Ground flow as a source of river flow in small watersheds in continuous, discontinuous permafrost and zone of seasonal ground freezing by data analysis and hydrological modelling

Lebedeva L[1,3], Semenova O[2,3]

[1]Melnikov Permafrost Institute, Yakutsk, Russia; [2]St. Petersburg State University, St. Petersburg, Russia; [3]Hydrograph Model Research Group

lyudmilaslebedeva@gmail.com; http://hydrograph-model.ru/

1. Introduction

- hydrological processes in cold environments are influenced by presence of frozen ground;
- properties and distribution of frozen ground are highly variable in space and time;
- many hydrological models do not account for ground freezing and thawing and associated changes in surface and subsurface flow.

The **aim** is to analyze interactions between ground freezing, subsurface flow and river runoff in three different northern watersheds using observational datasets and process-based Hydrograph model

2. Research questions

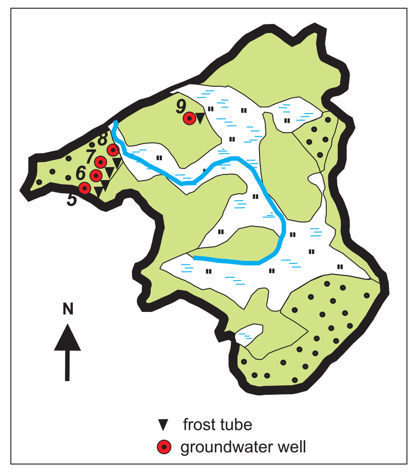
1) How does frozen ground influence generation of surface, subsurface and underground flow?
2) What is the role of the landscape in interactions between water and frozen ground?
3) Is Hydrograph model able to adequately represent hydrological cycle in different cold watersheds?

3. Study sites

Site	Area, km²	Altitude, m	MAAT, °C	P, mm	Landscape
Bomnak	22	300-470	-5.1	587	Larch taiga
Kolyma	22	800-1700	-11.6	400	Mountain tundra
Pribaltiys-kaya	40	174-260	4.4	719	Mixed forest and arable land

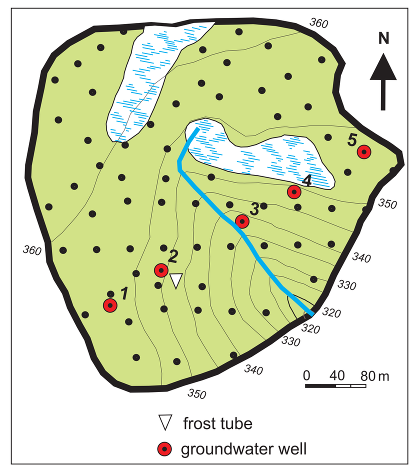
Pribaltiyskaya site

Seasonally frozen ground
V. Ezerupite watershed, 0.27 km²



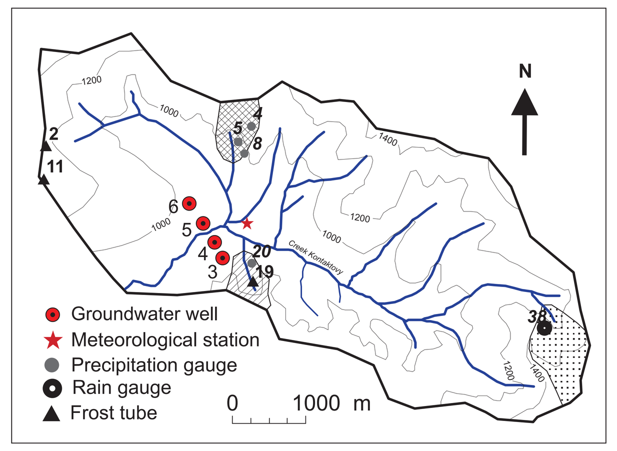
Bomnak site

Discontinuous permafrost
Bezymyanny watershed, 0.2 km²

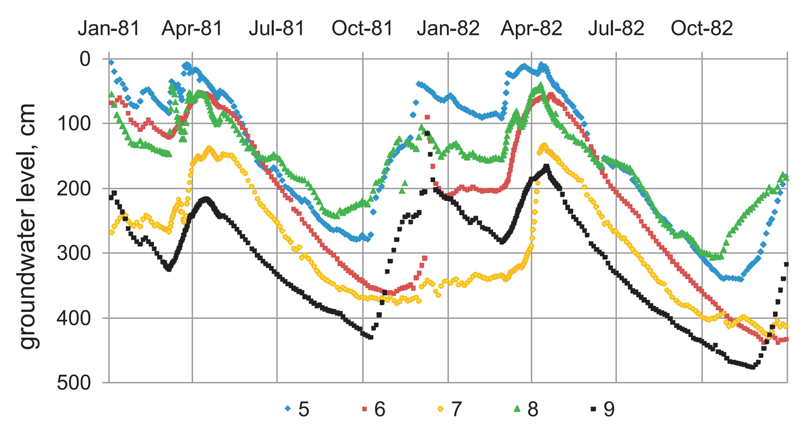


Kolyma site

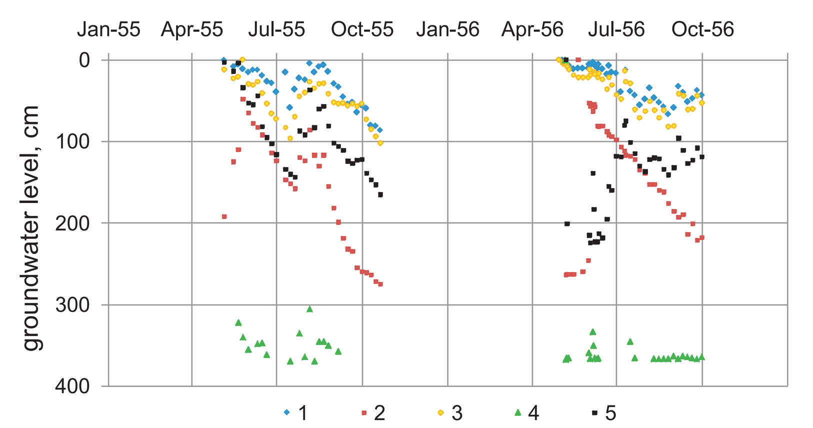
Continuous permafrost
Konaktovy watershed, 21.6 km²

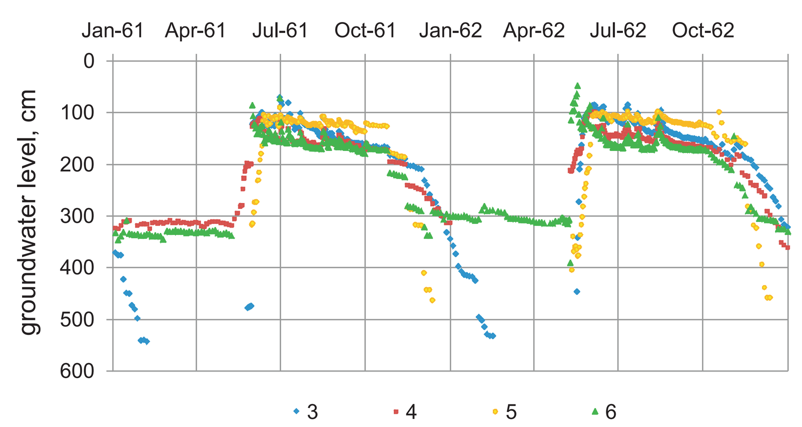


4. Groundwater seasonal dynamics and spatial variability

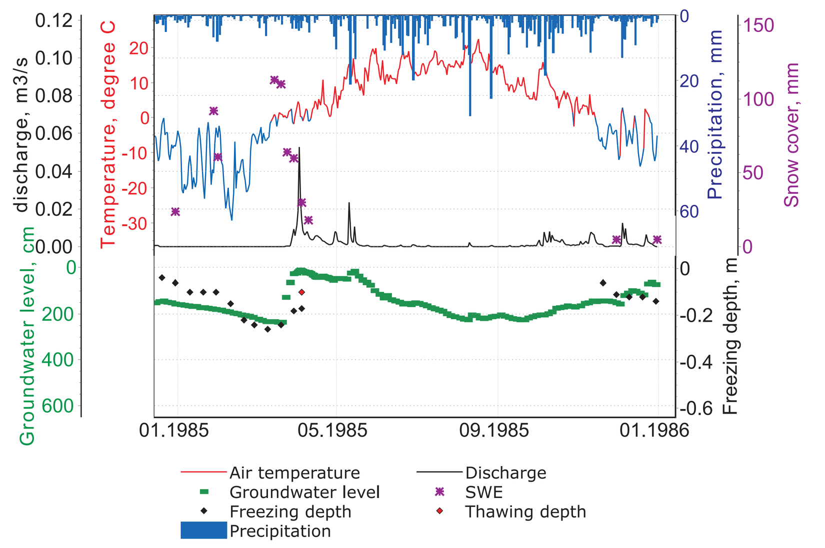


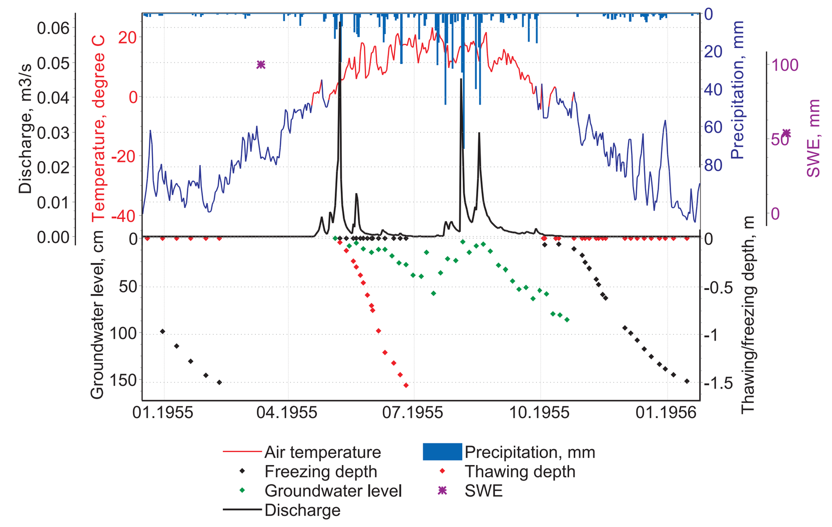
- groundwater flow is formed on stable aquifuge and is active all year round;
- there are two distinct seasons: wet (Dec-June) and dry (July-Oct);
- water level course is consistent in different wells;
- water level shows dependence on snowmelt, precipitation and evaporation

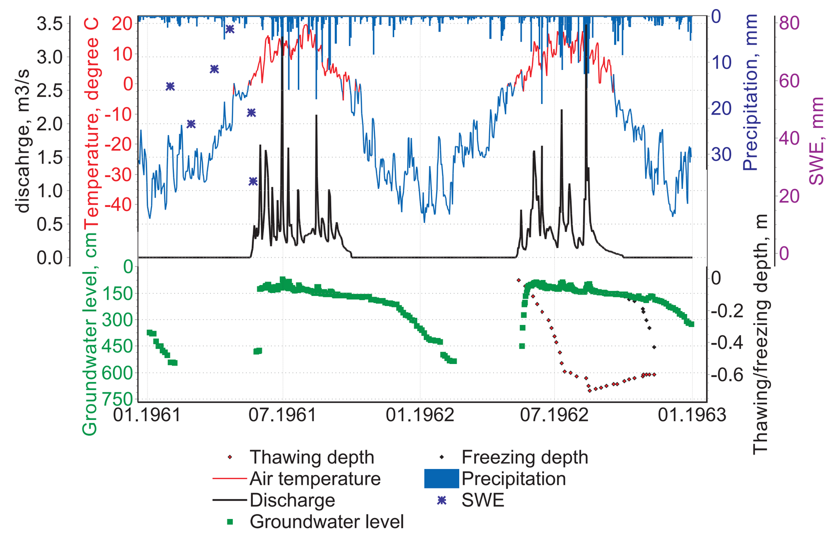




- groundwater flow is formed on temporary variable permafrost table;
- near-surface ground flow exists in summer period only. Ground freezes completely in autumn-winter except the talik zones;
- water levels in different wells could be significantly different mainly due to local permafrost properties;
- additional controlling factor to snowmelt, precipitation and evaporations is thawing of the active layer that causes aquifuge deepening and groundwater level decrease.



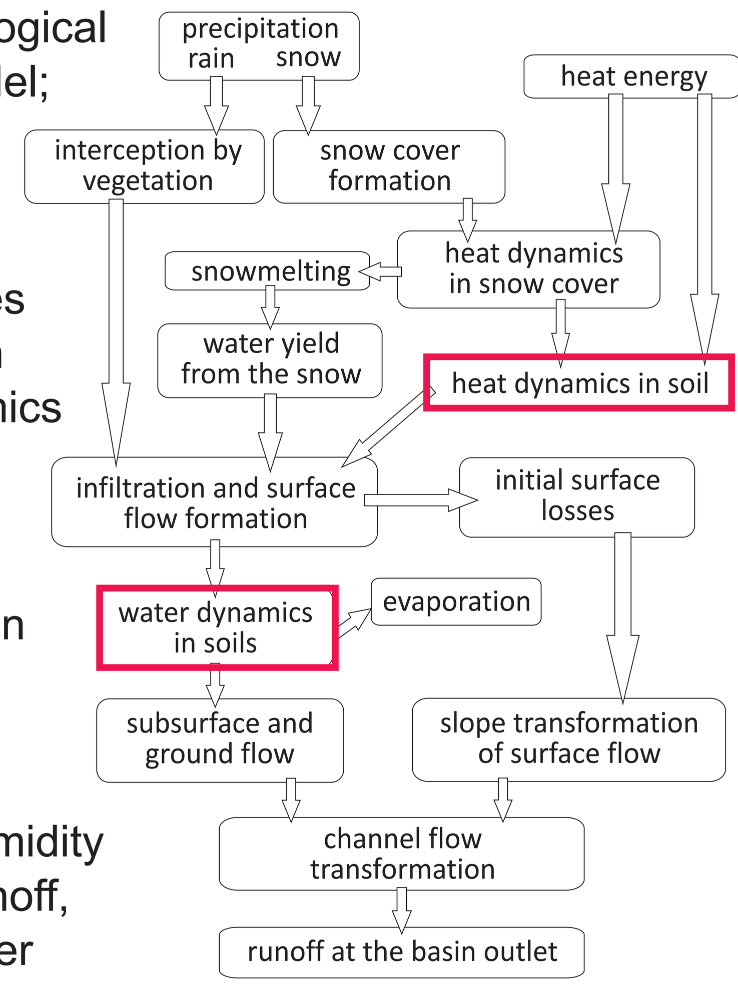




5. The Hydrograph Model

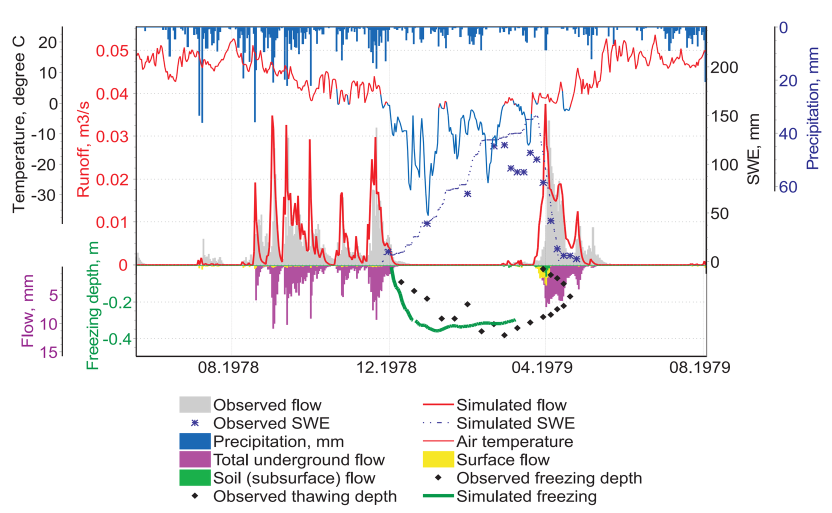
- distributed hydrological process-based model;
- most of the model parameters are observable landscape properties
- analytical solution of the thermodynamics equation in soil with explicit accounting for water dynamics in thawed and frozen soils
- forcing data: precipitation, air temperature, air humidity
- output results: runoff, variable states, water balance components

(Vinogradov et al., 2011; Semenova et al., 2013)

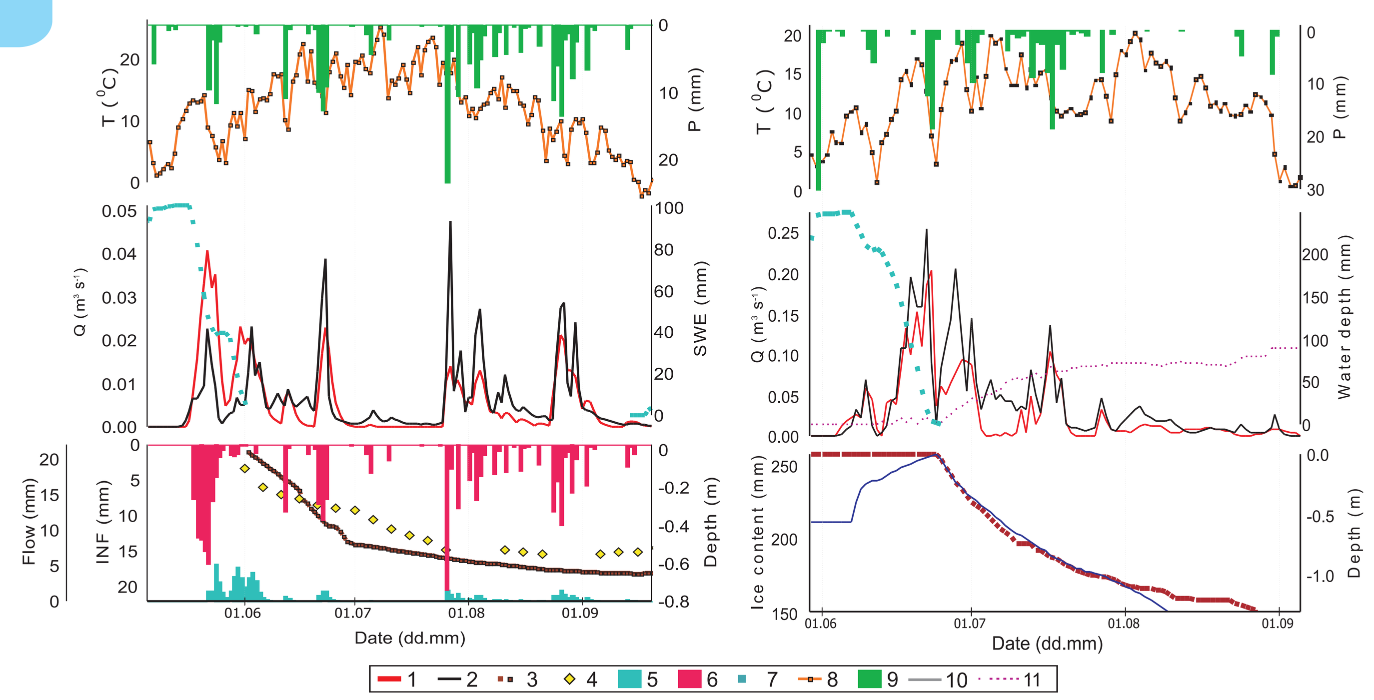


6. Modelling results

V. Ezerupite watershed, 0.27 km²



Kolyma station, rocky talus (left) and wet larch forest (right)



1 and 2 - simulated and observed runoff (m³s⁻¹),
3 and 4 - simulated and observed thawing depth (m),
5 - depth of surface flow (mm),
6 - depth of percolated water (mm),
7 - snow water equivalent (mm),
8 - air temperature (°C),
9 - rain (mm),
10 and 11 - the ice and water content in a 2-m soil profile (mm).

7. Conclusions

In permafrost watersheds ground flow is formed only in summer period in active layer. In winter ground is completely frozen with exception of talik.

Seasonal dynamics of groundwater in non-permafrost watershed is controlled by precipitation, snowmelt and evaporation. Additional factor in permafrost zone is seasonal thawing and freezing.

Modelled and observed SWE, thawing/freezing depths and hydrographs show satisfactory agreement in all studied watersheds.

Modelling results show that surface flow occurs when the ground is frozen and ice-saturated.

Landscape properties controls dominant hydrological processes in permafrost watershed.

8. References

Lebedeva L., Semenova O., Vinogradova T. (2014) Simulation of Active Layer Dynamics, Upper Kolyma, Russia, using the Hydrograph Hydrological Model // Permafrost and Periglac. Process. 25 (4): 270–280 DOI: 10.1002/ppp.1821

Semenova O., Lebedeva L., Vinogradov Yu. (2013) Simulation of subsurface heat and water dynamics, and runoff generation in mountainous permafrost conditions, in the Upper Kolyma River basin, Russia // Hydrogeology Journal 21(1): 107-119 DOI:10.1007/s10040-012-0936-1

http://hydrograph-model.ru/

The study was supported by Russian Foundation of Basic Research (projects No.15-35-21146)