Hydrological modelling over different scales on the edge of the permafrost zone: approaching model realism based on experimentalists' knowledge

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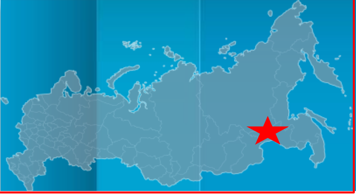
Motivation

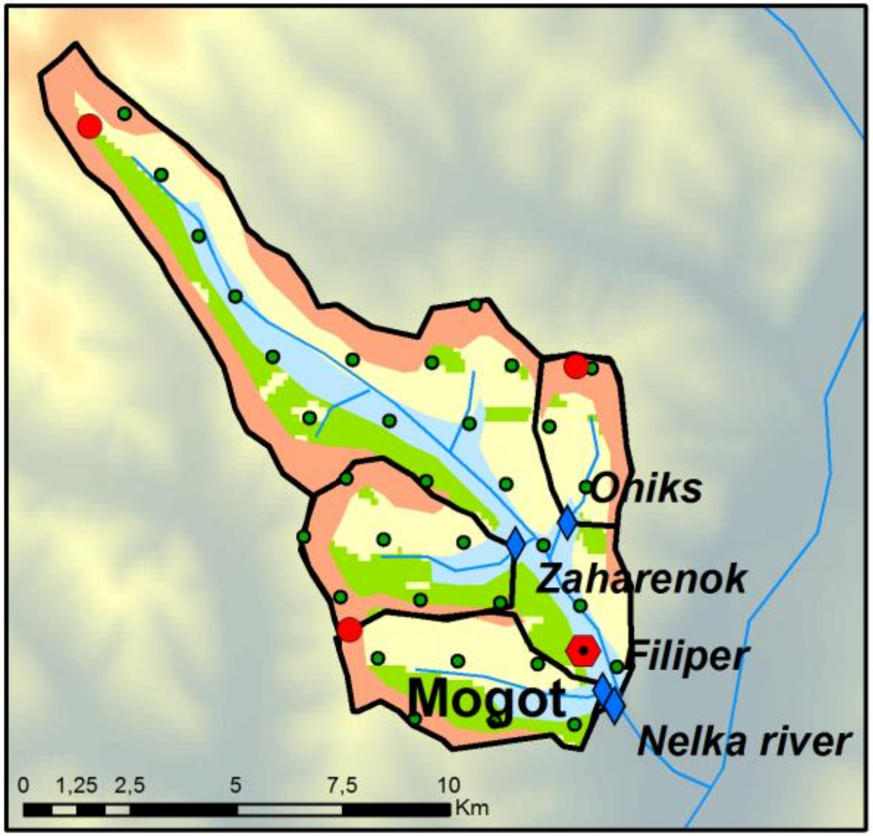
The aim: make use of historically hydrological data for modelling poorly-gauged river basins on larger scales near the southern margin of the permafrost zone in Eastern Siberia.

Research tasks

- Identify and systematize basic properties of land cover and land surface which determine hydrological processes based on filed data of small research watershed.
- Parameterize hydrological model
- Verify model parameters at different scales
- Again and again show that one hydrological model can be successfully applied at different scales



Research area



Experimental poligon “Mogot”
(1976-1985, State Hydrological Institute)

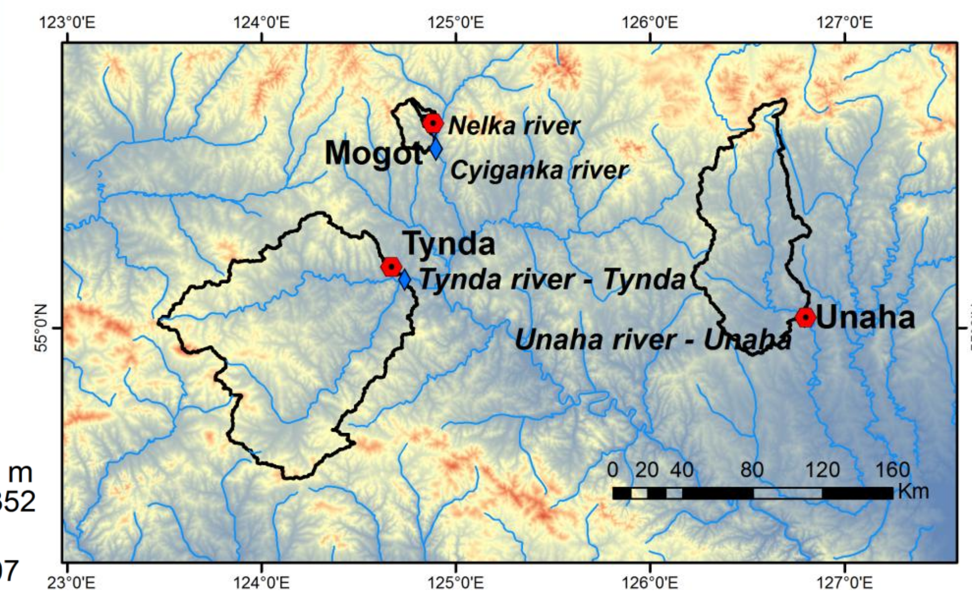
- Representative point
- Meteorological station
- Basin outlet
- Basin border
- Precipitation gauge
- Watershed divides
- Shaded slopes
- Exposed slopes
- Valley bottoms

Near the southern margin of the permafrost zone in Eastern Siberia. Baikal-Amur Main Line

The upper elevated (500 – 950 m a.s.l.).
Part of the Amur River basin.
Area: from 2 to 4060 km^2

MAT -7.5ºC
Precip. 600 mm
Flow ~ 300 mm

Altitude, m
2352
107



Research area

1976-1985 The experimental hydrological polygon **"Mogot"**

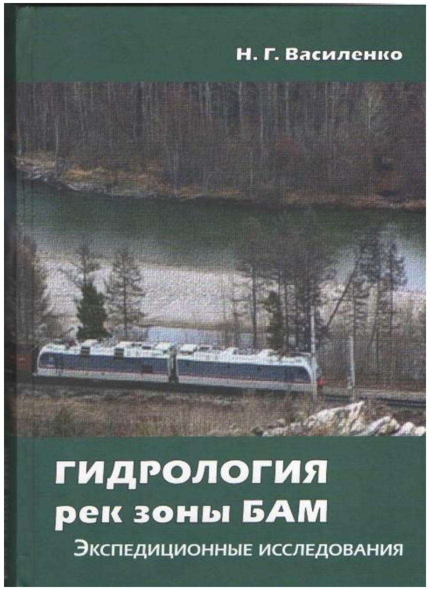
Meteorological information (temperature, precipitation, radiation, temperature balance, air humidity, cloudiness, evaporation).

Hydrological information (daily runoff for different gauges).

Landscape studies and mapping.

Soil survey (soil moisture, soil temperature at depth, depth of thaw).

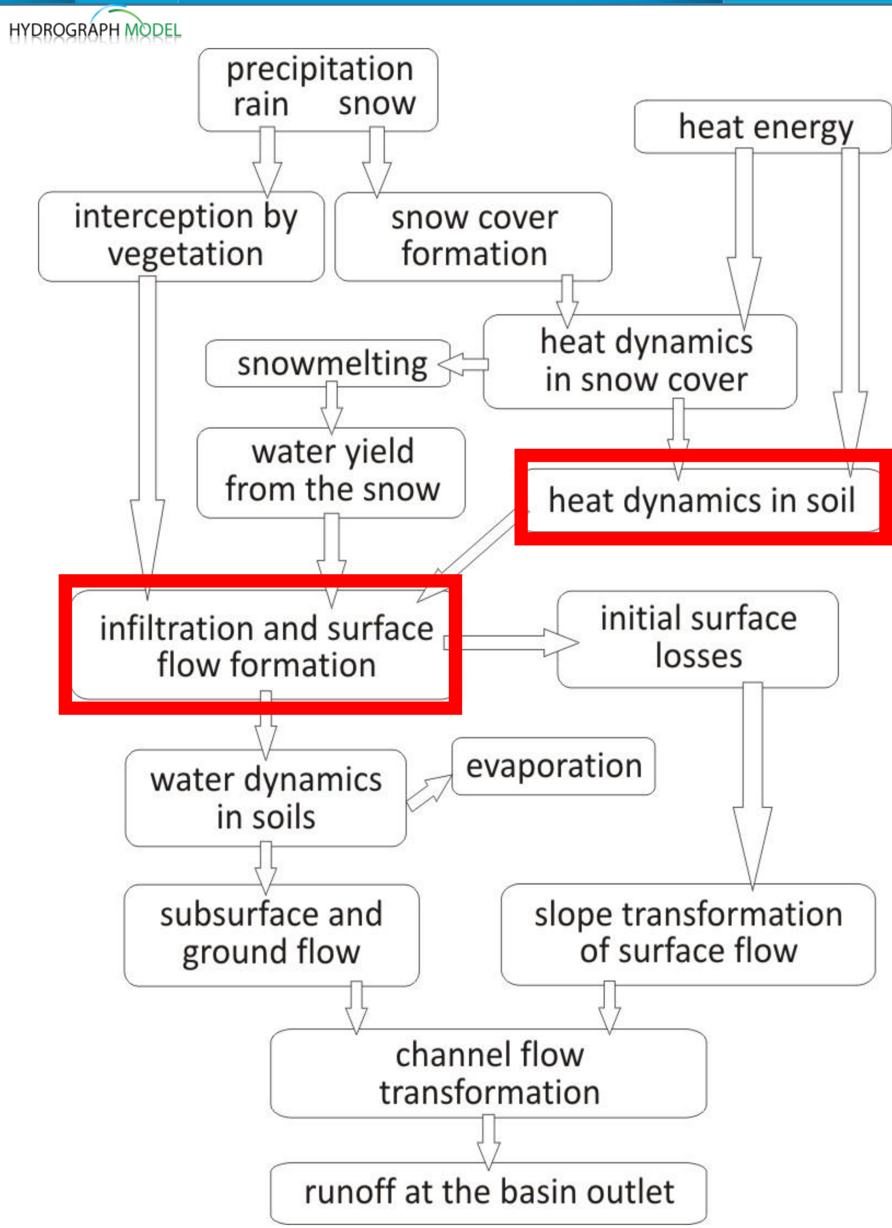
Snow surveys



Parameters

*Vasilenko N. Hydrology of the BAM Zone Rivers : Field Studies — SPb. : Nestor-Historia, 2013. — 672 p.

Hydrograph model



- ✓ **Distributed** hydrological **process-based model** with single structure for watersheds of any scale
- ✓ Forcing data (precipitation, air temperature, air humidity) is **suitable for remote data-poorly regions**
- ✓ Account for **heat and water dynamics in frozen and thaw soil profile** (permafrost!)
- ✓ Most parameters are **observable landscape properties**
- ✓ Most parameters are transferrable to other basins with similar landscapes of any size without change (**free of scale problem**)

initially developed by Prof. Yury Vinogradov

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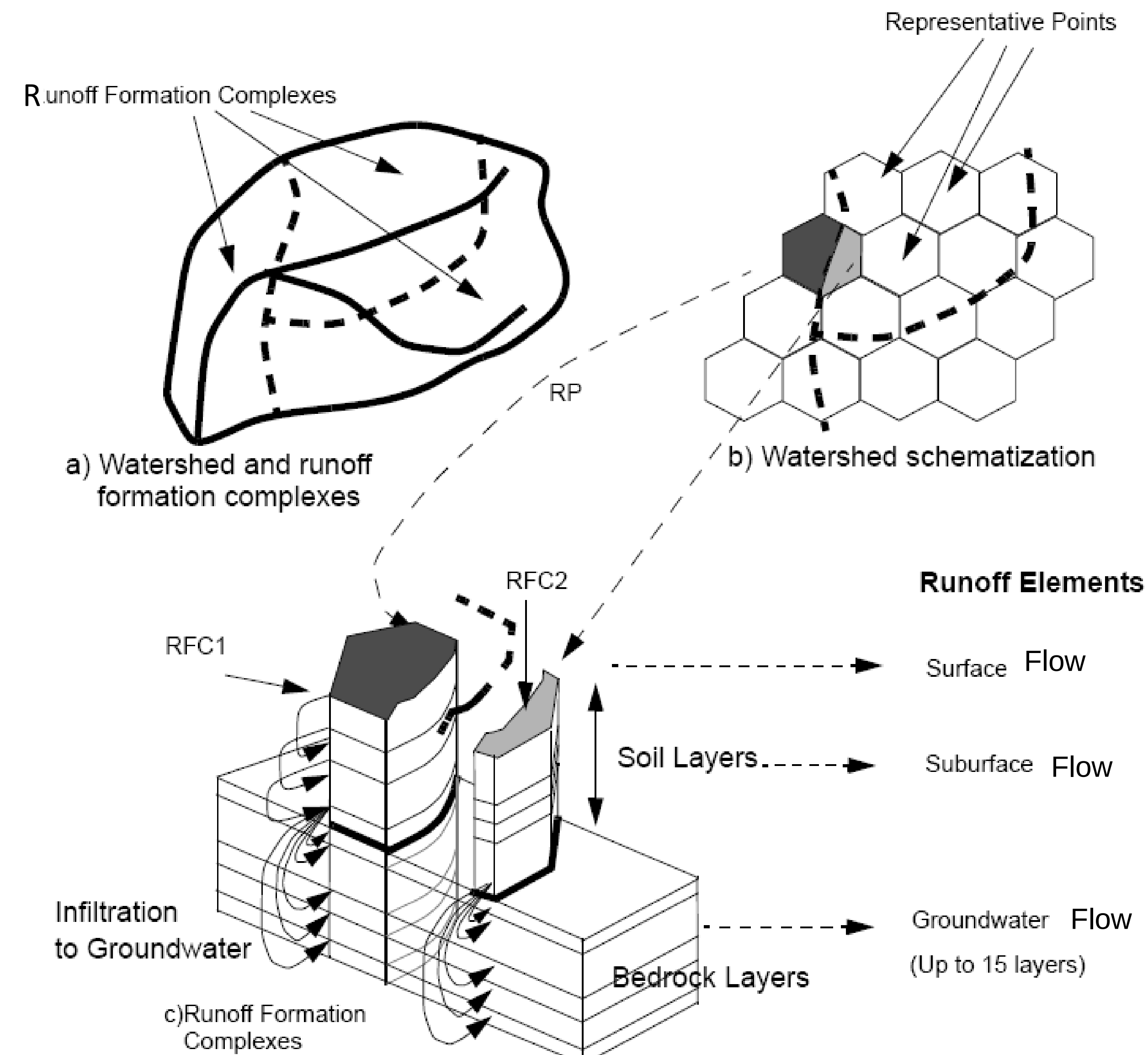
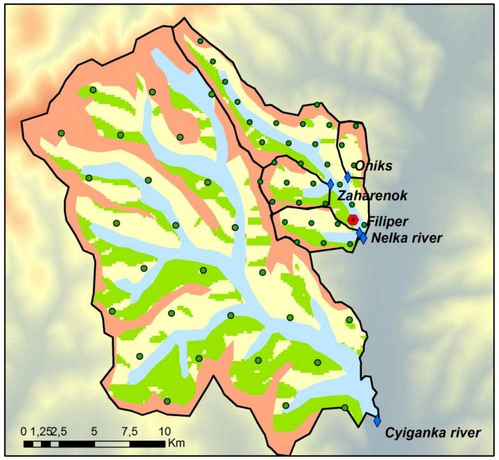
Hydrograph model



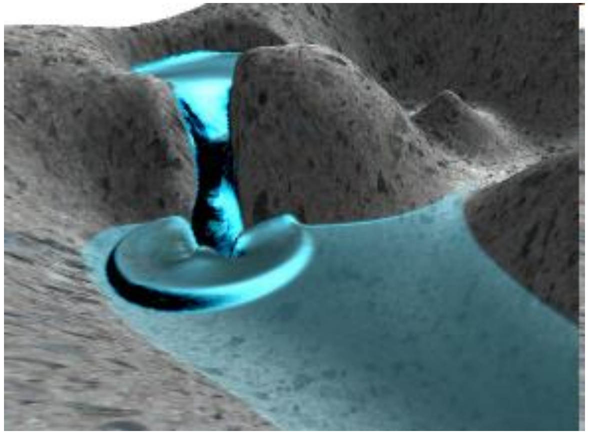


- Representative point (RP) = elementary slope characteristics
- Runoff Formation Complex (RFC) = vegetation soil profile parameters -> runoff elements outflow

Combination of RP and RFC = scale-free transfer of the parameters

The concept of runoff elements

Watershed – elementary slope – runoff elements system (**surface, soil**, underground)



Runoff element: a part of elementary slope limited by micro-divides directed with its open part to the slope non-channel or underground drainage system

1. Water balance $$q = \beta[\exp(\alpha w) - 1]$$

W – water volume (m^3), *q* – outflow ($m^3 s^{-1}$)

2. System of *n* runoff elements

$$\sum_{i=1}^{n} \beta_i \left[\exp\left(\alpha_i W_i\right) - 1\right] = B\left[\exp\left(A \sum_{i=1}^{n} W_i\right) - 1\right] \quad A = \alpha / F \quad B = F\,\beta \qquad n \sim \mathrm{F\ (basin\ area)}$$

α [m^{-1}], β [ms^{-1}] **Hydraulic parameters**

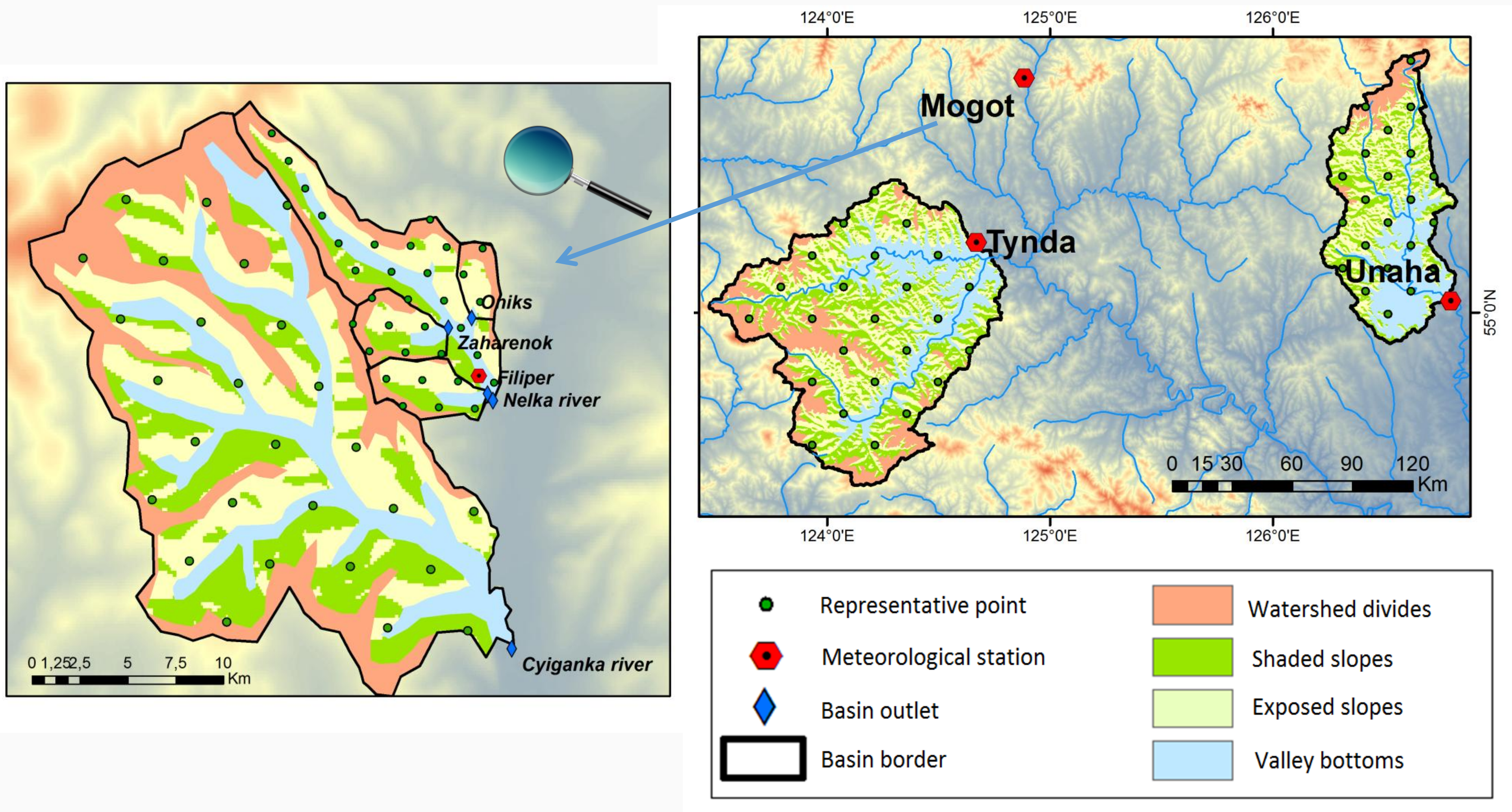
Characteristic outflow time

$$T = 1/(\alpha\,\beta)$$

Water storage

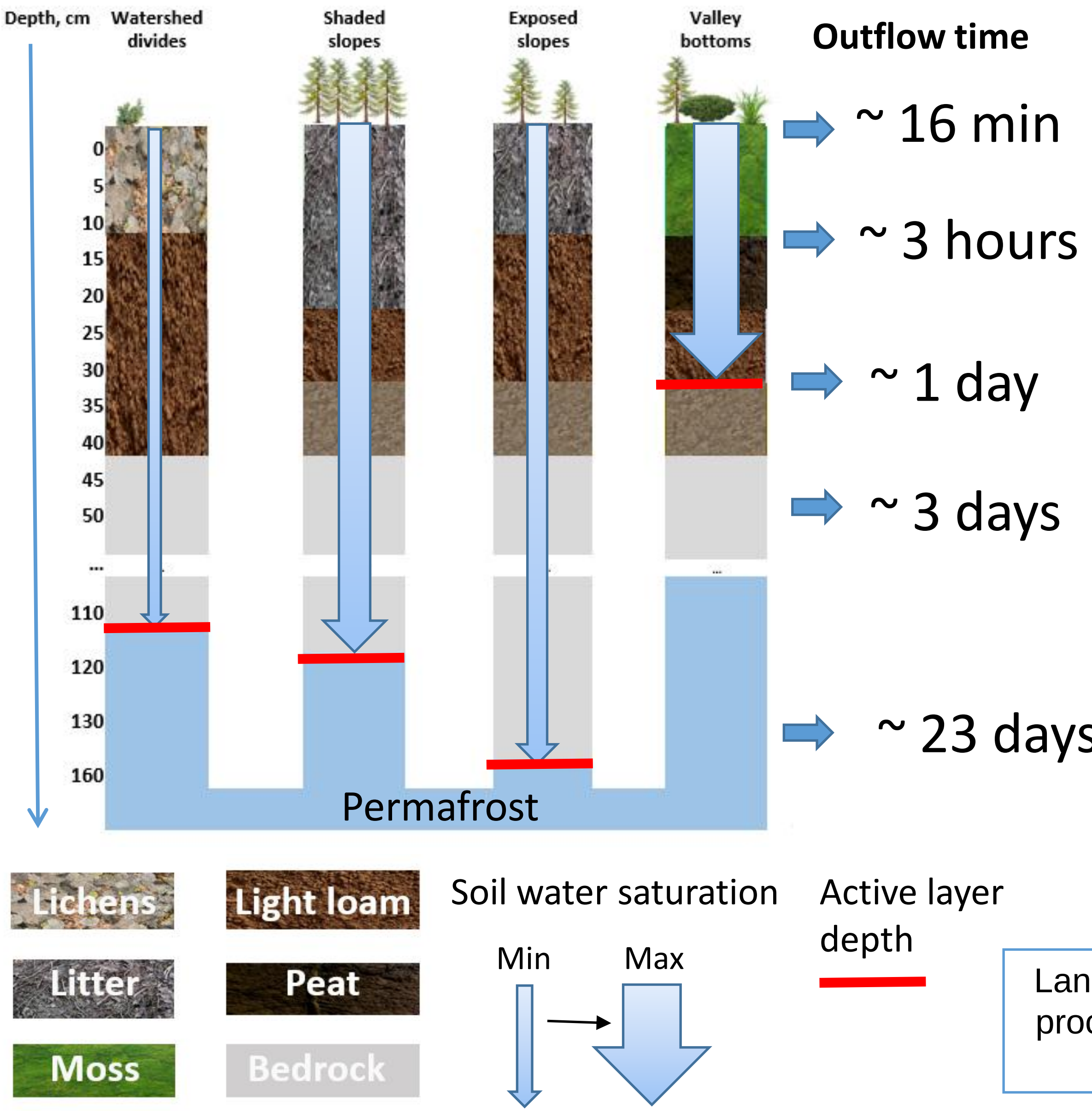
$$H = \ln(q/\beta + 1)/\alpha$$

Parametrization
Runoff formation complex



Parametrization

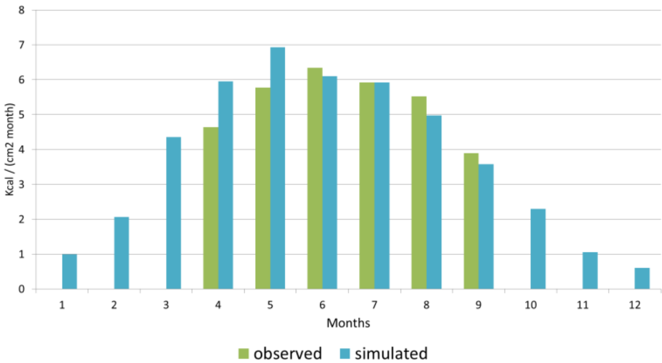
Soil columns



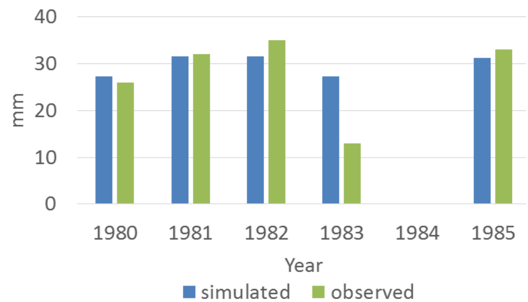
Soil parameters	Min/max
Density, kg/m^3	520/2630
Porosity, m^3/ m^3	0.35/0.93
Maximum water holding capacity, m^3/ m^3	0.10/0.45
Infiltration coefficient, mm/min	0.01/24
Specific heat capacity, J/(kg°C)	830/1930
Specific heat conductivity, W/(m°C)	0.8/1.7
Hydraulic parameter of soil runoff elements, m^3/s β	<u>Active layer</u> Upper layer:10 Bottom layer: 0.005

Landscapes govern specific hydrological processes. The set of model parameters was developed for each of them.

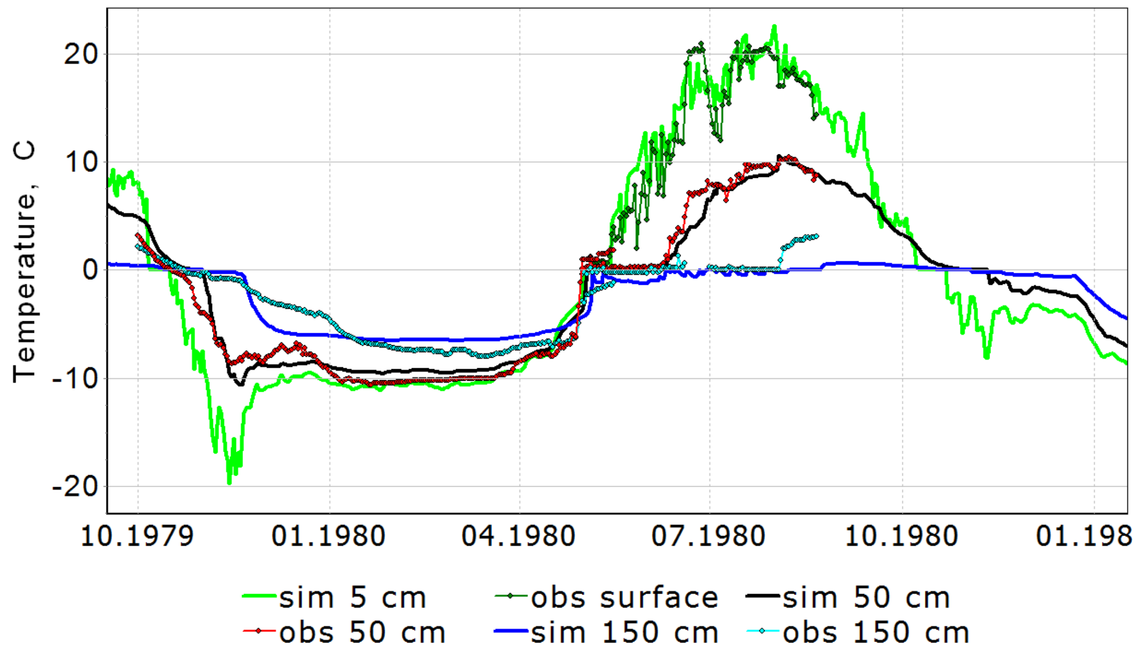
Soil and snow variable states



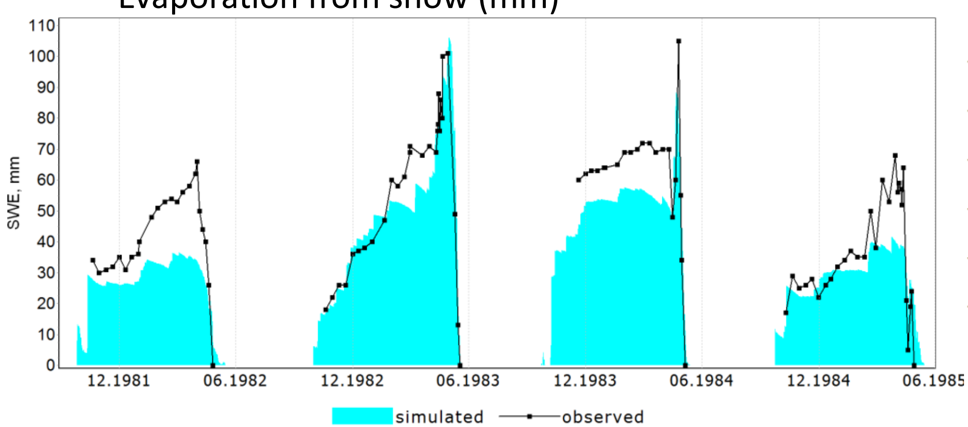
Solar radiation



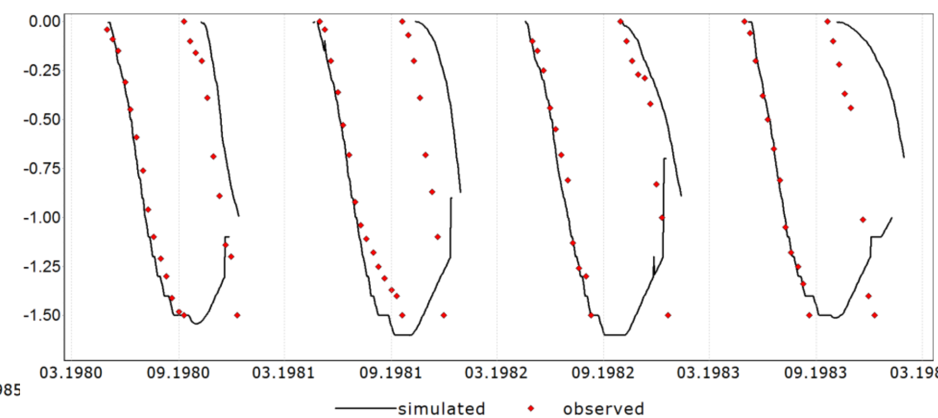
Evaporation from snow (mm)



Soil temperature at depths (°C)

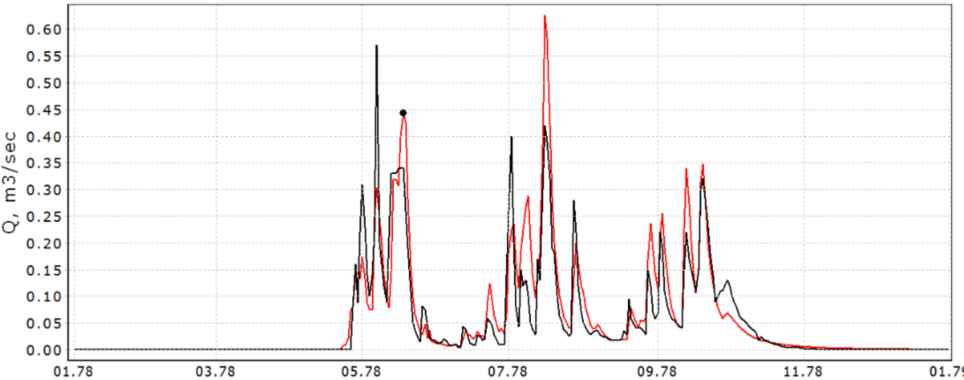


Basin average SWE (mm)

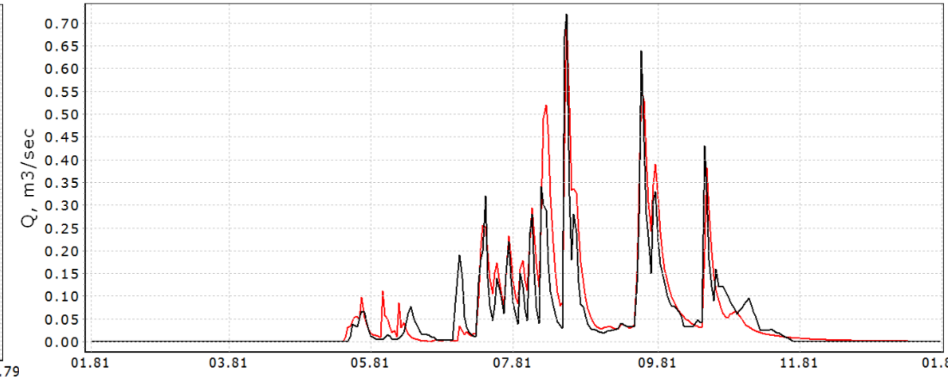


Depth of thawing and freezing of soil (m)

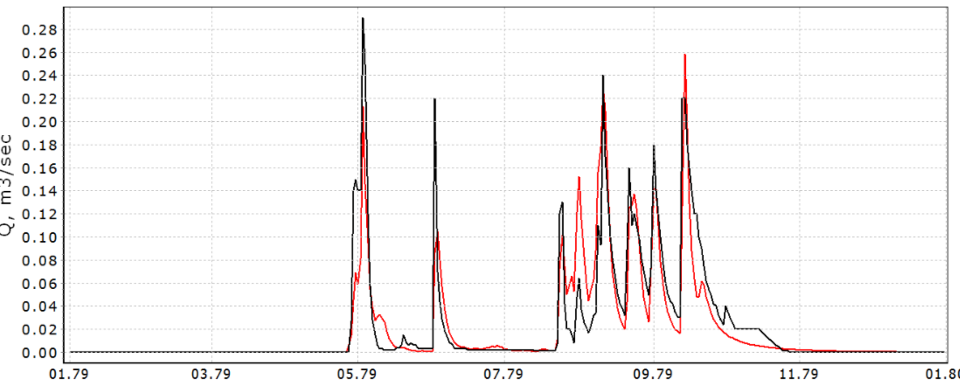
Small scale. 2-6 km²



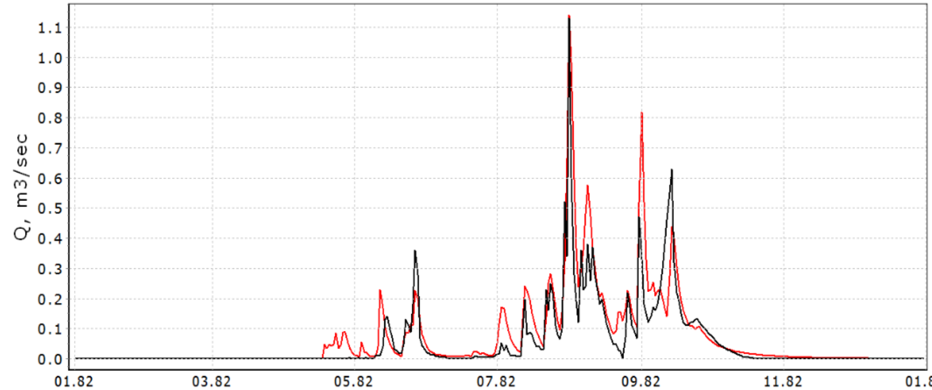
Zaharenok, NS=0.76, 1978



Filiper, NS=0.77, 1981



Onix, NS=0.79, 1979

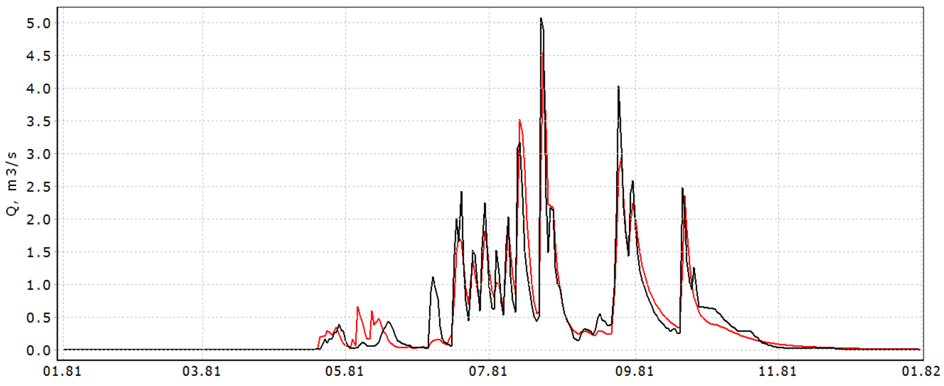


Filiper, NS=0.66, 1982

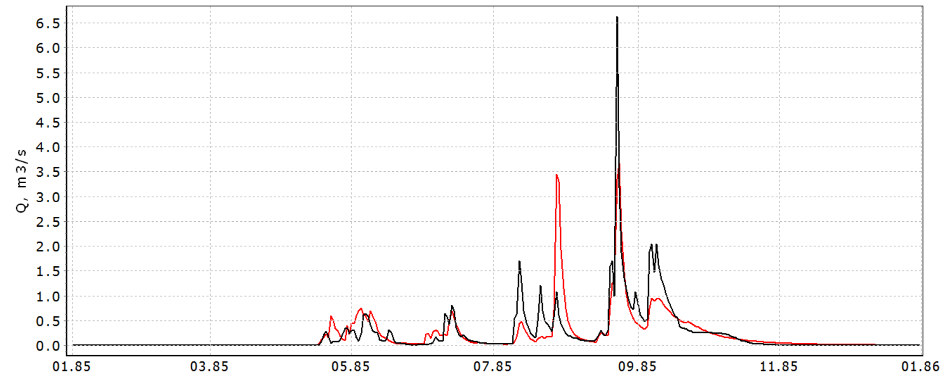
Simulated (red) and **observed (black)** hydrograph, 1976-1985

River	Area, km²	Observed flow, mm	Simulated flow, mm	Precipitation, mm	Evaporation, mm	NS (med./av)	NS (max)	NS (min)
Zakharenok	**5.8**	**216**	**363**	**628**	**260**	**0.35/0.26**	**0.76**	**-0.14**
Filiper	**4.5**	**255**	**346**	**634**	**285**	**0.55/0.40**	**0.77**	**-0.12**
Onix	**2**	**355**	**342**	**607**	**259**	**0.65/0.64**	**0.79**	**0.31**

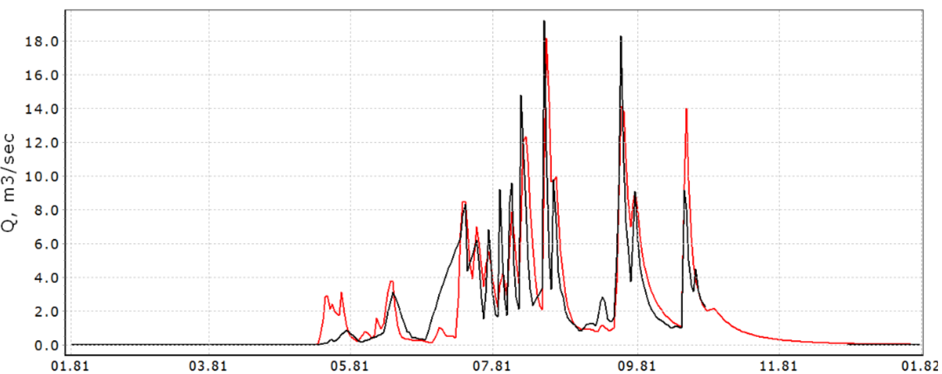
Middle scale. 31-150 km^2



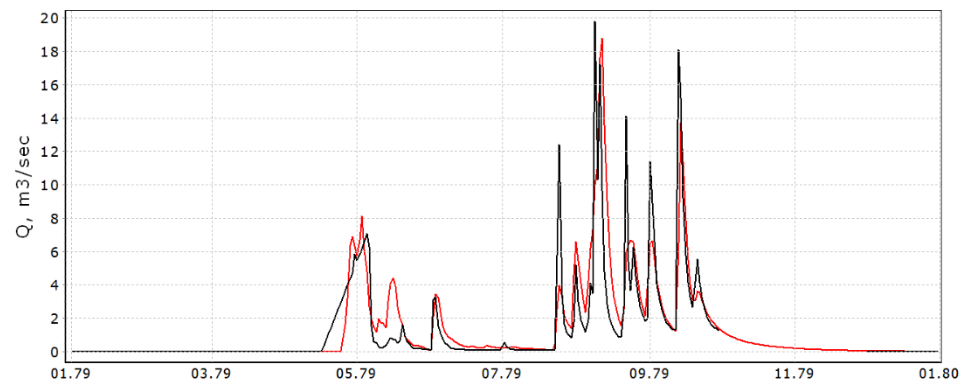
Nelka, NS=0.87, 1981



Nelka, NS=0.58, 1985



Tsyganka, 1981



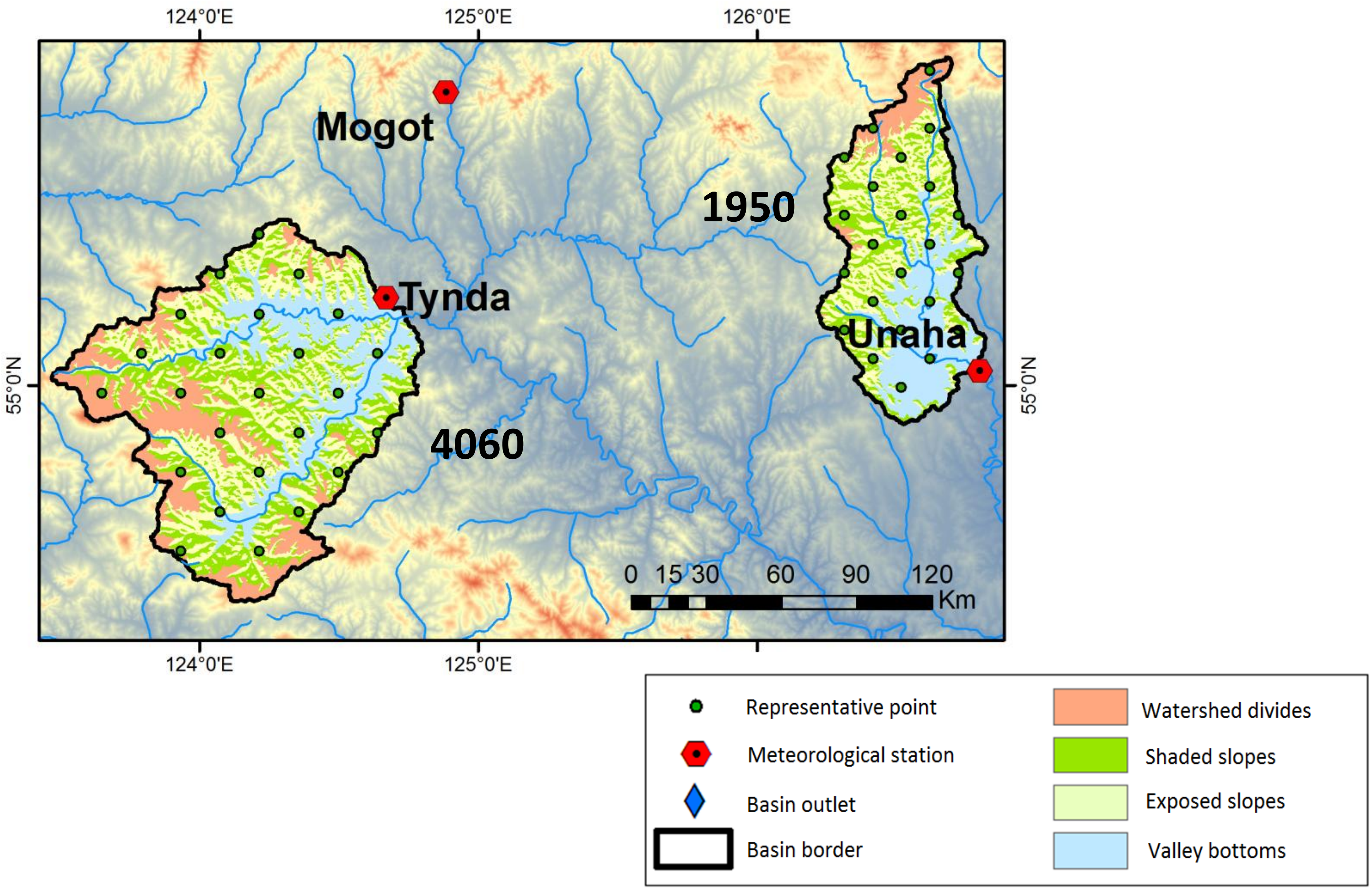
Tsyganka, 1979

Simulated (red) and **observed (black)** hydrograph, 1976-1985

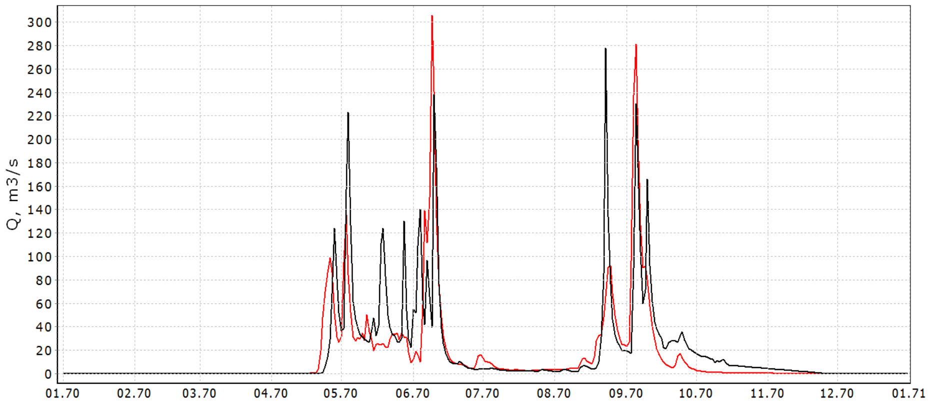
River	Area, km^2	Observed flow, mm	Simulated flow, mm	Precip., mm	Evap., mm	NS (med./av.)	NS (max)	NS (min)
Nelka	30.8	295	320	622	300	0.71/0.70	0.87	0.58
Tsyganka	150	-	308	617	306	-	-	-

Incomplete observational data

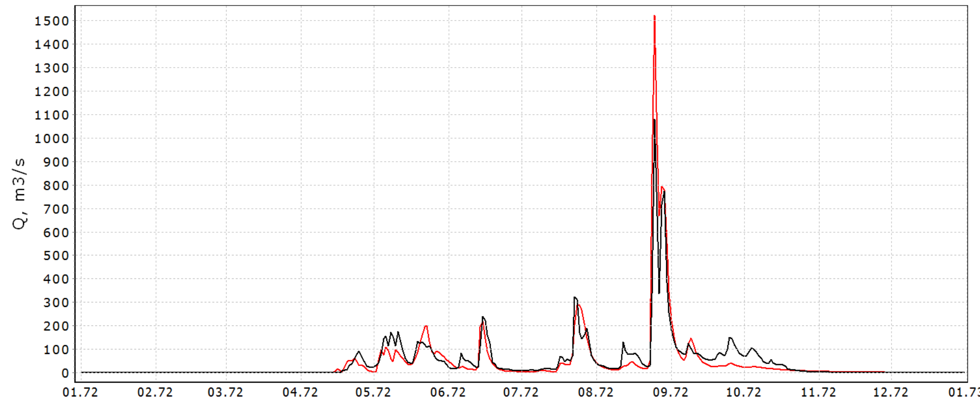
Large scale. 2000-4000 km^2



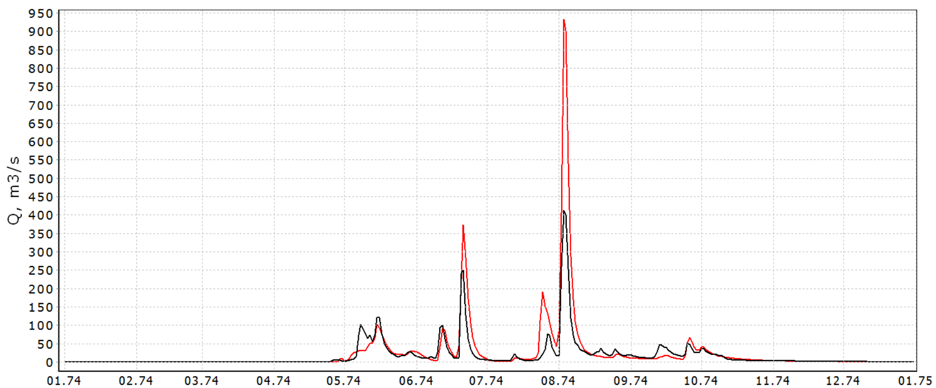
Large scale. 1950-4060 km^2



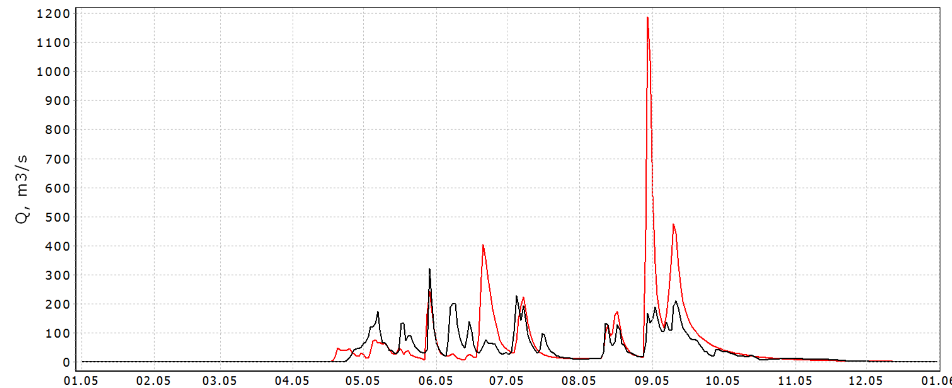
Unakha, NS= 0.58, 1970



Tynda, NS=0.73, 1972



Unakha, NS=-0.81, 1974



Tynda, NS=-2.3, 2005

Simulated (red) and **observed (black)** hydrograph

River	Area, km^2	Period	Observed flow, mm	Simulated flow, mm	Precipitation, mm	Evaporation, mm	NS (med./av.)	NS (max)	NS (min)
Tynda river - Tynda	4060	1966-2012	286	293	645	354	0.52/0.31	0.73	-2.37
Unakha river - Unakha	1950	1966-1994	327	342	640	300	0.46/0.40	0.69	-0.41

Conclusions

- Based on field data the model parameters were estimated for main landscapes of studied region.
- Model simulation of river runoff, snow depth, soil temperature and moisture in the Mogot study site are satisfactory.
- Model parameterization developed on the Mogot site was employed **without change** to simulate runoff generation in the four river basins with area from 150 to 4060 km^2 in the surrounded region.
- Hydrograph model complexity is suitable for remote regions as it allows for *a priori* assessment of the model parameters which can be used in ungauged basins in similar conditions at larger scales.

Thank you for attention

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HYDROGRAPH MODEL

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