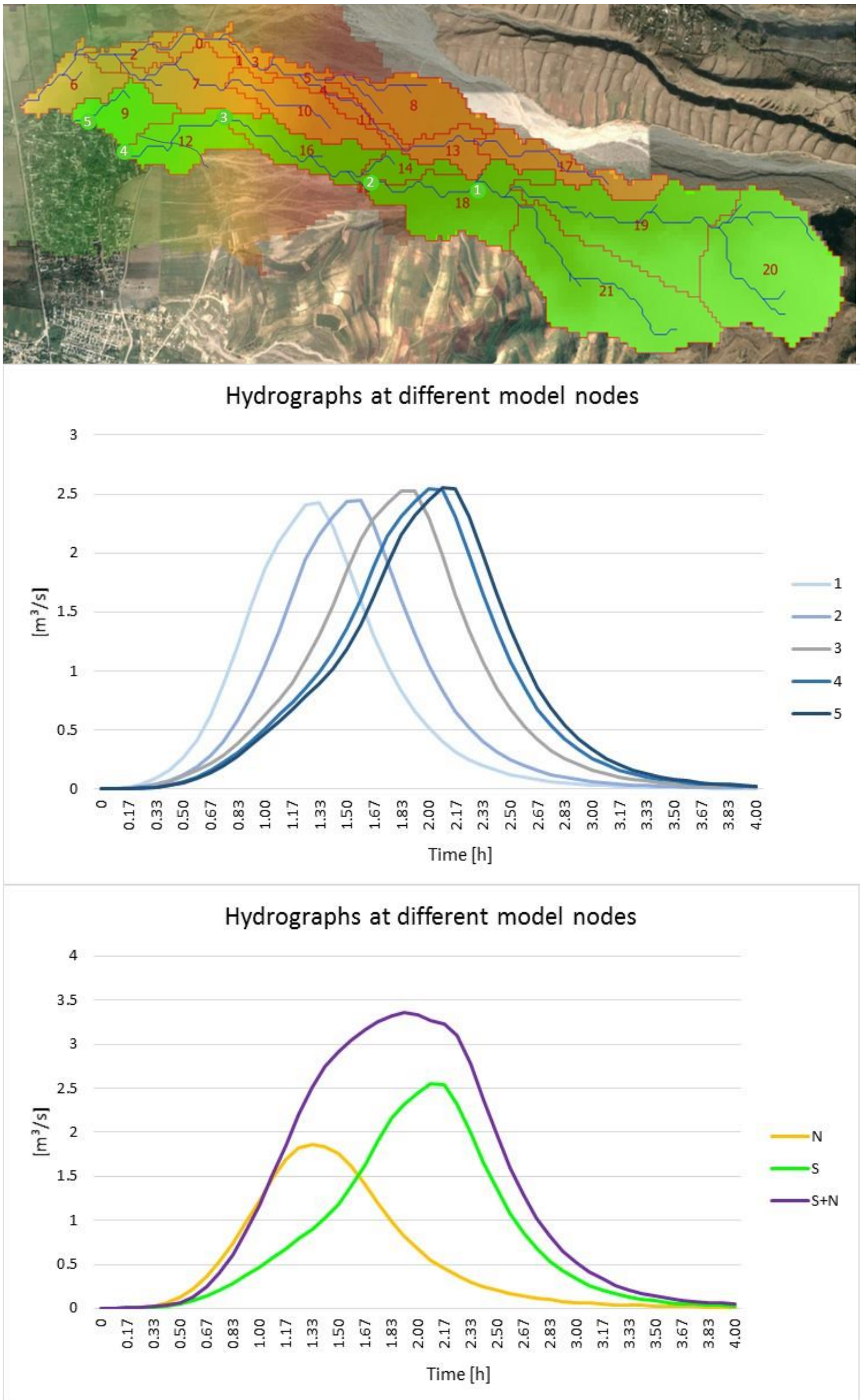


Figure 12: Flood hydrographs of the hydrological model at various nodes in a watershed

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 13: 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. 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)

4 DATA AND DATA SOURCES

This chapter aims to provide information about data and data sources which are required or very useful for modelling.

4.1 Data and data sources from the internet

4.1.1 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 can be found here: https://www.qgis.org/en/site/

4.1.2 Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) is indispensable for working with models. 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.

4.1.3 Climate

Information about climate is essential for model stress. Precipitation is the driver for runoff and estimates about rainfall depth and intensities associated with return periods constitute the basis for almost all model applications.

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 station, 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/

4.1.4 Land use

Land use information is necessary to obtain runoff coefficients and is required by hydrological or hydraulic models. Globally available land use information stems 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.

4.1.5 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.

4.1.6 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, they 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. 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.

4.1.7 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.

4.2 Be your own data manager

Usually, information and data 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. 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 is 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 8: 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 important. 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 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 9: 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

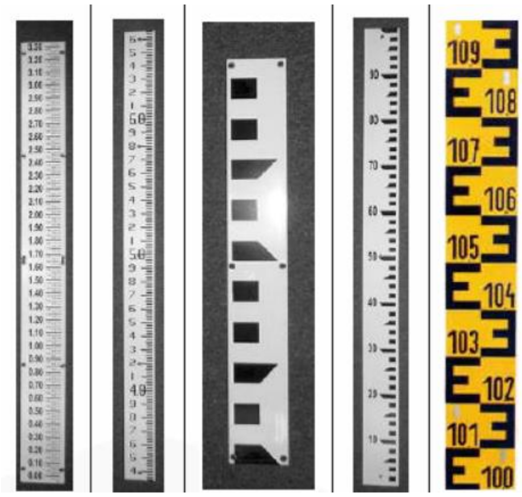
Water level:

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)

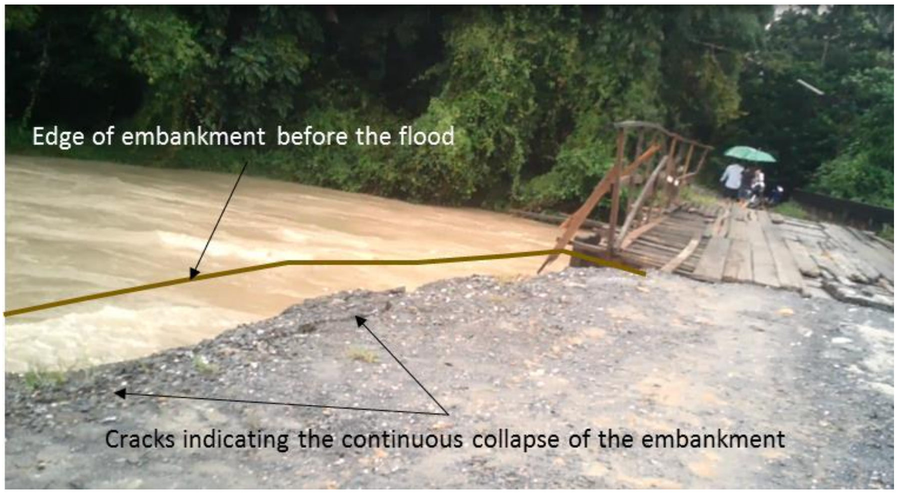
Staff gauge at the Mbuluzi River, Swaziland



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 10: 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.

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.

4.3 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.

It must be kept in mind that data is never 100% accurate and thus interpretation of formulas and results is important. This means that it is wise to conduct a sensitivity analysis and check what if when figures would be higher or lower.

The following list sorts parameters 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

5 MODELLING

5.1 Water Balance Modelling (Excel)

This part of the training refers to No. 4 in the overall structure of the training material given in Table 1.

A simple water balance model was developed for the Kura River Basin based on available data from different sources. The values might be not absolutely correct and 100% reliable but the model sheds light on interactions between main water users, fictive water users in the future and remaining flow. It is good as demonstration how hydrological processes can be simplified modelled with Excel.

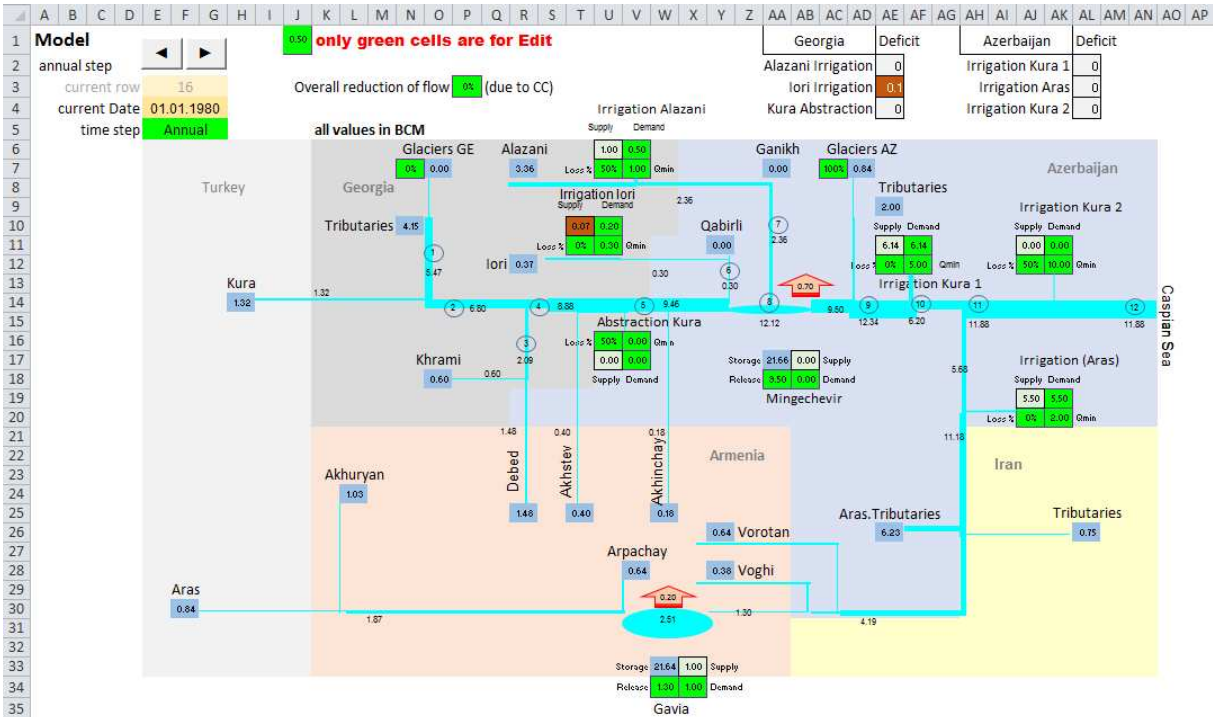
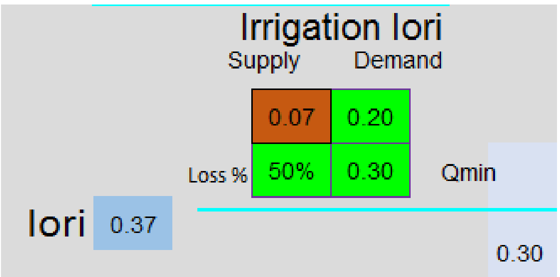


Figure 14: Overview about the simplified water balance model

The model is driven by annual data from 4 different observation points, namely Tbilisi, Novruzlu, Zardab and Surra taken from (UNECE, 2016). The data spans over a period from 1975 to 2010. Average annual inflows from 22 tributaries were taken from (UNECE, 2016) to derive a relationship between each tributary to one of the 4 observation points with time series in order to obtain time series for all tributaries. In doing so, it was possible to generate inflow time series for all tributaries such that resulting flow in the Kura or Aras River corresponds to the observed values.

The model is prepared to allow users to edit water demand, losses, minimum flow at 8 water diversion points and the contribution of glaciers. The model propagates the flow from node to node and indicates the magnitude of flow by adapting the thickness of the river reaches proportional to the flow.

Possible user intervention is demonstrated at the Iori irrigation abstraction point.



The Iori delivers 0.37 BCM. The minimum required flow in the Iori is given to 0.3 BCM. The amount left for abstraction is 0.07 BCM. With 50% losses, actual water supply is 0.035 BCM compared to a water demand of 0.2 BCM.

Figure 15: Example water abstraction point

The summary of abstraction and supply considering the losses is provided at the top of the page.

Georgia	Deficit	Azerbaijan	Deficit
Alazani Irrigation	0	Irrigation Kura 1	4.3
Iori Irrigation	0	Irrigation Aras	0.2
Kura Abstraction	0	Irrigation Kura 2	0

Figure 16: Summary of water deficit for all abstraction points

It could be interesting to change the contribution of the glaciers. To do so, the runoff coefficient from the glaciers is editable. A value between 0 (no water from the glaciers) to 1 (current situation) can be set.

A global factor of flow reduction can be set. This helps identify the vulnerability of river reaches and abstraction.

Two reservoirs are included: Mingechevir and Gavia. A reservoir is represented by a demand similar to a water abstraction point, by a release which represents the flow downstream and an evaporation loss from the surface. Storage and supply are calculated by using the input and the parameters.

In general, minimum flow downstream has a higher priority than water abstraction. In other words, downstream requirements are first fulfilled before water abstraction is considered.

The model runs in a step-by-step mode, that means only one time step is visible. No simulation over a period of time is possible. However, a flow and supply statistic is provided which shows average values.

The statistic reveals the impact on flow reduction or downstream water supply due to an increase of upstream abstraction or the impact of glaciers if their contribution is turned off or reduced.

Playing with the excel-based water balance model is a good warming up for the river basin model application.

5.2 Water Balance Modelling (Talsim-NG)

This part of the training refers to No. 5 in the overall structure of the training material given in Table 1.

The next level of complexity after the Excel water balance model is to use a hydrological model. It is suggested to use Talsim-NG developed by SYDRO. This software package can be made available free of charge. Unlike many other hydrological models, Talsim-NG has the marked advantage that the model is scalable, that is, the level of detail can be enhanced step by step as new data emerge and it can applied even with rudimentary data sets.

The water balance model set up in Talsim-NG is similar to the Excel model. The difference to Excel is that the reservoirs own more functionality and represent a more realistic behaviour in Talsim-NG. In addition, each model element can be enhanced by using more features of the Talsim-NG model. Model stress in the sense of flow time series is identical to what is used in Excel. The time step is variable and is preliminarily set to 5 days. This flexibility of Talsim-NG allows users to apply any time step completely independent from the input time series.

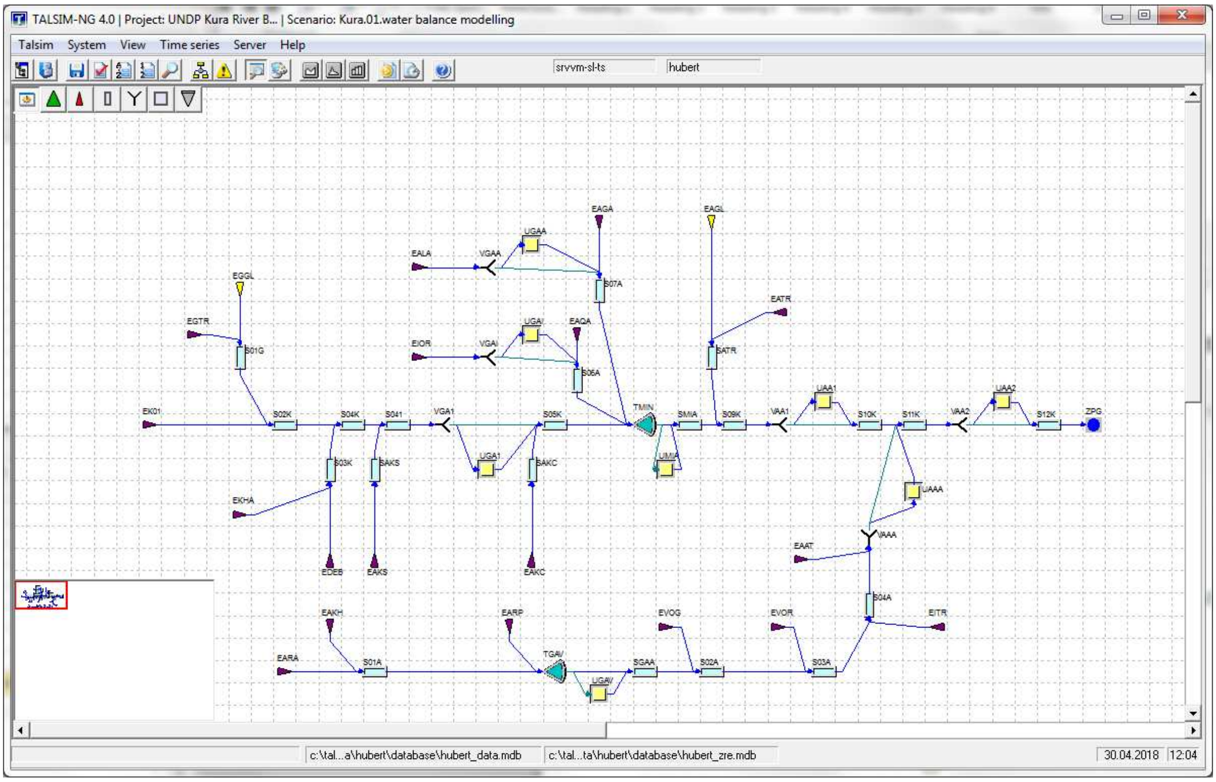


Figure 17: Flow network of the Kura River Basin with Talsim-NG

5.3 Evapotranspiration Calculator

This part of the training refers to No. 6 in the overall structure of the training material given in Table 1.

The calculation of evapotranspiration is a prerequisite for water resources planning and is essential not only for the purpose of irrigation. As such, the EToCalculator from FAO will be introduced. The application works seamlessly with the CLIMWAT tool from FAO which provides climate time series from all over the world, unfortunately with the exception of Georgia.

The stations listed in CLIMWAT can be exported and subsequently imported in EToCalculator. In addition, the input format of climate time series for the EToCalculator is very simple and be reproduces easily from within Excel or other tools.

Both CLIMWAT and EToCalculator do not have a help file but are rather self-explicable. Standard language is English but is could be possible that FAO offers even Russia as install version.

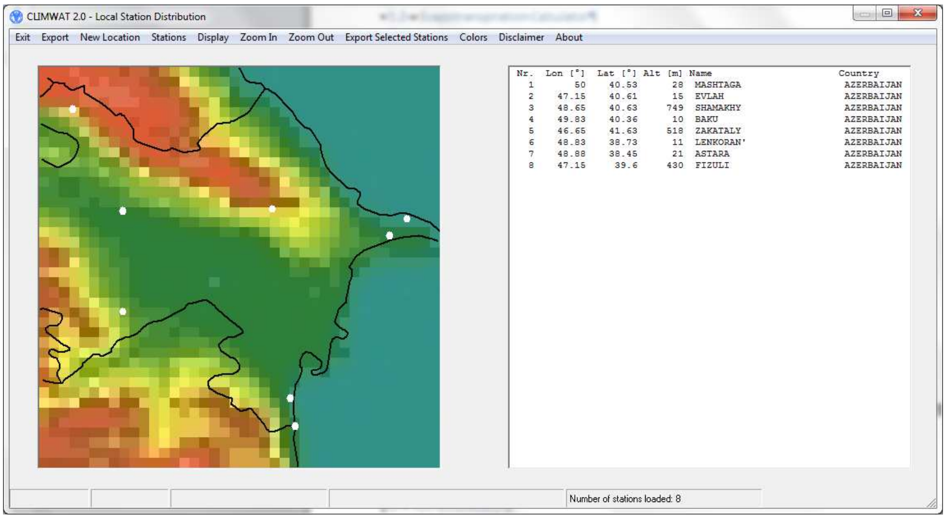


Figure 18: CLIMWAT (FAO) tool for climate time series retrieval

Result of a calculation for a station in Azerbaijan is illustrated below.

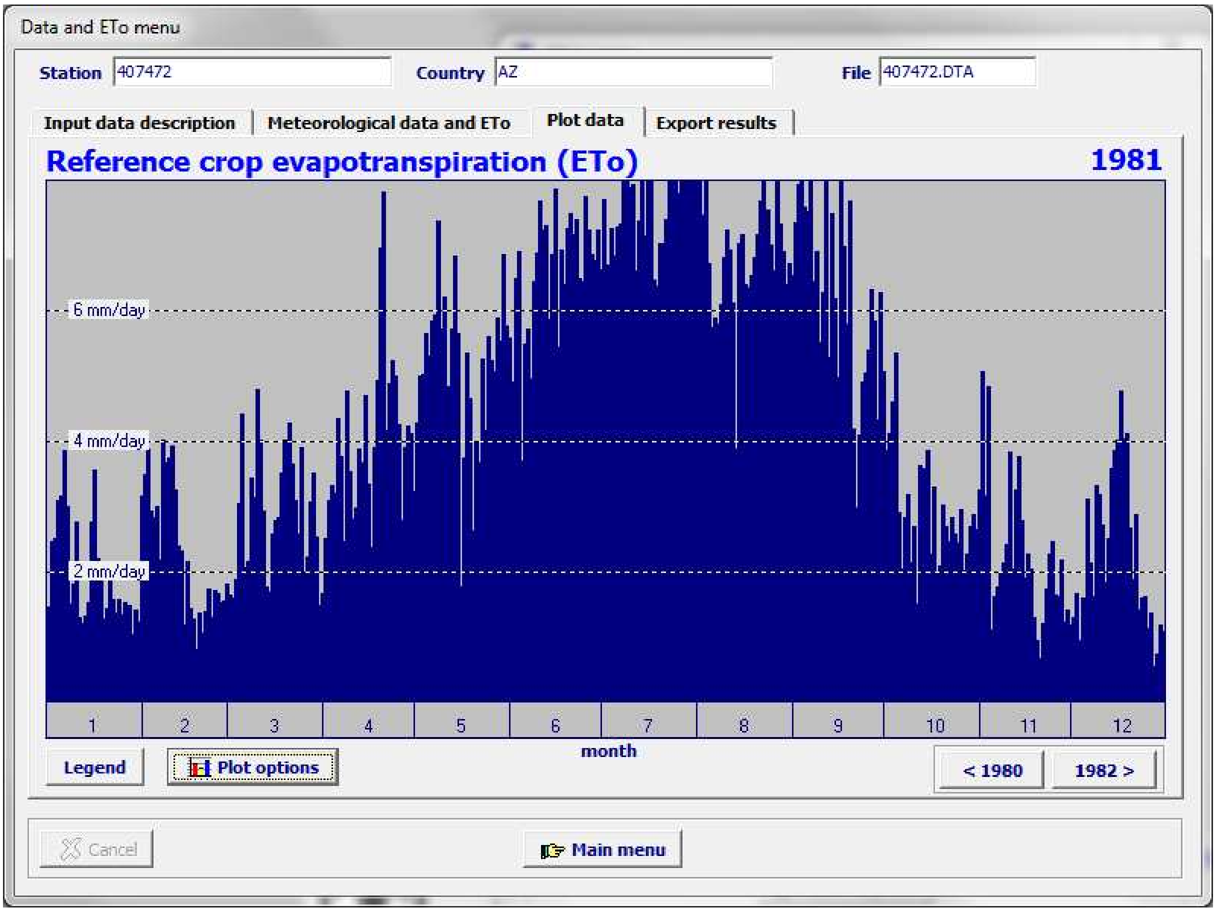


Figure 19: EToCalculator tool with a calculated daily time series of evapotranspiration

5.4 Irrigation calculator (Excel)

This part of the training refers to No. 7 in the structure of the training material given in Table 1.

Irrigation requirements and relationship to losses is introduced in this training module. This topic is certainly not new to the stakeholders. Despite that, it is introduced as a preparatory exercise for more complex irrigation calculations later on in the next module.

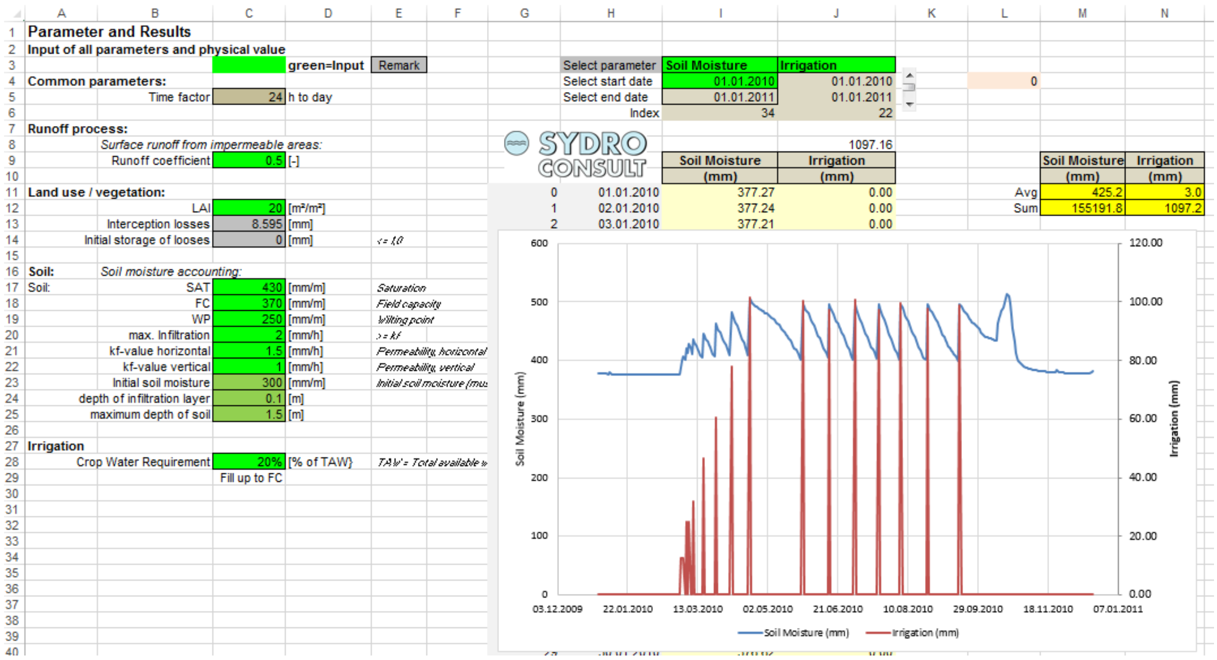


Figure 20: Excel-based training module for irrigation with soil moisture accounting

This module aims at dealing with simple soil moisture accounting and the way it is organised in Excel. The simple calculation routine help to understand more complex algorithms and parameters. Before the Excel exercise will be carried out, the topic and soil moisture accounting is addressed with a presentation.

5.5 Irrigation water management and water scarcity

This part of the training refers to No. 8 in the structure of the training material given in Table 1.

AquaCrop is the most advanced tool for assessing irrigation scheduling, incorporating soil, crop types, field management techniques under various climate conditions.

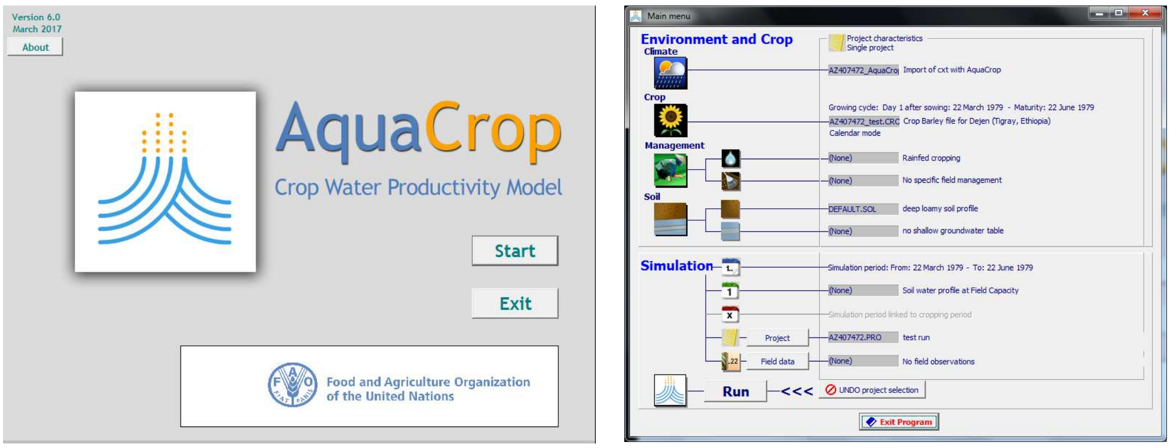


Figure 21: FAO AquaCrop for irrigation management

The level of detail of AquaCrop is immense and thus it is not possible to address all AquaCrop features the toll offers. The main objective with the introduction of AquaCrop is to enable and encoureage stakeholders to capitalise on tools which are free of charge and made for capacity building and training. Moreover, the tools reveals the parameters that should be observerd.

AquaCrop is introduces with a short presentation.

Another tool FAO provides is CropWat. CropWat is less intuitive and has less features but has the advantage of being available in Russian language. Having both will certainly turn out as beneficial for all those who are involved in irrigation, in particular for • Azerbaijan Amelioration and Water Resources.

AquaCrop and CropWat are equipped with a good documentation. Especially AquaCrop has a number of manuals for different topics which explains in an understandable language all features of the programme.

5.6 Irrigation water management and water scarcity

This part of the training refers to No. 9 in the structure of the training material given in Table 1.

The best tool for water distribution network modelling, model set up and application for loss control is EPANET. EPANET is a software that models drinking water distribution piping systems. EPANET is public domain and can be freely copied and distributed. EPANET performs extended period simulation of the water movement and quality behaviour within pressurized pipe networks. Pipe networks consist of pipes, nodes (junctions), pumps, valves, and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of the water in each tank, the type of chemical concentration throughout the network during a simulation period, the age of the water, and source tracing. The coverage of EPANET exceeds by far the scope of the training module. EPANET represents state-of-the-art modelling and is scalable and even extendable for own purposes due to its programmers toolkit. In other words, water supply companies could incorporate the tool in their work flows, GIS environment and much more.

6 REFERENCES

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

Arabitze, M. (2017). *Report on the changes that need to be made in the national water quality standards and regulations to be in line with EUWFD.* Tbilisi: UNDP Kura II Project.

Beldring, S. (2017). *Runoff map of Georgia.* Oslo: Norwegian Water Resources and Energy Directorate, ISBN 978-82-410-1579-3.

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

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

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

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

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

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

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

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

Chomakhidze, K. (2017). *Assessment of Physical Water Supply System for Municipal Water Use in Georgia.* Tbilisi: UNDP Kura Project.

Chomakhidze, K. (2017). *Minutes, National Consultant in the Kura II Project – Municipal Water Supply Expert - GE.* Tbilisi: UNDP, Kura II Project.

CISBCCI. (2018). Commonwealth of Independent States - Bangladesh Chamber of Commerce & Industry. Retrieved from http://cisbcci.org/azerbaijan/

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

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

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

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

Dzneladze, M. (2017). *Nationall Assessment report laws, regulations and enforcement mechanisms for rational water use in Georgia.* Tbilisi: UNDP Kura II Project.

Egis Bceom International. (2010). *Output 1 Sector Development Plan.* ADB, Project Number: 43556, Egis Bceom International In Association With GeoHydro Services, Developing an Urban Water Supply and Sanitation Sector Strategy and Regulatory Framework for Georgia.

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

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

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

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

FAO. (2018). Aquastat. *http://www.fao.org/nr/water/aquastat/main/index.stm*. Retrieved from http://www.fao.org/nr/water/aquastat/main/index.stm

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

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

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

Georgia, G. o. (2018). Statute of the Ministry of Environment Protection and Agriculture of 6 March 2018 (approved by Government Resolution #112). Tbilisi: Government of Georgia.

GEOSTAT. (2017). *Natural Resources of Georgia and Environmental Protection, 2016.* Tbilisi: National Statistic Office of Georgia, Statistical Publication.

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

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

GWP. (2015). *Financial statements, For the year ended 31 December 2015 with independent auditors' report.* Tbilisi: Georgian Water and Power LLC.

Hannan, T., Leummens, H., & Matthews, M. (2013). *Desk Study - Hydrology.* Tbilisi, Baku, Yerevan, 29 pp: UNDP/GEF Project Reducing transboundary degradation in the Kura-Aras river basin.

Hannan, T., Leummens, H., & Matthews, M. (2013). *Desk Study - Hydrology.* Tbilisi, Baku, Yerevan, 29 pp: UNDP/GEF Project Reducing transboundary degradation in the Kura-Arak(s) river basin.

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

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

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

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

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

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

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

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

Makarova, M. (2016). *Development of the new Water Law and bylaws in Georgia.* Tbilisi: Ministry of Environment Protection and Agriculture of Georgia.

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

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

Megrelidze, I. (2017). *Initial assessment of available ground and surface water in Kura river basin in Georgia.* Tbilisi: UNDP, UNDP GEF Kura Project.

Melua, D. (2015). *Municipal Water and Wastewater Sector in Georgia.* Tbilisi: Slovak Aid.

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

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

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

MOA. (2017). *Irrigation Strategy for Georgia 2017 - 2015.* Tbilis: Ministry of Agriculture of Georgia supported with Water Partnership Program and World Bank's "Georgia Irrigation and Land Market Development Project" funding.

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

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

pwc. (2015). *Cost Plus Tariff Methodolgy in the Water Sector.* Bratislava: PricewaterhouseCooper.

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

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

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

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

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

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

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

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

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

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

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

Ukleba, B. (2017). *Assessment on laws and regulations in agriculture water use in Georgia.* Tbilisi: UNDP Kura II Project.

Ukleba, B. (2017). *Report on Irrigation Infrastructure - ENG.* Tbilisi: UNDP, Kura Project.

UNDP. (2017). *Inception Workshop Report.* Baku, Azerbaijan: UNDP-GEF Kura II Project.

UNECE. (2016). *Environmental Performance Reviews, Third Review.* New York and Geneva: UNECE, ISBN 978-92-1-117101-3.

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

UNICEF. (2018). WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP). *https://washdata.org/*. Retrieved from https://washdata.org/

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

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

Verdiyev, A. (2017b). *Analyze the historical hydrological station data along the Kura river basin to estimate the seasonal variability along the river".* Baku: UNDP Kura Project.

Verdiyev, A. (2018). *Conduct an assessment of available ground and surface water in Kura river basin in Azerbaijan.* Baku, Azerbaijan: UNDP Kura II Project.

Vogel, B. e. (2017). *Historic Water Use, Projected Water Demand and Water Status in the Kura River Basin.* ENVSEC Initiative, comprising UNDP, UNEP, UNECE, OSCE and REC.

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

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

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

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

Wikipedia. (2018). Wikipedia. *www.en.wikipedia.org*. Retrieved from www.en.wikipedia.org

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

World Bank. (2017). Climate Change Knowledge Portal. *http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=historical*. Retrieved from http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=historical

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