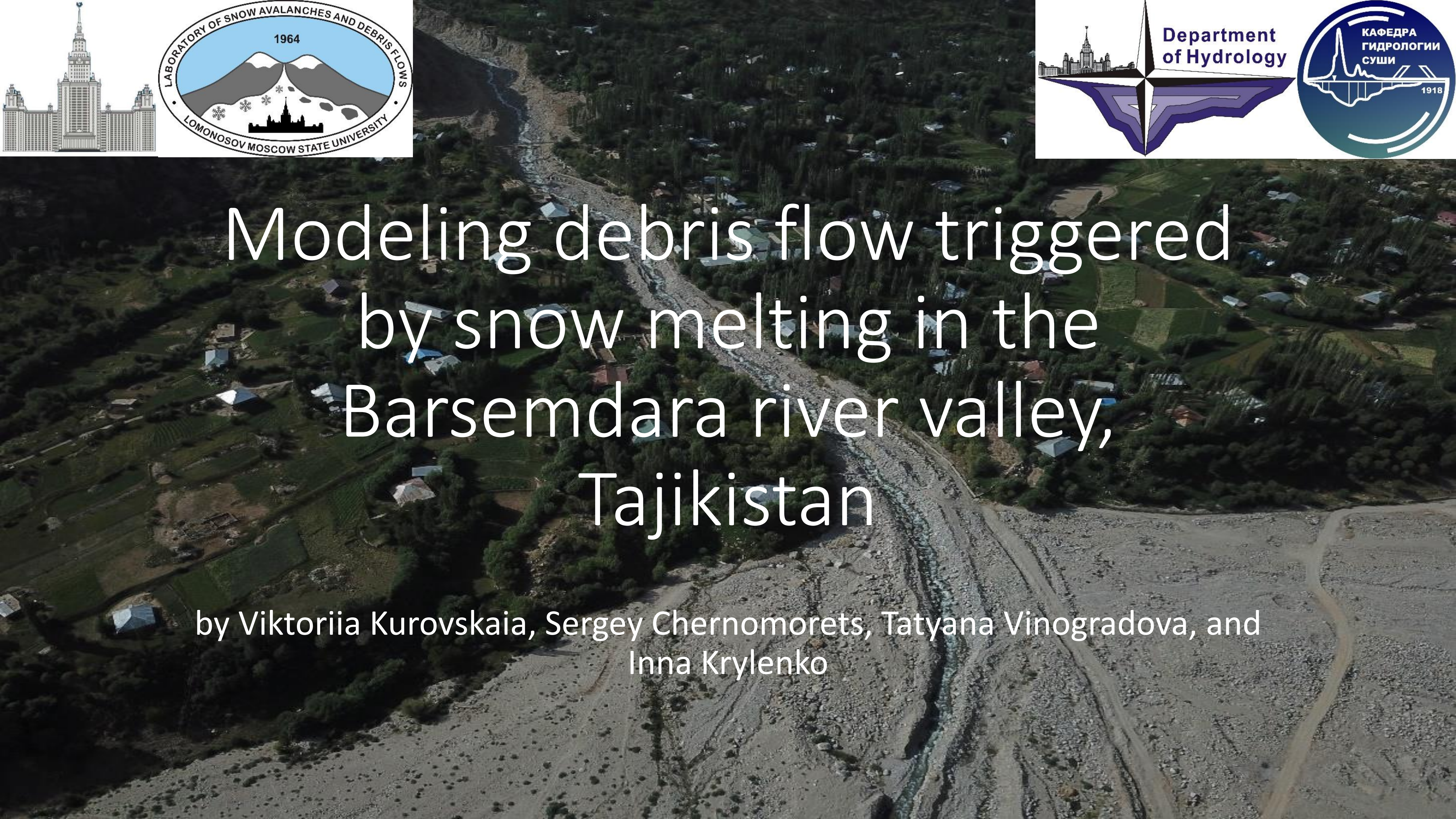
Laboratory of Snow Avalanches and Debris Flows
1964
Lomonosov Moscow State University

Department of Hydrology

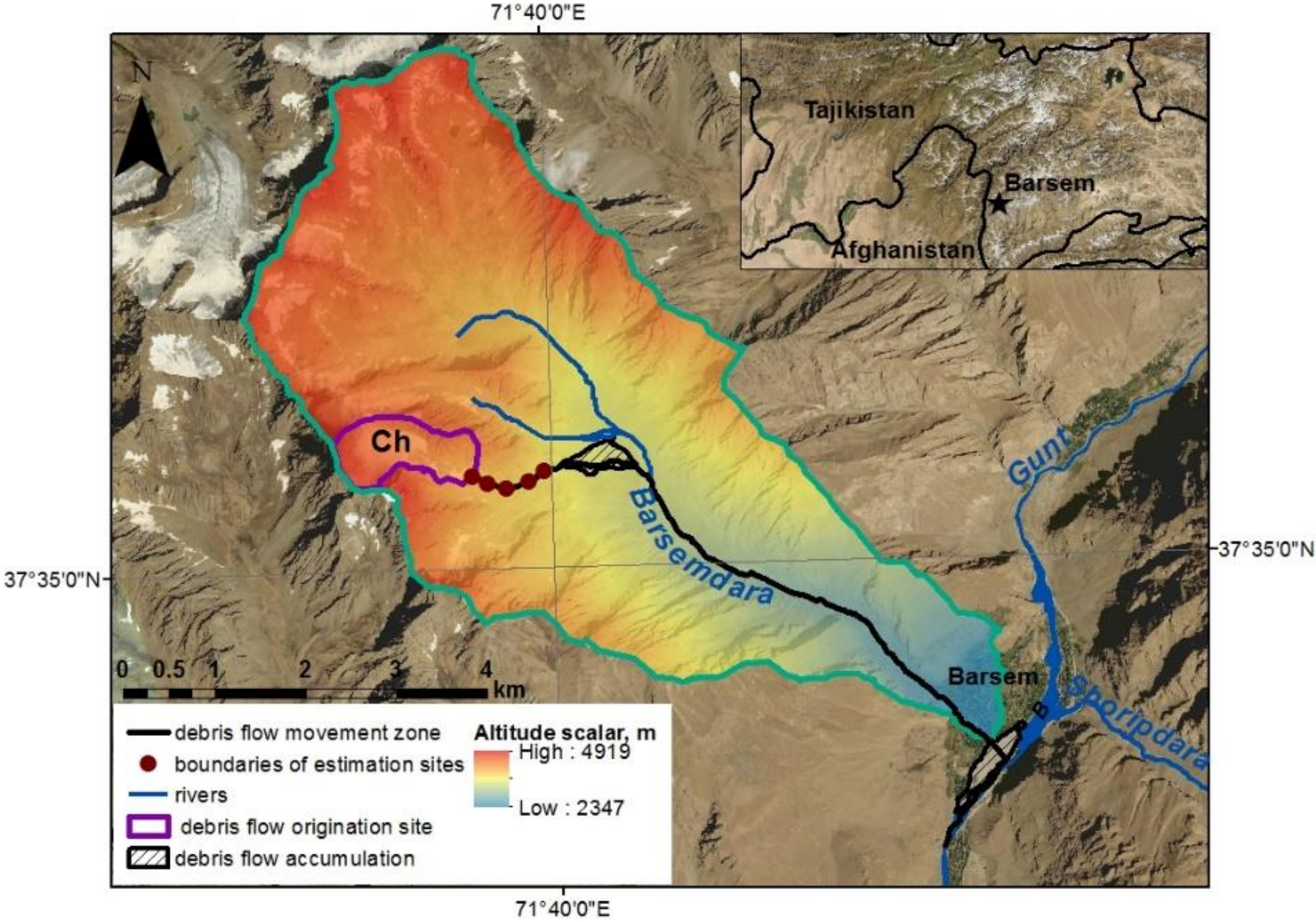
КАФЕДРА ГИДРОЛОГИИ СУШИ
1918



Modeling debris flow triggered by snow melting in the Barsemdara river valley, Tajikistan

by Viktoriia Kurovskaia, Sergey Chernomorets, Tatyana Vinogradova, and Inna Krylenko

Barsem debris flow disaster



The Barsemdara River is the right tributary of the Gunt river
The length of the river is 7.5 km
The elevation varies from 4100 m to 2400 m

- During the period from 16 to 24 July 2015, at least 14 series of debris flow waves. The total number range from 30 to 40.
- Overall debris flow volume reached 4.2 million m^3

The transport-shear formation model

This model is a one-dimensional and is intended for calculating high-density flows. The model was developed by Yu.B. Vinogradov through the Chemolgan experiments data on reproduction of artificial debris flows in nature.

1. **The coefficient of instability** of the PDFB as the reciprocal value of the well-known in soil mechanics and engineering Geology coefficient of loose-fragmental debris mass slope stability. In this case the coefficient is determined for PDFB as:

$$K = tg\alpha / th\varphi$$

2. **Elementary potential flow capacity** (ability to produce job per unit of track per time unity W / m = kg . m/s^3).

$$U = g[Qp_0 + (\zeta p_0 + p)G]sin\alpha$$

3. **The index of mudflow mass mobility**

$$R = \frac{Q}{G} + \zeta - \theta_{\text{пп}}$$

The transport-shear formation model

4. The increment in solid flow along the origination site

$$l = \frac{\left[\frac{Q\rho_0}{\zeta\rho_0+\rho}\, ln\frac{Q\rho_0+(\zeta\rho_0+\rho)G}{Q\rho_0+(\zeta\rho_0+\rho)G_0} - \frac{Q}{\zeta-\theta_{nn}}\, ln\frac{Q+(\zeta-\theta_{nn})G}{Q+(\zeta-\theta_{nn})G_0}\right]}{A\,\frac{tg\alpha}{tg\varphi}\, g\, Sin\alpha[Q\rho_0(\zeta-\theta_{nn})+Q(\zeta\rho_0+\rho)]} + l_0$$

Here A – is the coefficient of proportionality ($m \cdot s^2/kg$); l – distance over a thalweg; α – the angle of inclination of a debris flow hotbed bedplate containing the PDFB; φ – the angle of internal friction of damp rock (static) composing the PDFB; Q - water flow runoff into the debris flow hotbed (m^3/s); G - solid substance (rocks) runoff in a debris flow (m^3/s).

here Q/G is the ratio of water and solid rock substance runoffs in a mud-stone flow moving over the thalweg of a debris flow hotbed. ξ – relative humidity of PDFB (the ratio of volumetric moisture content by volume fraction of solids in a potential debris flow body of a debris flow hotbed); Θ_{nn} – the same ratio but at the limit of a mixture of water and rock fludity (in the first approximation is taken equal to 0,133). The formation and movement of debris flow is meant to stop when $R \leq 0$. In the mountains one can often see such "stalled debris flows" especially on extensive screes where the amount of water involved in such developments is almost always limited. Let us assume the following situation: the increment of the flow rate of the solid material involved in an incipient mudflow as it moves through the riverbed of debris flow hotbed is directly proportional to the above three arguments:

The transport-shear formation model

5. **Debris flow discharge**

$$Qc = Q + (1 + \zeta) * G$$

6. **Debris flow density**

$$y = \frac{Q * p_o + (\zeta * p_0 + p) * G}{Q + (1 + \zeta) * G}$$

Initial data for modeling

Water discharge (Q, m^3/c)	25
Density of potential debris flow body (ρ, kg/m^3)	2600
Water density (ρ_0, kg/m^3)	1000
Valley average slope (α, °)	13,5
Static angle of internal friction of damp rock, (ϕ, °)	40
Dynamic angle of internal friction of damp rock, (ϕ*, °)	22
relative humidity of PDFB(ζ_1)	0
relative humidity of PDFB (ζ_2)	0,133
relative humidity of PDFB (ζ_3)	0,2
Coefficient of proportionality(c_2, m^{-2})	0,000005

Debris flow velocity

We have improved the existing transport-shear model by including equations for calculating the speed and travel time of the wave.

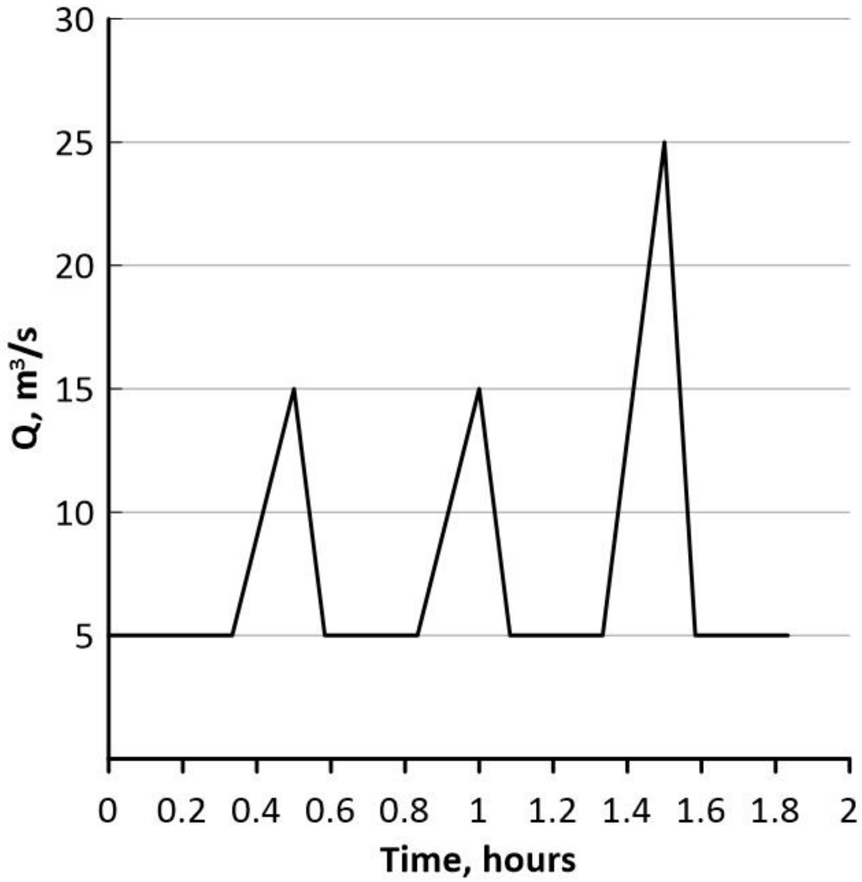
$$M = \mu/2\gamma\beta^2$$

$$N = g(sin\alpha - tg\varphi * cos\alpha)/\beta^2$$

$$S = ghsin\alpha/\beta^2$$

$$Vm = \left(\frac{1}{1.5NH}\right)\left[\left(\frac{M^2}{H^2} + S + NH\right)^{1.5} - \left(\frac{M^2}{H^2} + S\right)^{1.5}\right] - M/H$$

μ — coefficient of dynamic viscosity of the flow, Pa · s; γ - density of mudflow mass, kg / m3; β - coefficient of resistance to mixing, dimensionless; α - tilt angle of the mudflow focus, °; g - acceleration of gravity, m / s2.

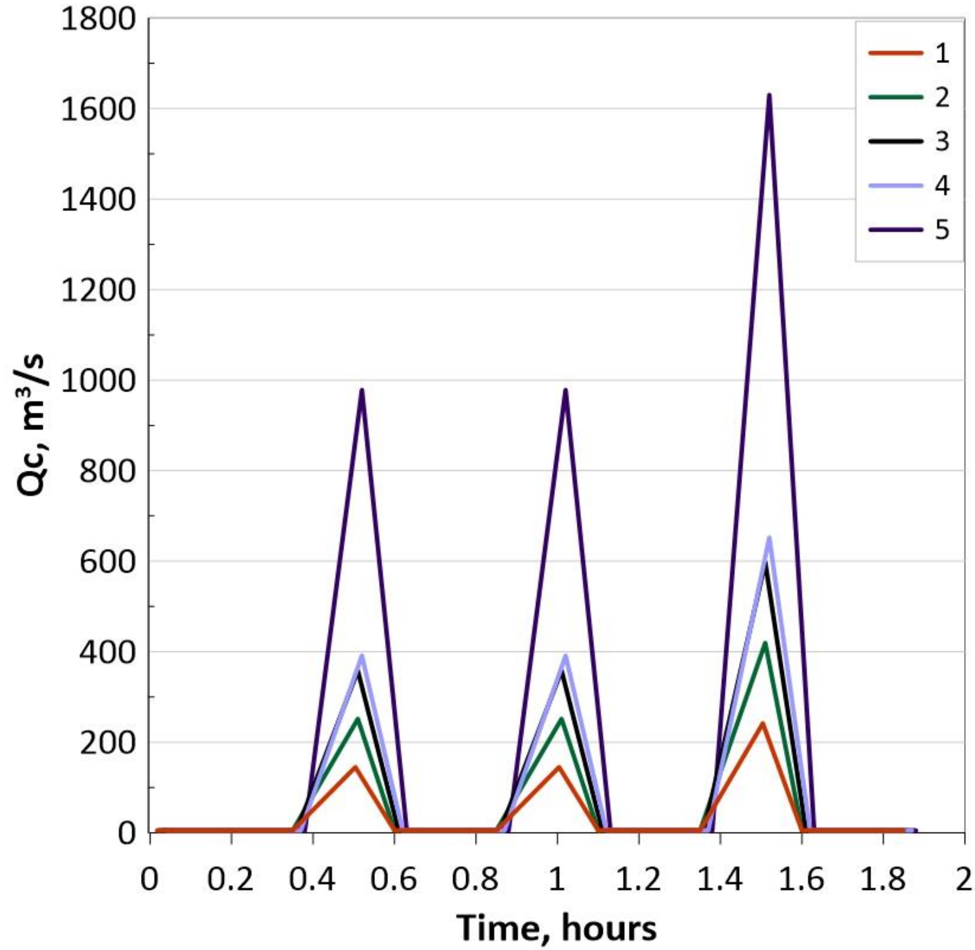


Input hydrograph for debris flow modeling

Modelled hydrograph

Debris flow velocity

№ section	Slope, degrees	Depth for the 1 and 2 waves, m	Velocity for the 1 and 2 waves, m/s	Depth for the 3 wave, m	Velocity for the 3 wave, m/s
1	28.2	2.2	14.6	2.0	15.0
2	26.6	2.0	13.9	2.1	14.3
3	24.6	2.1	13.1	2.3	13.1
4	20.4	2.8	11.2	2.3	11.2
5 (forward wave)	20.4	4.0	8.3	6.2	7.2
Debris flow origination site	25.2	2.7	12.4	3.0	11.9



Changes in the debris flow discharge in the 4 sections and forward wave (5).

FLO-2D Modeling

$$\begin{cases} \frac{1}{g}\cdot\frac{\partial u}{\partial t}+\frac{u}{g}\cdot\frac{\partial u}{\partial x}+\frac{v}{g}\cdot\frac{\partial u}{\partial y}+\frac{u^2}{C^2 h}=-\frac{\partial z}{\partial x} \\ \frac{1}{g}\cdot\frac{\partial v}{\partial t}+\frac{u}{g}\cdot\frac{\partial v}{\partial x}+\frac{v}{g}\cdot\frac{\partial v}{\partial y}+\frac{|uv|}{C^2 h}=-\frac{\partial z}{\partial y} \\ \frac{\partial(u\cdot h)}{\partial x}+\frac{\partial(v\cdot h)}{\partial y}=-\frac{\partial z}{\partial t} \end{cases}$$

where the unknowns *u* and *v* are the longitudinal and transverse components of the current velocity, *z* is the mark of the water surface, *g* is the acceleration of gravity, *t* is the time, *C* is the Shezy coefficient.

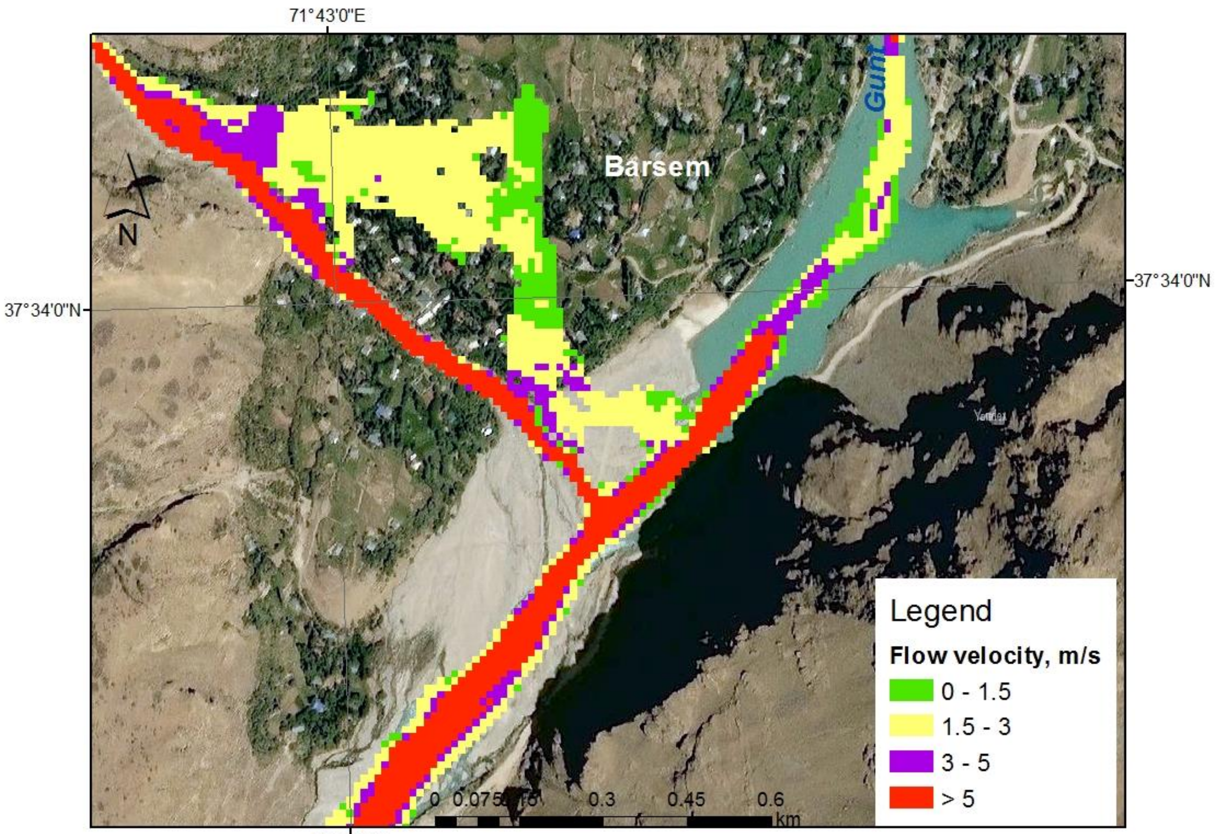
FLO-2D is a two-dimensional hydrodynamic model of water and mudflow movement, based on regular rectangular computational grids. Its application is possible for solving a number of tasks related to hazardous hydrological phenomena, for example:

- movement of streams in channels, on the floodplain and in the delta;
- flooding of urban areas, taking into account barriers and flow losses;
- propagation of hurricane waves and tsunamis;
- movement of mudflows;
- passage of floods caused by precipitation;
- flood risk assessment.

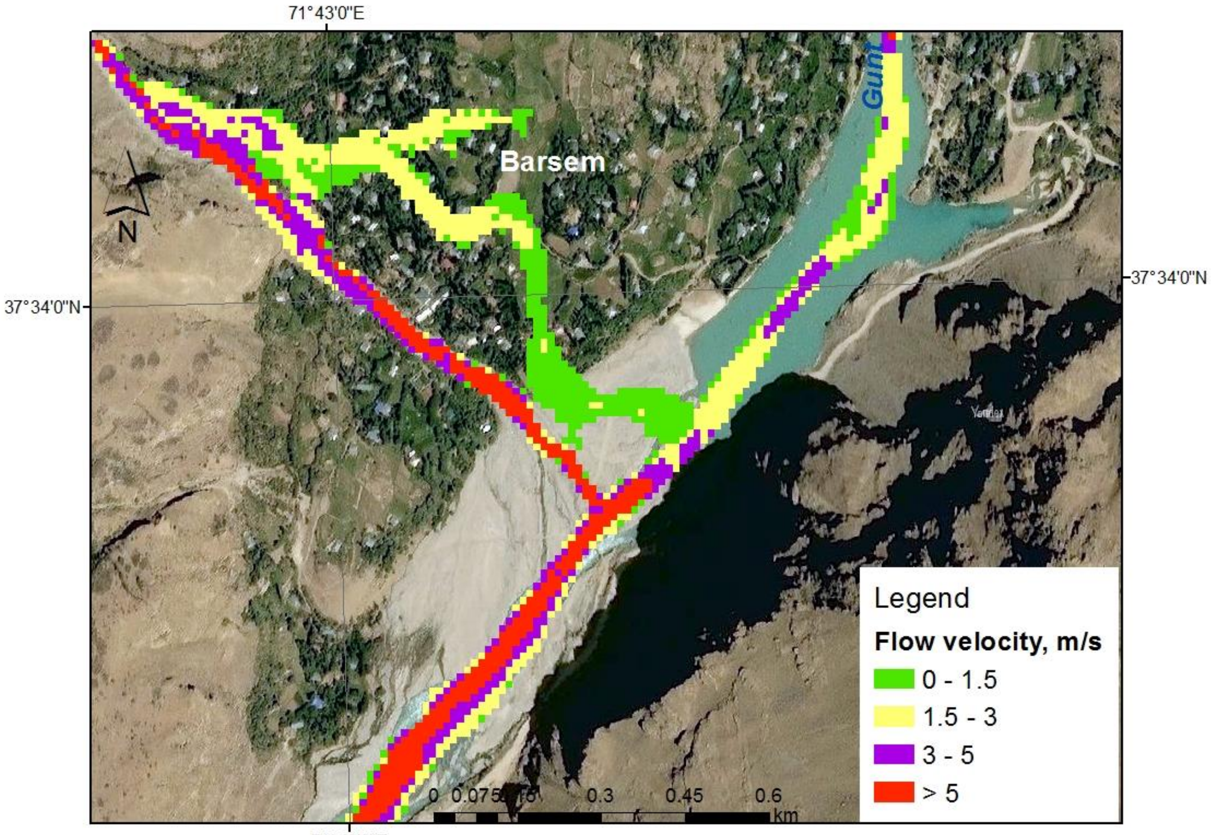
FLO-2D Modeling

To estimate flood prone zone 2 types of data obtained by transport-shear model:
1. Hydrograph of the forward wave (I scenario)
2. Hydrograph of the debris flow wave on the way out origination site (II scenario)

For the I scenario the flow discharge varied from 430 to 1939 m3/s. The travel time for the three waves changed from 3 minutes to 21. For the II scenario debris flow discharge was from 30 to 560 m3/s. The travel time in this case varied from 8.5 to 21.2 minutes.



Flow velocity according to I scenario



Flow velocity according to II scenario