A Draft on Extensive Studies in the Boreal Wetland Watersheds

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Abstract. Hydrology studies in the boreal wetland watersheds situated near the White Sea, northern European Russia, their technique and preliminary results were expounded. Examined are precipitation, snow water equivalent (SWE) evaporation, runoff and ground water storage (GWS) as obtained by observation on a peat bog for two years of different wetness. Basically found are the following: (1) Runoff (the stream outflow) from small wetland watersheds for a dry year is distinctively different from that generated on a highly forested river basin; (2) The evaporation rates are stable depending mainly on the surface (e.g. vegetation) types; (3) In contrary, the GWS has been found highly variable, quickly responsive to rainfalls and snow melt. Significant can be also that water amount which is contained within frozen layer of peat. The climatic wetness indices have been evaluated and the water balance calculations were performed on the base of the observation data.

Introduction

Research studies in boreal wetland watersheds in European Russia have long been extensive carried out at five special Wetland research stations (WRS) throughout the most of the boreal forest (*taiga*) zone: from the Kola peninsula to the area laid south of Lake Ladoga. At present, most of the observations are reduced, but two of the WRSs still are in operation, one situated north-west of St. Petersburg another near to the White Sea shore. The author was earlier head of this WRS named "Brusovitsa" (local for "red bilberry") and had immediately studied all the water balance components as well as the soil physical properties specific of a peat bog.

Russian leading explorers (Ivanov, 1975, Romanov, 1961) thoroughly investigated wetlands. Many followers (Baljasova, 1974, Kaljuzhny, 1974) had addressed only several hydrological issues: ground water, runoff, evaporation from wetland, etc. Presently, a problem is stated of how the climate changes can impact boreal wetlands and, in opposite, whether wetlands can intensify or moderate these climatic shifts. A synthetic water balance approach, as it seems, must to be used to cope with the problem. The aim of the report is to introduce the historical observational data and to discuss how they could be used more widely.

Study area and study objects

Typical *oligotrophic* boreal wetlands (somewhere called "blanket bogs") have generally convex surface with thick (up to 10 m at the central area) peat deposits. They are feeding almost exclusively by atmospheric water sources (precipitation). The landscapes of these wetlands are lawfully changing from central to marginal area: from the moist complex landscape abounded in shallow lakes with silt-layered bottom to the pine-forested *sphagnum*-moss landscape surrounding the wetland as a ring. Landscapes called *mesotrophic* have more plain surface and are covered with mostly herbaceous (e.g. *eriophorum vaginatum*) communities. They occur everywhere, but become dominated closer to the littoral lowland. There are also numerous "islands" amidst wetland plain with mainland bedrock substrate covered by high pine stands with green moss and grey lichen on the surface under tree canopy.

The wetland *Ilas* (88 km^2) being under study has the following landscape structure:

- *sphagnum* moss sparsely forested with oppressed pine trees – 28%,
- hollow-and-ridges complex with numerous small lakes – 27%,
- hollow-and-ridges complex (hollows mainly with bare peat soil) – 20%,
- forested wetland (mainly with pine), the so-called “forest ring” – 11%,
- wet grassland communities with dwarf shrubs – 5%,
- forest “islands” on mineral ground – 5% and, remained area is a shallow lake.

The wetland area is drained by a number of natural streams of which two, the *Chernaja* brook (watershed area $F = 8.9$ km^2) and the *Babja* brook ($F = 4.2$ km^2) are gauged with hydrometric weirs. Gauged is a river watershed, the *Brusovitsa* river which is wetland-covered partially, in 40% of its entire area ($F = 145$ km^2). Eastern part of the wetland are drained artificially by open drainage canals several of which are also gauged.

Climate of the study area is moderate cold, with mean annual air temperature close by 0^{o}C and precipitation totals about to 600 mm. Meteorological observations are carried out at two sites simultaneously, one site is situated at a large forest glade another at open wetland area. Observations are also carried out under precipitation (a few rain gauges) and snow accumulation in different wetland landscapes, soil temperature and soil frost depth.

Wetland hydrology, in addition to the stream discharge monitoring, includes observations of the ground water table (a number of wells located at transects across the wetland), evaporation from open water surface and from peat bog in different landscapes. Laboratory studies were also performed to investigate the soil physical properties and the water chemistry.

Several investigation results

Aimed to introduce the variety of study results, we should content only several ones for two contrasting years with relatively low (1974) and relatively high (1979) wetness conditions.

Summer rainfall rates (Fig. 1) vary timely, particularly during the wet year, and are slightly different for landscapes due to wind-related influence.

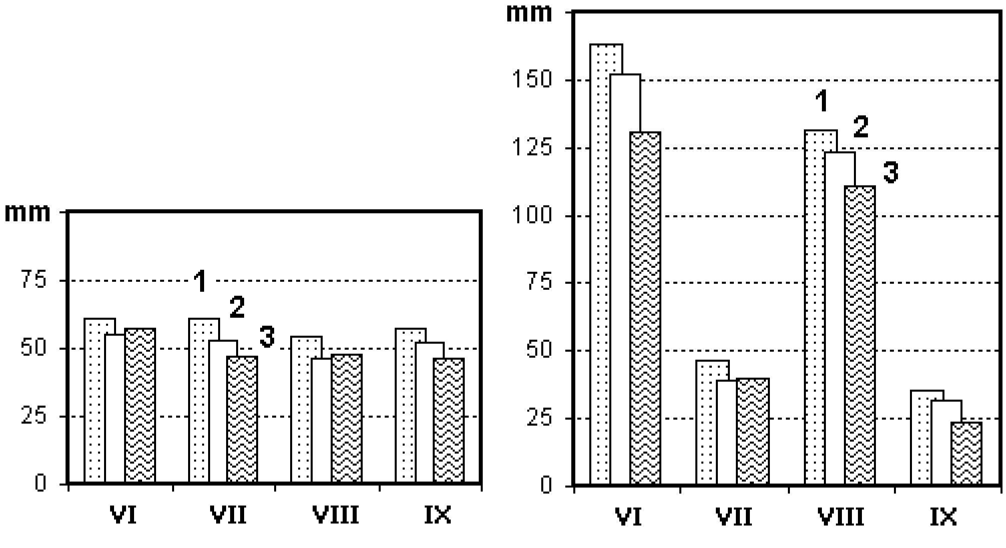

Fig. 1. Monthly rainfall amounts (mm) at different locations for two contrasting years: Mixed forest (1), hollow-ridge landscape (2), hollow-ridge landscape with small lakes (3)

Generally, the Tretjakov's rain gauges detect lower precipitation at open wetland. The differences between forest and open wetland amount to 30 mm/month by the highest rate (June 1979). However, to imply systematic correction factors, there are no definitive and independently observed data sets.

Snow cover is in general evenly distributed throughout the wetland due to the snow retention capability of the landscapes, but there is a great "internal" variability, mainly between snow depths (SD) and snow water equivalents (SWE) at different locations, rugged ridges and ice-covered hollows and small lakes. Because of there are no significant snow melt episodes during a winter time, the measured SWEs (see in Table 2) are only slightly less than precipitation totals. Spring snow melt usually lasts from early April up to mid May.

Table 2. Snow depth (SD) and water equivalent (SWE) in wetland landscapes

Landscapes	Relatively dry year		Relatively wet year	
	SD, cm	SWE, mm	SD, cm	SWE, mm
Hollow-ridges complex	32	115	63	166
Lake-abundant landscape	45	126	59	148
Forested moss	42	139	56	132
Drained wetland	43	150	61	149

Soil frost is studied for a number of landscapes, the observations are carried out on the soil frost depth (SFD) and the so-called ice water equivalent (IWE), i.e. moisture content of the frozen ground, that is practically the same as the gravimetrical soil moisture observations with drying up the soil cores. It is well known that snow greatly affects soil freezing.

The SFD and IWE are highly variable in space that is caused by varied snow depth and complex texture of the peat soil. The deepest frost and the greatest IWE (up to 40 mm) is observed at mid April on the icy hollow surface with practically no snow, but thaw of the ridges extends up to mid June. Deep snow obstructs soil frost penetration at forest locations, shallow snow along with high water level (and, respectively, peat moisture) entails the deepest frost (65 cm) in hollows. Notably is that the SFDs at hollows with two different surface (bare peat and herbaceous) are closely ($r = 0.94$) correlated that can simplify operational estimates.

Annual course of the ground water level (GWL) is featured by one maximal stages, by spring snowmelt from -10 cm to the surface, and two minimal stages, about to -100 cm (below the surface) at forest and -50 cm in moss mainly on March and early fall. Summer minimum in GWLs is usually expressed except for the *sphagnum*-herbaceous landscape where the lowest water stage is mainly observed before snow melt. As was found, there can be very rapid, often suddenly occurred increase in GWLs at the forest edges of the wetland. So, the GWL rose from -103 cm to -7 cm only for three days (26 to 29 April, 1979).

Due to their high levels, the ground water in boreal wetland is rapidly responsive to any precipitation event. Most of the pores within top friable layer of peat (the active layer) are of the order of 0.05-0.5 mm in diameter (Romanov, 1961). By this the GWL shifts upward immediately after a rainfall event. To study this quick response on rainfalls, special installations were used consisted of coupled GWL and rainfall recorders located close by. As was found, each 1 mm rainfall results in 6.8 mm of the GWL upraise, that corresponds to the water yield capacity of the active peat layer amounts to 0.16.

Evaporation from wetland was measured with the use of pan evaporimeter (for open water) and specially constructed weighable lysimeters which were installed duplicate (at ridge and at hollow). First thing is that the measured evapotranspiration rates from boreal wetland landscapes are unforeseeably less than those from an open waters surface (Fig. 2).

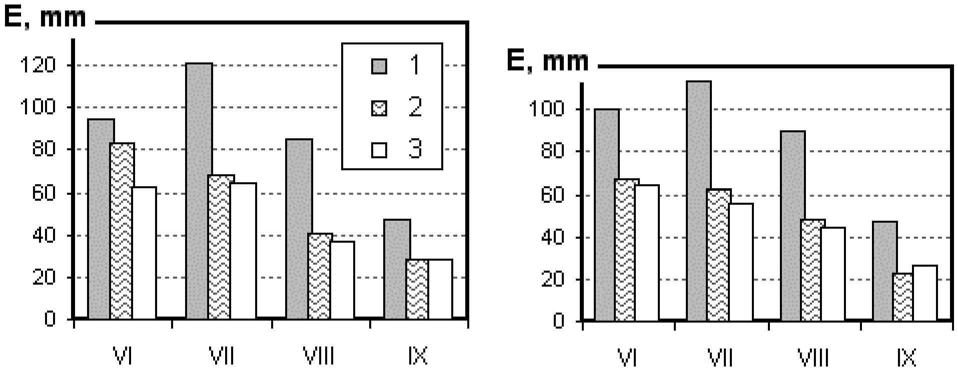

Fig. 2. Evaporation from wetland for two contrasting years

1 – open water surface, 2 – landscape abounded in small lakes, 3 – hollow-and-ridges landscape

Evapotranspiration is abrupt by deep GWLs, that results from that the top layer is highly porous. This turf has no fine pores so, the capillary fringe is only 15-20 cm (Romanov, 1961). Thereby, when GWLs become deeper than approximately -50 cm, a significant drought occurs for those dwarf plants which cover the wetland. This accounts for two geo-botanical features basic for wetland studies: firstly, each of the GWL ranges corresponds to several moss species (*sphagnum fuscum*, *sp. magellanicum*, etc.), and secondly, as anybody can see all the wetland dwarf shrubs look xero-morphic like those plants usual for semi-arid climate.

Runoff is affected by wetlands which generally attenuate flood discharges due to accumulation capacity of the peat deposits. Meanwhile, the results of runoff observations testify a complex influence of wetlands on the runoff distribution within a year that does not agree with the simplistic reduction scheme which became accepted. So, the *Babja* and *Chernaja* small wetland watersheds by normal or near-to-normal year generate much higher peaks of the spring snowmelt flood than that of the *Brusovitsa* river basin located close by which is much larger and has only 40% wetland area (Fig. 3). Of course, there is an effect of common areal reduction, though it cannot account for a considerable difference (in 8 l/s km^2 and more) for monthly specific runoff. Obviously, there appears a complex effect of local conditions such as the wetland types and properties of underlain soil.

One of the local factors may be uneven spatial distribution of the SWE. The *Chernaja* brook watershed is partially drained and, the forestry-oriented soil reclamation with a shallow drainage depth (only 30 – 50 cm) cannot by itself strongly affect the melt water runoff. Its depth can be defined by SWEs on the drained wetland with rugged surface: in the given case the SWE is 140% of that accumulated in representative hollow – ridge wetland landscape (115 mm). This is one, but not only, cause for increasing the spring runoff depth.

By wetter year, the influence reduces so that runoff time courses lie close by. There appears only an impact of drainage which slightly increases the specific runoff from drained peat bog. One of the opinions, in respect to a shallow drainage, is suitably account for the given case: the open drain canals are active pathways for melt water flow. Drainage leads to compaction of peat and, to a lowering of the landmarks herein. This lowering is permanently observed and, if it would not occur, then sloping would entail more increase of flow.

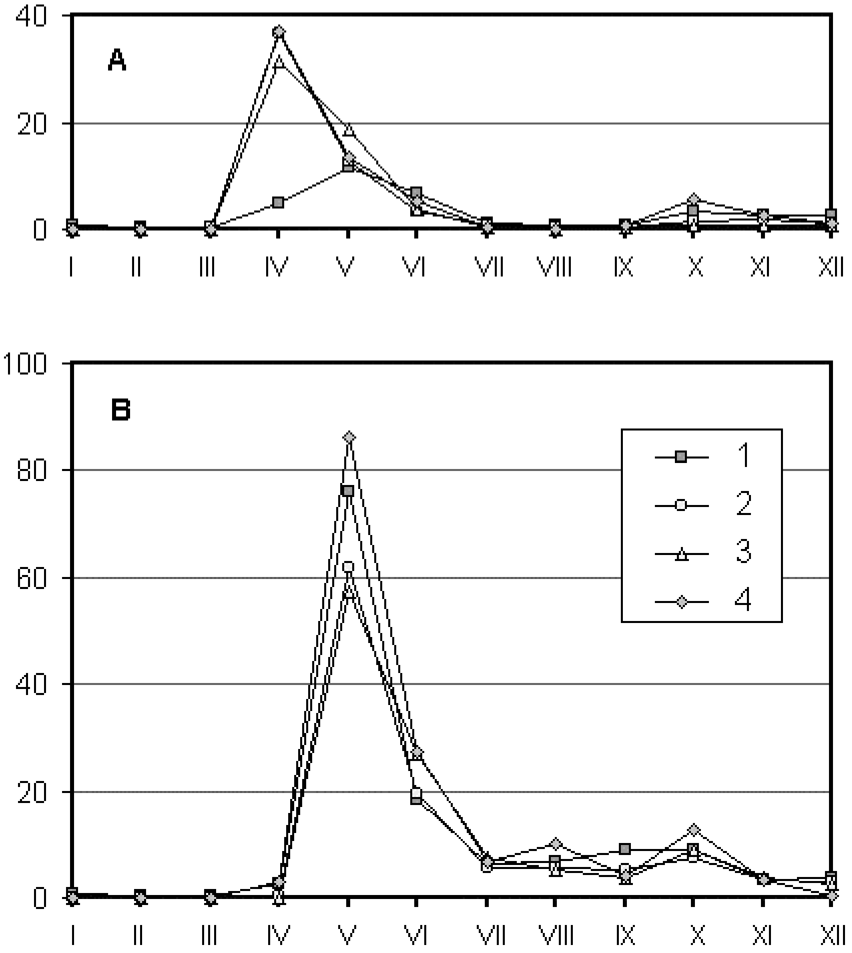

Fig. 3. Specific runoff from wetland watersheds for a dry (top) and wet (bottom) years
1 – *Brusovitsa* river (145 km^2), 2 – *Babja* brook, 3 – *Chernaja* brook, 4 – drainage canal

Water balance

Water balance of the *Ilas* wetland is examined by using the observation data for two contrasting years. We have also taken into account the landscape structure of the area when related and spatially averaged SWEs, rainfall and evaporation rates. Preliminary, we have an important query: how do the basic water balance components indicate the climate conditions? Or, what are these climatic wetness indices? We have evaluated them in three different ways (Table 2). The evaporation rates were resulted from lysimetric measurements, as against most of the publications, e.g. (Rovansek *et al.*, 1996), where they were calculated.

As to the potential evaporation, we defined it through the ratio of the global solar radiation to the latent heat of fusion ($E_0 = Q/L$), or the water equivalent of solar energy flux. As was clearly found (Kaljuzhny, 1974), evapotranspiration from the boreal wetland landscapes is closely correlated with Q/L. Having high correlation rates ($r = 0.85 – 0.92$), the relationship $E = c\,Q/L$ (where c is an empirical factor) allows to estimate evaporation from wetland.

Table 2. The climatic wetness indices as evaluated by three different ways

Months	Relatively dry year			Relatively wet year		
	P/E_W	E/E_0	P-E	P/E_W	E/E_0	P-E
VI	0.674	0.795	2	1.630	0.753	99
VII	0.504	0.621	-3	0.407	0.577	-10
VIII	0.635	0.607	17	1.456	0.595	87
IX	1.213	0.509	29	0.745	0.605	9
Totals	0.756	0.633	45	1.059	0.632	185

The water balance equation we used looks generally as follows:

$$P = E - R \pm \Delta H \pm \Delta I \pm \Delta U, \qquad (1)$$

where P – precipitation, ΔH – snow water accumulation, ΔI – water content within frozen layer of peat, E – evapotranspiration, R – runoff, ΔU – temporal changes in the ground water storage (GWS). The latter we determined as $\Delta U = \mu\Delta Z$, where μ is the above mentioned water yield of the peat soil. Evaluating the total accumulation $A = P - \Delta H - \Delta I - E - R$, we can relate it to observed ΔU and the difference between them is that "imbalance" which includes inevitable measurement errors and all the components beyond the scope of the estimation.

Table 5. The basic water balance components (in mm) of the *Ilasskoje* wetland evaluated for two years with taken landscape structure (percentage) into account

A). Relatively dry year (Runoff-to-precipitation ratio $R/P = 0.24$)

Period	P	ΔH	ΔI	E	R	A	ΔU
XII-III	157	115	22	5	4	11	2
IV-V	107	-115	-22	54	128	62	24
VI-VIII	179			189	11	-21	-20
IX-XI	183	84	11	49	10	29	25
Yearly sum	626			297	153		

B). Relatively wet year (Runoff-to-precipitation ratio $R/P = 0.36$)

Period	P	ΔH	ΔI	E	R	A	ΔU
XII-III	153	131	26	6	5	-15	-17
IV-V	109	-166*	-19	66	161	67	25
VI-VIII	340		-7	189	80	78	12
IX-XI	188	65	17	38	41	27	13
Yearly sum	790			299	287		

*) melting the SWE accumulated for the entire winter period including preceding year

The results quoted in Table 3 clearly testify a very stable evaporation independent of the wetness (depending, obviously, on what plant communities are producing the transpiration flux), seasonally varied runoff, and a considerable role of that water accumulated within snow pack and frozen peat. In spite of highly variable monthly GWS, seasonal ground water recharge ΔU does not affect the entire water budget, even for a spring snow melt when it amounts only to 12% of the SWE plus precipitation value. Runoff (exactly, stream outflow) from the wetland was found less than its regional averaged value (255 mm/year), but the evaporation quite corresponds to the regional normal rate (300 mm/year).

One of the preliminary issues is that the wetland accumulates water most of the year, except for seasonal droughts. Total evaluated accumulation A exceeds respective recharge ΔU (i.e. that ΔU determined by the GWL measured in shallow wells) during snow melt and rainy summer. This can signify a leakage from the peat-holding layer to the ground water aquifers laid beneath. These are not drained by in-wetland streams that effects imbalance. One more aspect consists of that by filtration within turf probably near to one fifth of the ground water volume flows through capillary pores above the water table (Romanov, 1961). That part of the ground water is moving under capillary tension, it is mainly confined within tissue of the wetland moss and, unfortunately, cannot be determined *in-situ*.

Conclusions and prospects

Boreal wetlands play one of the most important role in the water balance, are affecting river runoff and ground water recharge and, possibly, influence on the climate system. In addition to the largely developed hydrological investigation of boreal wetlands, the following directions should be proposed as, in particular, necessary for prediction of future climate.

Estimating is needed of the climatic influence on wetland hydrology, in particular, clarifying the processes: evaporation – GWL – albedo – net radiation income, that negative feedback which stabilize evaporative loss. Another mechanism should thoroughly be discovered: precipitation – snow – GWL, which is a affecting the local plant community.

It needs to develop (or improve) simulation models of the wetland hydrology, in particular, to create a model for continuous water balance computations including the components very sensitive to rainfall and snowmelt. Of a particular importance is also to predict the “resilience” and evolution (maybe, enlargement?) of wetlands.

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