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Influence of Atmospheric Pressure Surges on the Level of Suprapermafrost Waters and the Flow of Small Rivers (Anadyr Lowland, Chukotka)

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Abstract. It is known that atmospheric pressure surges affect the discharge of underground water sources in large artesian basins. In southern latitudes, the groundwater tables change insignificantly following the diurnal variations of atmospheric pressure. There is no information on the influence of rapid changes in atmospheric pressure on the position of the surface of the suprapermafrost waters and river flow in the Arctic region. The study of the diurnal course of the level of underground suprapermafrost and surface waters was carried out to identify the links of river flow with atmospheric phenomena and cryogenic processes. It was found that the daily atmospheric pressure drop with an amplitude of 1.2 kPa in the area of the small Ugolnaya-Dionisia river, located in the Anadyr lowland in Chukotka, led to a simultaneous decrease and then an increase in the level of suprapermafrost underground and surface river basin waters by 2.5-7.8 cm. This corresponds to a short-term decrease and then an increase in the river water discharge by more than 3.5 times. To clarify the factors that determine the mechanism of the influence of atmospheric pressure on the water level and river flow, a consideration of the hydrophysical properties of aquifer-containing peat soils was carried out. Compression tests revealed that the elasticity of the peat soils horizon remains within the range of 0-15 kPa, which contributes to a dynamic change in porosity even with a slight change in the external load. This means that the atmospheric pressure changes during weather development are sufficient to modify the water capacity of peat soils and deposit them, and then discharge a part of the suprapermafrost flow. The discovered pressure impact in the tundra soils of the permafrost zone is a unique mechanism for providing plants with moisture during droughts and reducing the risk of tundra fires. As part of the further study of the pressure impact, it is planned to conduct laboratory experiments to determine the quantitative parameters of the change in the peat soils moisture capacity under pressure drops in the atmosphere. Mathematical modeling of the capillary moisture capacity of peat soils will be performed under conditions of ambient load changes. The results of experiments and theoretical studies are assumed to be useful for predicting the flow of bogged-up river basins, design of reclamation, and irrigation of areas of peat soils distribution.

1. Introduction

The influence of transient atmospheric pressure surges on the groundwater regime was discovered long ago. Using measurements in Arizona, Hylckama [1] revealed a strong connection between diurnal groundwater level changes and atmospheric pressure. When studying the diurnal groundwater level evolution in the Bonneville area, Utah, Turk [2] considered that it was most likely determined by barometric pressure variations. Salama et al. [3] reported on a variety of changes in groundwater levels and atmospheric pressure at a research ground in Australia. Lautz [4] analysed groundwater level fluctuations in the bottom land area of Red Canyon Creek, Wyoming, changes in atmospheric pressure and air temperature as probable causes of groundwater diurnal changes. Moraetis et al. [5] found out that the karst groundwater level on Crete, Greece, was associated with atmospheric pressure. In their paper, Shtengelov et al. [6] study the influence of atmospheric pressure fluctuations on the yield of well in large artesian basins. There is hardly any information on the atmospheric pressure impact on the suprapermafrost water level and river flow in permafrost zone flats.

The report demonstrates the results of a study of sources of nourishment and the diurnal flow pattern of rivers and brooks of the Anadyr Lowland in the 2019 low-water season. Field investigations revealed that a 1.2 kPa atmospheric pressure surge affected the Ugolnaya-Dionisia River flow. The results of field experiments were used to establish possible mechanisms and conditions for the atmospheric pressure impact on the tundra rivers flow. The report is aimed at acquainting general readers with an unusual natural phenomenon. Another objective is to discuss the importance of the discovery of the atmospheric pressure impact on the suprapermafrost flow for the study of hydrological processes and the aquifer relating tundra and bog soils of the permafrost zone.

Section 2. *Natural conditions* present a brief description of the climate and permafrost of the Anadyr lowland, considering the changes in climatic and geocryological conditions in recent years. Further, in Section 3. *Materials and research* methods, the basin of the Ugolnaya-Dionisia river, the equipment used in the observations, and the measurement mode are described. The Section - *Research results and their discussion* provides data on the dynamics of the flow of the Ugolnaya-Dionisia river, the sources of water supply in the low-water summer period. The figures show the temporal relationship between fluctuations in water levels and atmospheric pressure. References to literary sources supplement the substantiation of the hypothesis of the pressure impact associated with a change in the moisture capacity of peat soils under deviations of the ambient pressure.

2. Natural Setting

The Anadyr Lowland is a plain with bench marks of 2–150 m, which is divided and framed by mountain folds and isolated elevations (mountain ridges and ranges). The lowland rivers regime is characterised by spring floods, discontinuous summer and autumn freshets and persistent winter low-water seasons. Rivers are mainly nourished by atmospheric precipitation. According to long-term observations, the runoff depth is about 250 mm. Most of the territory being described has a subarctic oceanic climate. According to the Anadyr weather station, the average annual temperature in 1981–2010 was -5°C (Here and elsewhere the authors use climate data from the website of the Hydrometeorological Centre of Russia: https://meteoinfo.ru/). Annual precipitation is 382 mm and mainly takes place in winter. According to the Hydrometeorological Center of Russia, from 1976 to 2016, the average annual air temperature increased by 2.2°C, and the annual precipitation increased by 66 mm.

Continuous permafrost thickness decreases from 300 to 50 m from north to south, and in the southern areas, it becomes discontinuous. Frozen soil temperature decreases from -7.1 to -1°C from north to south. Seasonal melting depth varies between 0.45–0.6 m on smooth hillsides of tundra sloping hills. On slopes, which are over 3° steep, and in high-water beds, it is up to 0.6–1.5 m. In 1994–2019, the seasonal melting depth of autonomous landscapes increased by 15 cm or 36% from the baseline. In the bottom of lacustrine-boggy kettles, the increase was 34%, and on the slopes and at the foot of tundra sloping hills, it was 27% [7]. Tundra gley and gleyed peaty and peat soils are most common within the lowlands. The suprapermafrost aquifer is built in the first third of June and stays until the active layer is completely frozen in late autumn. The thickness (0–45 cm) and depth (0–120 cm) of the suprapermafrost aquifer vary depending on the landscape and seasonal melting depth during the warm season.

3. Research Materials and Techniques

The objects of investigation are situated in the Ugolnaya-Dionisia River basin and have an area of 96 km^2 (figure 1). The river is located on the eastern boundaries of the Anadyr Lowland, 15 km west of Anadyr. Its length is 24 km. The water edge bench marks vary between 100–180 m at the river heads and 2.5 m at its mouth, which is situated on the right bank of the Anadyr estuary. The river flow was observed 6 km from the river mouth and in the upper basin reaches in the Yagodny Brook. The water level was measured in three pits with a depth of 35 cm in the Yagodny Brook basin on the smooth hillside of a tundra sloping hill. The characteristics of the river flow and the suprapermafrost water level were studied from 29 June to 10 July 2019. In the period of field investigation, the mean daily temperature was 12.1°C. The continuous snow cover on the Anadyr Lowland and in the river basin in particular had melted 2 weeks before the observation starts. After the snow cover melted and before the work was started, there was 2.2 mm of precipitation; during field investigation, 1.5 mm of precipitation took place. According to the Anadyr weather station, the mean temperature for the 4 months of the 2019 warm period was 10.1°C. In addition, 95.6 mm of precipitation fell. In 2019, weather conditions were generally close to normal according to long-term observations by the Anadyr weather station.

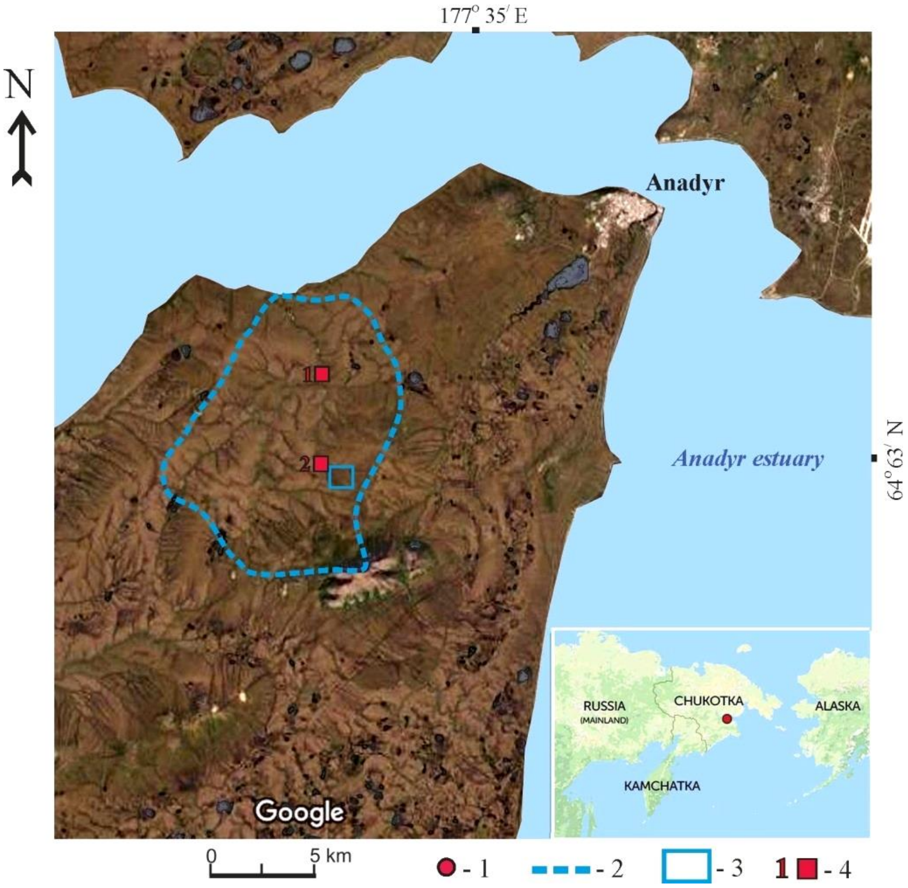

Figure 1. Research area and objects: 1 - the exploration area on the insert map; 2 - the border of the Ugolnaya-Dionisia River basin; 3 - the pits location; 4 - hydrologic sections on the Ugolnaya-Dionisia River (1) and the Yagodny Brook (2).

The Ugolnaya-Dionisia River discharge was measured at the main section four times a day. The water level in the pits and watercourses at the sections as well as soil and water temperatures were measured every 30 minutes using automation aids. The following measuring devices and equipment were used: ПОТОК-мкр ГР-100 and ПОТОК ГР21М propeller flowmeters, automatic temperature loggers by HOBO ONSET, and U20L-04 and U23-003 level gauges. The data pre-processing was performed according to the recommendations of the device manufacturers. Microsoft Excel tools were used to process data of monitoring observations.

4. Research Results and Their Discussion

In the period of observations, the melting depth of the peat soils prevailing in the basin increased from 20–25 to 30–35 cm. The peat soils thawed 6–8 cm through. The water discharge at the main section decreased from 709 to 145 l/sec (figure 2). Automated measurements of temperature, water levels in the pits and watercourses, and the flow rate of the Ugolnaya-Dionisia River demonstrated subharmonic diurnal cycles of characteristic values. The detected fluctuations in the river water levels and temperatures as well as soil and water temperatures were in the reverse phase. This led to the conclusion that snowmelt water of seasonal subsurface ice was the main source of the river nourishment in the absence of precipitation. Its reserve in the 30 cm of topsoil is estimated at 100–200 mm [8-9] for the basin tundra landscapes.

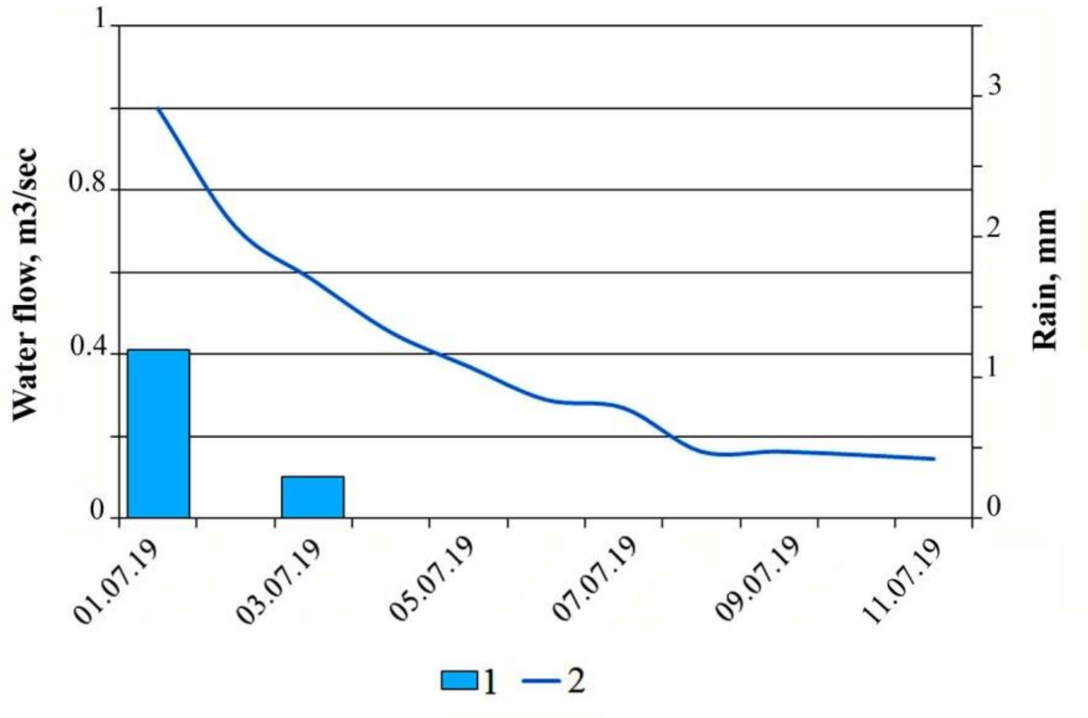

Figure 2. Precipitation (1) and discharge evolution of the Ugolnaya-Dionisia River (2) during the observation period.

The pre-processing of automated measurement data revealed that perturbations of the daily fluctuations amplitude and water level values took place between July 2 and July 5. Perturbations of diurnal cycles were recorded with a small-time difference by all the level gauges in the pits and watercourses. This fact eliminated technical malfunctions of the equipment. No significant deviations in the diurnal cycles of water and soil temperatures were detected. A flowmeter (ПОТОК ГР21М) stopped continuous measurements at 11 PM on 02/08/19; it was retrieved from the water and restarted on 03/08/19. When a failure was detected, the device was out of order: the propeller flowmeter blades were covered with aquatic plants.

When discussing the reasons for the detected perturbation of the river flow pattern, attention was drawn to the sharp deterioration of weather between July 2 and July 5: fog, low cloud cover and a drop in atmospheric pressure from 101 to 100.2 kPa, followed by its increase to 101.4 kPa (figure 3).

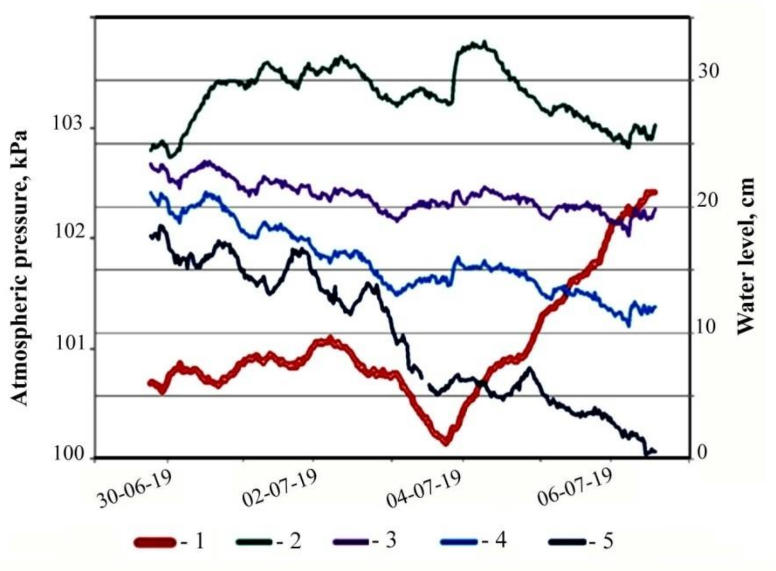

Figure 3. The evolution of the suprapermafrost and surface water levels under the changed atmospheric pressure: 1 -atmospheric pressure; 2 - the pit in peat soil; 3 - the pit in peaty soil; 4 - the Yagodny brook water level (the pit); 5 - the Ugolnaya-Dionisia River water level (the riverbed)

When the pressure fell, the water level in the pits decreased by 2.5 and 4.4 cm depending on their position on the slope and then increased by 2.6 and 5.2 cm, respectively. The water level surge (fall/rise) in the Yagodny Brook was 3.5 and 3 cm, and that in the Ugolnaya-Dionisia River was 7.8 and 2 cm. Tentatively, the changes were attributed to the baric effect of the atmospheric influence on the water capacity of tundra peat. According to the assumption, a decrease in atmospheric pressure causes the water capacity of tundra soils containing the aquifer to grow. The aquifer water yield falls, thus lowering the water level in the pits and the suprapermafrost flow. A sharp increase in pressure and a reduction in the soil water capacity results in a locked-in water escape, which leads to a saltatory suprapermafrost flow and restored river flow, given the current aquifer nourishment with snowmelt water. The described mechanism fully corresponds to the observed evolution of the water level in the pits and watercourses.

Can the atmospheric pressure fluctuations amplitude alone change the hydrophysical properties of tundra soils? How can changes in ambient pressure increase or decrease their water capacity? The compression tests results showed that the external load limit at which the surface turf retains its elasto-plastic properties is 15 kPa. Compaction and residual displacement of peat soil are recorded only at an ambient pressure of 200 or more kPa. These indices are used for calculation of the safe transport load on the tundra cover and for road construction [10-12]. The maximum value of elasticity is comparable to the recorded atmospheric pressure surges in cyclones (8 kPa) and is 500 times greater than diurnal pressure fluctuations in high latitudes (0.03 kPa). This means that the surface turf cover is soft, i.e. it is susceptible to the most insignificant values of ambient pressure and exerts elastic properties within the limits of diurnal and non-cyclic atmospheric pressure fluctuations: it restores its shape and volume after the load disappears. Peat soils are very porous (90% porosity). In fact, an atmospheric pressure fall means an ambient pressure release, which will lead to a change in the balance of forces between the external load and the turf cover elasticity. As a result, the compensatory rise of the surface contributes to an increase in the volume of peat soil horizons. This will lead to an increase in the macropores size and the formation of new capillaries. Near-surface groundwater provided, the amount of locked-in soil moisture will increase. As atmospheric pressure rises, the opposite process will be observed: a decrease in the effective porosity will release most of the inherent water. Despite many assumptions, the described model seems to be quite realistic.

Now we are going to study the possible natural constraints of the pressure impact. First of all, the peat soil horizon should prevail in an area, and a groundwater surface should be present on its bottom. The second condition includes incomplete humidification of the top peat (outstanding water capacity) under insignificant precipitation or its absence. These are the conditions that developed in the Ugolnaya-Dionisia River basin in the first third of July when the active layer thawed 20–30 cm through and 3.7 mm of precipitation fell. For the pressure impact to take place in the flow pattern of small rivers of permafrost zone lowlands, the third condition should be met: there should be a ramified drainage on the slopes of tundra sloping hills and high-moor and low-moor bogs. If there is no such drainage, the pressure impact is likely to show itself only through a rise and fall of the groundwater surface and the bog water level.

In terms of the environmental conditions of tundra and bog landscapes in general, the described pressure impact gives additional watering of the root layer in the lack of precipitation and reduces the risk of tundra and peat fires. Possible consequences of river flow fluctuations associated with atmospheric pressure surges for freshwater ecosystems are unknown. It should be noted that the pressure impact registered through the field experiment at the main section of the Ugolnaya-Dionisia River made the flow rate fall from 0.25 to 0.05 m/s within half an hour.

5. Conclusions

In the course of observations of the diurnal regime of suprapermafrost underground and surface river waters in the Ugolnaya-Dionisia River basin (Anadyr Lowland, Chukotka), a positive reaction of water levels to the atmospheric pressure surge was recorded. Not only did the pressure drop by 0.8 kPa and then increased by 1.2 kPa, but the permafrost water level fell by 2.5–4.4 cm and then rose by 2.6–5.2 cm. The river water level showed a fall of 3.5–7.8 cm, followed by a rise of 2–3 cm.

The known physical characteristics of the tundra turf cover and the hydrophysical properties of the tundra peat allowed for a hypothesis of the atmospheric pressure effect on the permafrost water level through changes in the turf water capacity under its flexible-springy deformation. A positive reaction of the suprapermafrost and river flow to atmospheric pressure surges is possible if these three conditions are met: a groundwater surface touches the peat soil horizon; the peat water capacity is incomplete; the river is mostly nourished with suprapermafrost waters and has a ramified drainage.

We consider further study of atmospheric baric effects in the underground and surface waters of permafrost zone lowlands as well as in bog landscapes of more southern latitudes with suitable conditions to be promising. Laboratory experiments are planned to determine the quantitative parameters of the change in the peat soils moisture capacity under pressure drops in the atmosphere. It is planned to perform mathematical modeling of the capillary moisture capacity of peat soils will be performed under conditions of ambient load changes. The results of experiments and theoretical studies are assumed to be useful for predicting the flow of bogged-up river basins, design of reclamation, and irrigation of areas of peat soils distribution.

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References

[1] Hylckama, T.E.A.V. 1968 Water level fluctuations in evapotranspirometers, *Water Res. Res.* **4** 761–768.
[2] Turk, L.J. 1975 Diurnal fluctuation of water tables induced by atmospheric pressure changes, *J. Hydrol.* **26** 1–2, 1–16

[3] Salama, R.B., Bartle, G.A., and Farrington, P. 1994 Water use of plantation Eucalyptus camaldulensis estimated by groundwater hydrograph separation techniques and heat pulse method *J. Hydrol.* **156** 163–180
[4] Lautz, L.K. 2008 Estimating groundwater evapotranspiration rates using diurnal water-table fluctuations in semi-arid riparian zone *Hydrogeol. J.* **16** 483–497
[5] Moraetis, D., Efstathiou, D., Stamati, F., Tzoraki, O., Nikolaidis, N.P., Schnoor, J.L., and Vozinakis, K. 2010 High-frequency monitoring for the identification of hydrological and bio-geochemical processes in a Mediterranean river basin *J. Hydrol.* **389** 127–136
[6] Shtengelov, R.S. Filimonova, E.A., and Shubin, I.S. 2017 Obrabotka otkachki iz napornogo vodonosnogo gorizonta pri peremennom debite i atmosfernom davlenii (Processing pumping test data for a confined aquifer at varying debit rate and atmospheric pressure), *Vestn. Mosk. Univ., Ser. 4: Geol*. **3** 50–58
[7] Tregubov O.D., Uyagansky K.K., Nuteveket M.A 2020 Monitoring of permafrost-climatic conditions of the Anadyr lowland *Geography and Natural Resources*. **2** 143–152. [Monitoring merzlotno-klimaticheskikh usloviy Anadyrskoy nizmennosti // Geografiya i prirodnyye resursy. 2020. № 2. S. 143–152.]
[8] Tregubov O., Nuteveket M., Uyagansky K., Gartsman B., Lebedeva L., Shepelev V., Tarbeeva A., and Shekman E. 2020 Landscape-permafrost conditions and factors of summer runoff formation of small coastal lowland rivers, *E3S Web of Conferences.* 4th Vinogradov Conference "Hydrology: from Learning to Worldview" in Memory of Outstanding Russian Hydrologist Yury Vinogradov, VC 2020, 2020, 05015.
[9] Tregubov O.D., Garcman B.I., Tarbeeva A.M., Lebedeva L.S., SHepelev V.V 2021 Prostranstvennaya i vremennaya dinamika istochnikov pitaniya i vodnogo rezhima rek Anadyrskoj nizmennosti [Space and time dynamics of contributing sources and water regime of the rivers in Anadyr Lowland] *Vodnye Resursy*. 48(4) 1-12
[10] Amaryan, L.S. 1990 Svoistva slabykh gruntov i metody ikh izucheniya [Properties of Soft Soils and Methods for Their Studying] (Moscow: Nedra) 220 p
[11] Ermichev, V.A., Lobanov, V.N., Krivchenkova, G.N., and Artemov, A.V. 2006 Prognozirovaniye osadki i plotnosti lesnykh pochv posle proyezda gusenichnykh mashin [Forecasting of forest soil settlement and density after tracked machines pass], Izv. Vyssh. Ucheb. Zaved. Lesnoi Zhurn. (*Rus. Forestry Jour.*) **2** 48–51
[12] Ivanov K E. 1981 Vodoobmen v bolotnykh landshaftakh. Gidrometeoizdat; Leningrad, 1975, 280 p (Trans. by Thomson A, Ingram H.A.P., Water movements in mirelands, Academic Press: London, 1981, 277 p)