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Baltic Earth Workshop

Hydrology of the Baltic Sea Basin: Observations, Modelling, Forecasting

St. Petersburg, Russia, 8 - 9 October 2019

185 YEARS of hydrometeorological service of Russia

State Hydrological Insitute
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Helmholtz-Zentrum Geesthacht
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Baltic Earth Workshop on

Hydrology of the Baltic Sea Basin: Observations, Modelling, Forecasting

State Hydrological Institute, St. Petersburg, Russia

8 - 9 October 2019

Co-organized by Helmholtz-Zentrum Geesthacht,
and State Hydrological Institute, St. Petersburg

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Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Workshop Committee

Sergei Zhuravlev
(s.zhuravlev@hydrology.ru, State Hydrological Institute)

Maria Mamaeva
(mamaeva.maria.anatolyevna@gmail.com, State Hydrological Institute)

Valery Vuglinsky
(vvuglins@mail.ru, State Hydrological Institute)

Olga Zadonskaya
(ov-zadon@yandex.ru, State Hydrological Institute)

Stefan Hagemann
(stefan.hagemann@hzg.de, Helmholtz-Zentrum Geesthacht

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About the workshop

Scope

Climate change affects the water cycle of the Baltic Sea catchment basin, and adaptation will be required in the future. The extent to which the Baltic Sea region will be affected by changing hydrological conditions, and what the best adaptation strategies are, is an issue of open discussion.

The workshop aims to bring together scientists to overcome the barriers in hydrological studies, including monitoring, modelling and forecasting. Both water quantity and quality issues will be discussed. We hope that covering the different facets of hydrology will help us to develop a more integrated understanding of the interactions between the water, energy and matter cycles, and the direct and indirect anthropogenic effects.

Objectives

- to review recent scientific contributions to assess past, current and future changes of the water cycle,
- to share the experience of hydrological and hydrochemical monitoring, using different tools and approaches,
- to review recent developments in hydrological modelling in the Baltic Sea basin and neighboring domains, and
- to discuss water quality issues and waste water treatment projects in the Baltic Sea basin.

Programme

Tuesday, 8 October 2019

Cultural and social programme (by invitation, details to be communicated)

Afternoon: Guided Museum tour (limited availability)
Boat Trip on the Neva
Ice breaker dinner

Wednesday, 9 October 2019

Scientific programme

09:00 **Welcome address the host of the workshop**
Sergey Zhuravlev, State Hydrological Institute, St. Petersburg, Russia

09:10 **ECV-lakes and climate change - Vision from satellites** (keynote)
Jean Francois Cretaux, Laboratoire d'Etudes en Géophysique et Océanographie Spatiales/Centre National d´Etudes Spatiales, Toulouse, France

09:40 **Improved understanding of hydrological change by satellite remote sensing data?** (keynote)
David Gustafsson, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

10:10 **The complex and interdisciplinary study of water ecosystems of largest lakes of Europe (a review)**
Nikolai Filatov, Northern Water Problems Institute of the Karelian Research Centre of the Russian Academy of Sciences, Petrozavodsk, Russia

10:30 **Modelling system for heat and mass transfer in the system: Catchment area – water course – water body**
*Kondratyev S.A., Golosov S.D., Shmakova M.V., Zverev I.S., Ivanova E.V., Shipunova E.A.,*Institute of Limnology of the Russian Academy of Sciences, Saint-Petersburg, Russia

10:50 **Runoff in small catchments in the Flysch Carpathians (Bieszczady Mountains)**
Karolina Mostowik, Institute of Geography and Spatial Management, Jagiellonian University, Cracow, Poland

11:10 ***Break***

11:40 **Changes in projections of maximum discharge of Lithuanian rivers and their uncertainties in near and far future**
Vytautas Akstinas, Laboratory of Hydrology, Lithuanian Energy Institute, Kaunas, Lithuania

12:00 **Sinusoidal and autocorrelation training prediction of the local water runoff in administrative regions of the Northwestern Federal District**
Babkin A.V. and *Babkin V.I.,* State Hydrological Institute, St. Petersburg, Russia

12:20 **Long-term monitoring of water chemistry in the Eastern Gulf of Finland**
Alexander Korshenko, Marine Monitoring Department, State Oceanographic Institute, Moscow, Russia

12:40 **Assessing regional water flow changes and their drivers and implications for water quality**
Georgia Destouni, Department of Physical Geography, Stockholm University, Stockholm, Sweden

13:00 ***Lunch***

14:00 **The effect of sampling frequency and strategy on water quality modelling driven by high-frequency monitoring data in a boreal catchment**
Mikolaj Piniewski, Paweł Marcinkowski, Warsaw University of Life Sciences, Department of Hydraulic Engineering, Warszawa, Poland*; Jari Koskiaho, Sirkka Tattari*, Finnish Environment Institute, Helsinki, Finland

14:20 **The effect of nutrient river loads on the nitrogen and phosphorus balance in the Gulf of Finland based on model data**
Oksana M. Vladimirova, Tatiana R. Eremina, Russian State Hydrometeorological University, Russia; *Alexey V. Isaev, Vladimir A. Ryabchenko*, P. P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, Russia, and *Oleg P. Savchuk*, Institute of Earth Sciences, St. Petersburg State University, Russia and Baltic Nest Institute, Stockholm University Baltic Sea Centre, Sweden

14:40 **High-resolution large-scale modeling framework for a transboundary Nemunas River watershed**
Natalja Čerkasova, Klaipeda University, Marine Research Institute, Klaipeda, Lithuania; *Georg Umgiesser,* ISMAR-CNR, Institute of Marine Sciences, Venezia, Italy and Klaipeda University, Marine Research Institute, Klaipeda, Lithuania; *Ali Ertürk,* Department of Inland Water Resources and Management, Faculty of Aquatic Sciences, Istanbul University, Istanbul, Turkey and Klaipeda University, Marine Research Institute, Klaipeda, Lithuania

15:00 **Poster Session with coffee/tea and refreshments**

16:30 Open Discussion and Wrap-Up

17:00 ***End of workshop***

Abstracts

(first author alphabetical order)

Changes in projections of maximum discharge of Lithuanian rivers and their uncertainties in near and far future

Vytautas Akstinas

Laboratory of Hydrology, Lithuanian Energy Institute, Kaunas, Lithuania (vytautas.akstinas@lei.lt)

1. Introduction

According to the geographical and climatic conditions of Lithuania, the floods can be identified as the spring floods and flash floods of summer and autumn seasons. These types of floods differ from each other by different conditions of their formation. Snow melting is a major factor of formation for spring flood. Meanwhile, flash floods of summer-autumn seasons are caused by prolonged rain or heavy rainfall (Barredo 2007). The projections of mentioned phenomena are important for the assessment of future flood hazard; however, for trustful suggestions, it is important to evaluate not only quantitative changes but also the uncertainties related to the selected source of projections. According to Kundzewicz et al. (2017), the difference in future projections can be caused by selected climate scenarios, global climate models, hydrological models, different downscaling techniques, different types of flooding, different return periods, selected control period, natural variability, and presentation of results. Summarizing these factors it is possible to expect the probable uncertainties of created projections. Some authors state, that main sources of uncertainty is associated with global climate models (Ahlstrom et al. 2013, Shen et al. 2018), but there are studies which combine several sources of uncertainties e.g., emissions scenarios, global climate models, statistical downscaling, and parameterization of hydrological model; and highlighted them as more significant (Lawrence & Haddeland 2011). In Lithuania, the uncertainties related to several sources of origin are not widely discussed (Kriaučiūnienė et al. 2013). Therefore this research focuses on changes in projections of maximum discharge and uncertainties regarding selected global climate models, RCP climate scenarios, and statistical downscaling methods.

2. Study area, data and methods

Three river catchments (Minija, Nevežis, and Šventoji) represented by water gauging stations of Minija-Kartena, Nevėžis-Dasiūnai, and Šventoji-Ukmergė were selected from the Nemunas River basin (fourth largest river in the Baltic Sea region) for the projections of future maximum discharges (Q_{max}) of spring floods and flash floods of summer-autumn (Figure 1). Meteorological stations were also selected for hydrological modeling of mentioned rivers and the weight of each meteorological station in the selected river basins was determined using the Thiessen polygon method. The HBV (Hydrologiska Byråns Vattenbalansavdelning) hydrological model (Lindström et al. 1997) was used for simulation of projections of maximum discharges. Calibration and validation period was from 1986 to 2005 and the daily observations of the average air temperature (T, °C) and precipitation amount (P, mm) for that period were taken from the meteorological yearbooks.

The data of daily average air temperature and daily precipitation amount of three global climate models (GFDL-CM3, HadGEM2-ES, and NorESM1-M) generated by three RCP climate scenarios (RCP2.6, RCP4.5, and RCP8.5) were performed by three different statistical downscaling methods – Bias Correction with variable (BC), Change Factor with variable (CF), and Quantile Mapping (QM). The major purpose of these methods is to downscale the low resolution data to a fine spatial scale for the purpose to reproduce local conditions. All methods were implemented according to the reference period (1986-2005). The adjusted meteorological data of GCM output were used for projections of Q_{max} of spring floods and flash floods in the near (2021-2035) and far (2081-2100) future and compared with the reference period.

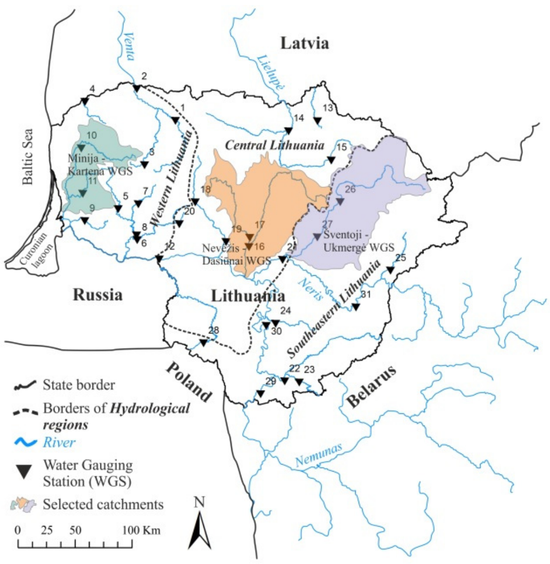

Figure 1. Location of selected river catchments.

The uncertainty analysis is important for projections of Q_{max} in the future, especially when uncertainties are associated with several sources of uncertainty. In this research, the uncertainty of runoff projections arises from the selection of climate scenarios (RCPs), global climate models (GCMs), and statistical downscaling methods (SDs). In Lithuania, the uncertainties of runoff projections were already evaluated using other sources of uncertainty (GCMs, climate scenarios of SRES group, and calibration parameters of HBV model) (Kriaučiūnienė et al. 2013), but the influence of statistical downscaling methods hasn't been evaluated. Therefore the methodology based on the mentioned paper was applied in this study for the in-deep analysis of the uncertainty of Q_{max} projections regarding RCPs, GCMs, and SDs.

3. Results

The projection of maximum discharges (Q_{max}) of spring flood and flash flood of summer-autumn were created according to the output of three GCMs for each RCP scenario adjusted by three SD methods in near and far future; and analyzed comparing to the simulation of reference period. The greatest changes of Q_{max} of spring floods are going to happen at the end of the 21st century and according to simulated projections, the largest decrease of spring floods was estimated in the rivers of Nevėžis and Šventoji (Figure 2). The main reason for such a response is projected higher temperatures in winter season: snow cover is likely to melt or would not form at all and, as a consequence, no spring flood will occur.

Instead, small, less expressed flash floods are going to emerge because of increased precipitation. Hence the flash floods of analyzed rivers are going to increase in their average Q_{max}, which were projected by most of the combinations of projection sources. According to particular sets of RCP, GCM, and SD, the very extreme values were projected and in separate years the mentioned values beyond historical observations. This confirms the probability of happening of flash floods of the rare return period. The exception is related to the statistical downscaling method of BC when the projected Q_{max} of flash floods drastically decline.

The calculations of the percentage of uncertainty according to the selected sources of uncertainty revealed which source had the greatest impact on the wide scattering of projected values of Q_{max} in the rivers of Minija, Nevėžis, and Šventoji. The uncertainty of projections of Q_{max} of spring floods and flash floods of the summer-autumn season in Minija River were strongly related to SD methods (42-51%). The same was obtained in projections of Q_{max} of spring floods of Nevėžis River when SD methods caused the largest uncertainties in near (56%) and far future (46%). The projections of Q_{max} of flash floods highly depended from the SD methods as well. Only the uncertainties caused by SD methods raised from 44% in the near future up to 57% in the far future, while uncertainties related to RCP scenarios, decreased by 6.1 percentage points. Similar patterns of uncertainties of Q_{max} of the flash flood were obtained in Šventoji River.

The largest scattering of projections of Q_{max} of spring floods in the Šventoji River was determined for the SD method as well because uncertainties related to the SDs consisted of 41% in the near future. In case of projections of Q_{max} of spring floods in the far future, the effect of RCP scenarios on uncertainties increased (41%) and exceeded all remaining sources.

4. Conclusions

According to the newest RCP climate scenarios, the projections of maximum discharges (Q_{max}) indicated the decrease (from -9% to -32%) of spring floods in the near and far future. Although the decrease of average Q_{max} of spring floods was estimated, extreme values of rare probability are expected to rise in particular years. According to the projections of Q_{max} of flash floods of summer and autumn, the increase (1.3-16.2%) of their average Q_{max} is expected together with the increased probability of extreme discharges.

Evaluation of the uncertainties of projections of Q_{max} of spring floods and flash floods was done according to three

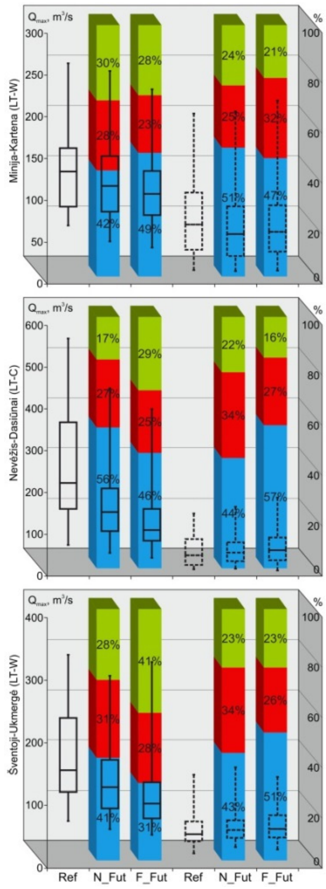

Figure 2. The projections of maximum discharge (Q_{max}, m^3/s) of spring floods (line box) and flash floods (dotted box); and uncertainty (%) according to different sources of origin (RCP-green, GCM-red, and SD-blue) in the periods of the near (N_Fut) and far (F_Fut) future.

selected sources of uncertainties (RCP scenarios, global climate models, and statistical downscaling). Statistical downscaling methods determined the largest uncertainties (41-57%) in projections of Q_{max}.

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Assessment of afforestation of river basins based on remote sensing data.

Diana Azarova[1], Nikolay Reshin[2]

[1]Russian State Hydrometeorological University, Saint Petersburg, Russia (diana.azarova97@gmail.com)
[2]Russian State Hydrometeorological University, Saint Petersburg, Russia

1. Introduction

Afforestation is one of the morphological characteristics of river watersheds that affects water flow in various climatic and soil conditions.

The aim of the study is to assess the afforestation of catchments of small rivers based on remote sensing data of the Earth using GIS technologies. Forests are subject to natural and man-made changes, such as climate change, forest fires and deforestation, there is a need to update obsolete data and develop methods for assessing forest cover using remote sensing data.

For the study we took the catchments of the rivers of the Pskov region, Russia, which were allocated on the basis of the digital elevation model SRTM.

2. Methodology for assessing the afforestation of river basins.

The NDVI vegetation activity index was calculated according to the Sentinel-2 satellites to assess the afforestation of catchments area.
This satellite was chosen because it has the best resolution available. The satellites were taken from the USGS portal, where they are stored in the public domain.

The NDVI index is calculated using the following formula: $NDVI = \frac{NIR-RED}{NIR+RED}$, (1)
where NIR - infrared reflection, RED reflection in the red region of the spectrum.

For Sentinel-2 shots, this corresponds to bands 8 and 4.

Construction and calculations were made in the ArcGIS program. According to satellite images obtained with a combination of "natural color", allocated reference areas, which were divided into groups (forests, fields, water bodies, artificial buildings, clouds). Using the method of maximum likelihood has been classified map of NDVI vegetation to the same type of plots. Thus, maps of forested areas of river catchments were obtained (example, Figure 1) and the area covered by forest was calculated.

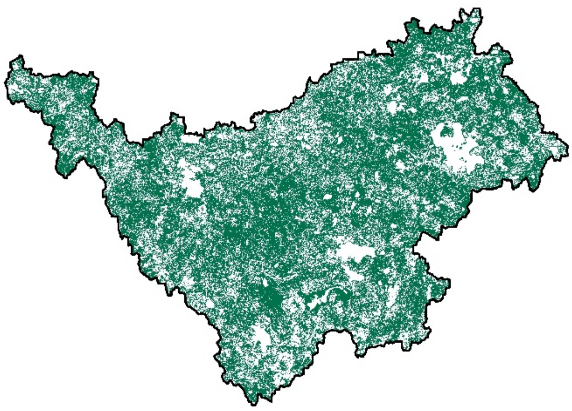

Figure 1. Overgrowth of the river basin Larch - village Krasiki.

3. Results of assessing the afforestation of river basins.

The results were compared with reference data from the Surface Water Resources of the USSR “Main hydrological characteristics” (hereinafter referred to as MHC) According to the data obtained, it is possible to say about the change of river watershed, but it is impossible to give an accurate assessment for a number of reasons: first, the calculated area of river watersheds differs from the reference data; second, the study of the territory occurs at different time intervals; third, the assessment of the salinity was carried out on different scale cartographic materials.

Therefore, to compare and clarify the results, it was decided to conduct an automatic digitization of forest cover topographic map of the Pskov region for 2001, the scale of 1:50000.

Table 1 shows the difference between the afforestation obtained by reference data, a topographic map, and remote sensing data.

Table number 1. A summary table of afforestation of the studied river catchments, Pskov region.

Catchment area	Afforestation, per cent			Increase	
	ОНС (1966 г)	Map (2001 г)	NDVI (2017-2018 г)	ΔMap-ОНС	ΔNDVI-Map
р. Яня - д. Лавынь	65	94	53	0,83	-2,58
р. Руя - д. Малые Рожки	73	86	67	0,37	-1,21
р. Ситня - д. Пески	56	85	76	0,83	-0,54
р. Плюсса - с. Плюсса	52	79,5	59	0,79	-1,26
р. Черная - д. Большое Захонье	49	75	61	0,74	-0,88
р. Полонка - д. Новые Буриги	37	63	88	0,74	1,54
р. Исса - д. Визги	53	52	65	-0,03	0,81
р. Льста - д. Глазатово	49	83	88	0,96	0,34
р. Кудеб - д. Свериково	38	58	40	0,57	-1,13
р. Вяда - д. Латышево	40	58	58	0,51	0,00
р. Кухва - д. Кахново	18	32	47	0,40	0,94
р. Лада - д. Рушляки	26	38	67	0,34	1,81
р. Лиственка - д. Красики	32	59	62	0,77	0,19

4. Practical significance of the results.

The methodology for assessing afforestation can find application in hydrological calculations, for example, to calculate the maximum river flow of a given supply in the absence of hydrological observations.

$$Q_{P,\%} = \frac{k_0 h_{P,\%} \mu_{P,\%} \delta \delta_1 \delta_2 \delta_3 A}{(A + A_1)^n}, (2)$$

When using the formula (2), it is possible to make errors in the assessment of maximum water flow rates with inaccurate determination of the afforestation and, consequently, the parameter δ_1 (3).

$$\delta_1 = \frac{\alpha}{(f_л+1)^{n'}}, (3)$$

$f_л$ – relative forest cover, %;

α и n'– parameters depending on the natural zone, soil texture and pool afforestation.

The estimation of the error in determining the maximum water flow rate according to formula 2 was carried out, depending on the error in determining the degree of overgrowth of the catchment.

The influence of the forest most significantly affects the value of the maximum water flow with afforestation up to 30 per cent. At positive errors of afforestation, the calculated maximum flow rate is underestimated. The error increases most intensively at the forest cover in the range from 0 to 10 per cent. At this range, an overestimation of 10% of the forest cover can lead to an error of 30-40% of the maximum flow, and an overestimation of 40% to an error of 50-55% – which more than 2 times reduces the maximum flow rate. The greatest errors of overestimation are in the range from 20 to 40-50%.

Negative values mean degradation or deforestation. If afforestation of 0-50%, a small error significantly affects δ_1, and therefore the calculated value of Q (P,%). If afforestation of the catchment is 60-100% overgrown, the error practically does not affect the value δ_1. At a negative forest cover errors, the estimated maximum flow rate is overstated. If the afforestation is underestimated by 10%, the maximum runoff error can be from 10 to 70%, and an underestimation by 40% - from 15 to 125%.

Current data on afforestation coefficient obtained by modern methods will give a more reliable calculation result, in comparison with outdated data.

5. Conclusion

The advantages of the methodology for assessing the afforestation of river catchments according to the data of remote sensing by the Sentinel-2 satellite and the application of the vegetation activity index NDVI are as follows: firstly, satellite images are the most reliable source of relevant and objective information about the surface state of river catchments; secondly, there is the possibility of automated information processing when obtaining maps of forest areas and calculating the afforestation of watersheds.

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Sinusoidal and autocorrelation training prediction of the local water runoff in administrative regions of the Northwestern Federal District

Babkin A.V.[1], Babkin V.I.[1]

[1] State Hydrological Institute, St. Petersburg, Russia (Abav@mail.ru)

The total area of Northwestern Federal District of Russia is 1,687 10^6 km^2. It is characterized by the significant water resources. The total volume of water runoff from its territory is equal to 560 km^3/year, Shiklomanov et al. (2008).

The Federal District combines the eleven subjects of Russian Federation: the Republic of Karelia, Komi Republic, Nenets Autonomous Okrug (related with the Arkhangelsk Oblast), Arkhangelsk, Vologda, Murmansk, Leningrad, Pskov, Novgorod and Kaliningrad Oblasts and the St. Petersburg – the city of federal importance. The time series of local runoff of these administrative regions excepting the St. Petersburg city are kept and processed by the Information and analysis center of the State water inventory of the State Hydrological Institute. These time series starts from 1930. The regular annual time series of local runoff could be applied for its long range forecasting.

These time series were analyzed by the methods of "Periodicities" and of Yu.M. Alekhin. The time series were analyzed from their beginning up to the 2009. The last five their points of 2010 – 2014 were designed for the computation of the training forecasts and for estimation of the results of predictions.

The long range forecast is estimated as true if its mistake – the difference between the real and predicted values of the runoff is lower than the accepted mistake of prediction Δ_{ac}. The mistake Δ_{ac} very often is considered as equal to 0.674 from the standard deviation of the runoff time series, Apollov et al. (1974). The prediction for the given time interval could be evaluated through the total quantity of its true annual forecasts and their percentage or justification.

The results of the long range forecast for the time interval could be estimated also through the relative mistake of prediction *dr* calculated from the sum of squared mistakes of annual forecasts S_f :

$$dr = \frac{0.674}{\Delta_{ac}} \sqrt{\frac{S_f}{l}} \quad , \tag{1}$$

where *l* is equal to five the number of years of training forecast interval.

The forecast of one time series is better than another if its number of true forecasts is larger and the relative mistake of prediction is smaller. If the number of true forecasts and the relative mistake of prediction of one time series are larger than another it could be concluded that the results of their predictions are approximately the same quality.

The method of "Periodicities" is based on the approximation of time series by the sine functions successively with the unitary period step, Babkin (2005). The amplitude, phase, additional item of any approximation sine and its sum of squared differences with the respective time series are estimated by the method of the least squares. In dependence from period there should be the local minima of sums of squared differences of time series and approximation sinusoids. It could be as the indication of the presence of periodicity here.

The numbers of the same periods in all ten time series were estimated. The period of 11 years was revealed more times that the others. There were eight 11 year periods from ten time series, seven periods of 4 years and six – of 8 years. All other periods were revealed no more than several times.

The more reliable and suitable for the prediction period should be revealed large number of times in the group of time series and could be related with any physical process as with its possible reason. The revealed 11 year period could be associated with the respective dynamics of solar activity.

The method of Yu.M. Alekhin permits to produce the forecasts by the model of multiple regression of analyzed time series with the group of time series of it values but successively displaced to the analyzed time series, Alekhin (1963). The step of such displacement of annual runoff time series is accepted equal to one year.

The coefficients and additional item of the regression equation are estimated through the composing of the matrix of coefficients of correlation between the analyzed and displaced time series and between displaced time series. These regression parameters are calculated through the relations of determinants of the minors of correlation matrix taking into account the mean values of the respectively reduced analyzed and displaced time series and their standard deviations, Romanovskii (1938).

In this study the rank of the correlation matrix is designed to be equal four. This not high rank permits to form the simple regression models of small volume which could be analyzed and controlled by independent calculations. The model with this rank of matrix could reveal the determined component of times series which is the analog of sine function by its complexity. It could make the comparison of results of prediction of runoff by 11 year harmonics and by the model formed on the base of method of Yu.M. Alekhin more valuable as these schemes has approximately the same capability to reveal the determined component of time series.

The succession of values of the model of Yu.M. Alekhin is shorter than analyzed time series. If the rank of the correlation matrix is equal to four, the autocorrelation time series will be with 77 numbers. It will permit to compute the sine with the period of 11 years in the autocorrelation succession of values by the approach of J. Fourier and to delete it. The autocorrelation time series without the 11 year period could be useful for its combination with this sine revealed by the method of "Periodicities".

Such application of the method of Yu.M. Alekhin provides the possibility to forecast the runoff only for the one next year. The predicted runoff is added to the initial time series making it longer for one value. The extended runoff time series modeled and predicted as previous and the forecast substituted to it again. So all values of runoff of the training forecast interval of 2010 – 2014 for ten administrative regions were computed.

Figure 1 illustrates the time series of the local runoff of Novgorod Oblast, the 11 year sine revealed by the method of "Periodicities" and the autocorrelation model formed by the method of Yu.M. Alekhin. The sine and the autocorrelation time series are extended for the training forecast interval.

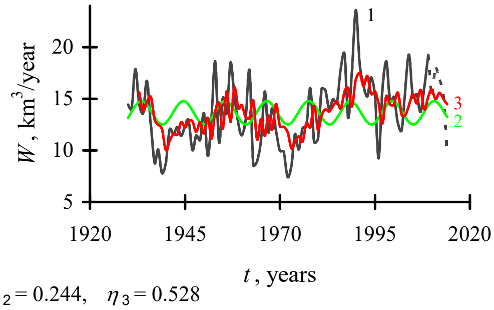

Figure 1. Runoff of local formation of the Novgorod Oblast: 1 – runoff time series, training forecast interval is underlined by the dotted line, 2 – sine with the period of 11 years, 3 – model, formed by the method of Yu.M. Alekhin

The sine and the autocorrelation model describe on some extension the local runoff variation. Sine reflects the cyclically changing groups of years with the increased and reduced water runoff. The maxima and minima of the autocorrelation model more often delay to the respective extreme of runoff for one year. Correlation with the runoff time series η of model of Yu.M. Alekhin is larger than of the sine.

There are two true forecasts of the runoff by the sine and three by the autocorrelation model. The relative mistake of prediction by the sine is slightly lower than by the autocorrelation method mainly because the sine better reflects the extremely low runoff of 2014.

So, the results of forecasts of the runoff of the Novgorod Oblast by these two schemes are approximately the same quality. Both of them are better than the prediction by the mean value of the runoff.

The numbers of true forecasts and relative mistakes of prediction of local runoff by its mean values, by the 11 year sine, Babkin et al. (2018), and by the autocorrelation model for all administrative regions of the Northwestern Federal District are presented in the tables 1 and 2 respectively. In the time series of runoff of the Arkhangelsk and Vologda Oblasts the 11 year sine was not revealed. Instead it the results of predictions by the mean values of the runoff were taken into the account. In the lowest rows of the tables the general justification of the forecasting and mean relative mistakes are estimated.

We can conclude that the results of forecasts of runoff by the sine and by the model of Yu.M. Alekhin are approximately the same quality. The forecast justification and the mean relative mistake both are higher by the autocorrelation method than by the sine. However, because the results of forecasts by the method of Yu.M. Alekhin are better than by the mean value of the runoff, while between by the sine and by the mean value are approximately the same quality, it could be concluded, that autocorrelation forecasting is better than by the 11 year sine.

Table 1. Justification of training forecasts of the local runoff of the subjects of Federation of the Northwestern Federal District for 2010 – 2014

№	Name of time series	Number of true forecasts		
		N_m	N_{11}	N_{au}
1.	Arkhangelsk	3	3	4
2.	Vologda	2	2	2
3.	Kaliningrad	2	*1*	3
4.	Leningrad	0	1	0
5.	Karelia	3	3	3
6.	Murmansk	3	3	3
7.	Komi	4	*3*	*2*
8.	Novgorod	2	2	3
9.	Nenets	1	1	1
10.	Pskov	4	4	4
	At total	24	23	25
	Jastification	0.48	0.46	0.50

Table 2. Relative mistake of training forecasts of the local runoff of the subjects of Federation of the Northwestern Federal District for 2010 – 2014

№	Name of time series	Relative mistake of prediction		
		dr_m	dr_{11}	dr_{au}
1.	Arkhangelsk	0.611	0.611	0.568
2.	Vologda	0.873	0.873	*0.878*
3.	Kaliningrad	0.775	*0.888*	0.709
4.	Leningrad	1.196	1.105	*1.268*
5.	Karelia	0.893	*0.951*	0.852
6.	Murmansk	0.727	0.625	0.724
7.	Komi	0.552	*0.648*	*0.761*
8.	Novgorod	0.977	0.766	0.777
9.	Nenets	1.544	*1.612*	1.539
10.	Pskov	0.626	0.478	0.619
	At total	8.774	8.557	8.695
	Mean	0.877	0.856	0.870

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Cool episodes in the Baltic Sea Basin and surrounding regions over the Early Holocene time: Lessons from the past for future

Irena Borzenkova [1], Olga Borisova[2], Tatyana Sapelko [3]

[1]Climate Department, State Hydrological Institute, St. Petersburg, RF (irena_borzen@mail.ru)
[2] Institute of Geography, Russian Academy of Sciences, Moscow, RF
[3]Institute of Limnology, Russian Academy of Sciences, St. Petersburg, RF

1. Introduction

The deglaciation process was characterized by the instability of the global and regional climate, when against the background of positive temperature trend rapid and relatively short-term temperature drops alternated with the warming episodes occurred. (Several cool episodes occurred in the Early Holocene, about 10.2, 9.2 and 8.2 thousand years ago, the latter two being better documented by proxy data Fleitmann et al., 2008). Cold episode in northern Europe about 8200 years ago (so-called "8.2 ka cold event") has been known for a relatively long time, mainly due to palynological data obtained by analyzing lake and peat sediments. A detailed analysis of ice cores from Greenland GRIP, GISP2, and NGRIP with a high-time resolution revealed the duration and peculiarities of the temporary structure of this cold event (Thomas et al., 2007; Rasmussen et al., 2014). An independent method to estimate both air temperature change and the duration of this cold phase is based on the concentrations of ^{15}N in N_2 in ice cores (Kobashi et al., 2007; Thomas et al., 2007). The total duration of the 8.2 ka cold event was approximately 160 yr. The genesis of the cool episodes of the Early Holocene is connected with the fluxes of melt water into North Atlantic as the result of the Laurentide ice sheet melting. At present similar processes are possible due to the rapidly shrinking Arctic sea ice cover and an increase of the precipitation in high latitudes in response to the recent global warming.

2. Empirical data and reconstructions

Pollen analysis of the lake deposits from the northern Europe, as well as the studies of the deep-sea sediments from North Atlantic, indicate that the mean annual air temperature during the maximum cooling at 8.2 ka BP decreased by 1-2°C, and in some regions by more than 3°C (Daley et al., 2011; Morrill et al., 2013). The most significant decrease in summer air temperatures occurred in the north of the North Atlantic, in the region of British islands, in the west of Norway, and in the Baltic region. The cooling spread from the coast of North Atlantic onto the European continent and was manifested most clearly in Sweden, Finland, in the Baltic States and to a lesser extent – in the north-west and west of the Russia (Borzenkova et al., 2015, 2017; Holmes et al., 2016; Morrill et al., 2005; Seppä et al., 2007; Szeroczyńska et al., 2011). In the central regions of the Russian Plain and north of 70°N the cooling was expressed weakly or not at all evident (Borzenkova et al., 2017; Novenko et al., 2015). Seppä et al. (2007) clearly identified "the 8.2 ka cold event" across entire West Europe, with the lowest air temperatures in areas adjacent to the North Atlantic. The map in Fig. 1 shows the key sections with various proxy data (palynological, faunistic, sedimentological, and others) used for reconstruction of summer temperature drop during this cold episode.

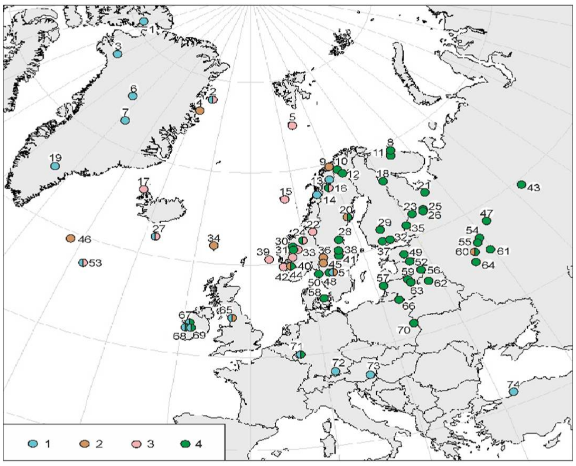

Figure 1. Key sections used for the climate reconstructions of the cold episode about 8200 years ago.
The data on the sites are presented in http://www.fluvial-systems.net/Borzenkova_et_al_supplement.html
The paleodata used for the reconstruction: 1 – isotopic; 2 – sedimentological; 3 – faunistic; 4 – palynological

In Fig. 2 a map of summer air temperatures in Northern Europe is represented. This map shows a decrease in the summer temperature (°C) during the 8200 ka cold event in comparison to the preceding and following warmer interval. Almost all proxy data indicate that the decrease in air temperature was significantly larger in winter than in summer. This promoted an earlier freezing and later thawing of sea and lake surface water (Prasad et al., 2009).

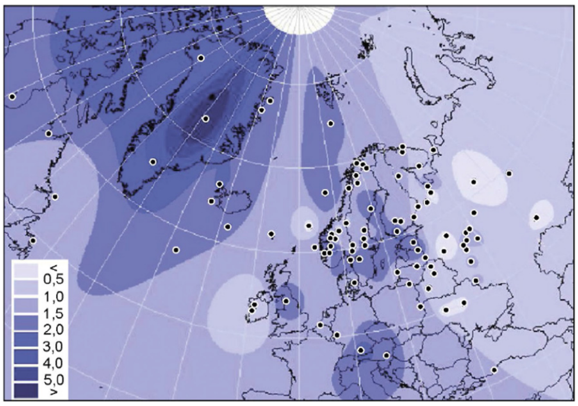

Figure 2. Summer ir temperature decrease (°C) during the cold episode about 8200 years ago compared to the previous warmer time. Points show positions of the key sections.

3. Causes and mechanisms

The question of the mechanisms of this cold event, and other cold events of the Lateglacial, such as the Oldest, Older, and Younger Dryas, is widely discussed in the scientific literature. The hypothesis proposed more than 20 years ago, that the reason for the reduction of air temperatures in the regions adjacent to the North Atlantic was a large flux of melt water discharged into the ocean as a result of disintegration and melting of ice-sheets, is accepted by most researchers (Carlson et al., 2009; Clark, 2001; Clarke et al., 2004; Li et al., 2012). Most researchers attribute the abrupt cooling events in the past 14,000 years to changes in the thermohaline circulation of surface and deep water in the North Atlantic driven by melt water drainage from the continental ice sheets. Clark (2001) and Clarke et al. (2004) assumed that freshening of the sea surface layer of the North Atlantic not only disturbed the circulation in the surface layer but also hindered the formation of deep water. The most important of such events was the drainage of glacial lakes Agassiz and Ojibway resulting from the Laurentide ice sheet melting (Li et al., 2012), during which a huge volume of fresh water could have been discharged into the ocean within less than 100 years. This fresh water outburst could have hindered the formation of deep water and considerably influenced the Atlantic "conveyor belt" itself.

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High-resolution large-scale modeling framework for a transboundary Nemunas River watershed

Natalja Čerkasova [1], Georg Umgiesser [2, 1] and Ali Ertürk[3, 1]

[1] Klaipeda University, Marine Research Institute, Klaipeda, Lithuania (natalja.cerkasova@apc.ku.lt)
[2] ISMAR-CNR, Institute of Marine Sciences, Venezia, Italy
[3] Department of Inland Water Resources and Management, Faculty of Aquatic Sciences, Istanbul University, Istanbul, Turkey

1. Introduction

The recent State of the Baltic Sea report shows that more than 97% of the Baltic Sea area suffers from eutrophication due to past and present excessive inputs of nitrogen and phosphorus (HELCOM, 2018). Owing to the implementation of the Baltic Sea Action Plan by the Baltic Marine Environment Protection Commission (also known as Helsinki Commission, HELCOM) member states, the inputs from land have decreased considerably, but the effects of these measures are generally not yet reflected in the status. According to the assessment of the progress towards the national targets for input of nutrients achieved by 2014, Lithuania, as a HELCOM member, has yet to reduce the inputs to the Maximum Allowable Input (MAI) levels.

Adaptation to climate change is a central issue for the planning and implementation of measures to reduce nutrient inputs, as well as for adjusting the level of nutrient input reductions to ensure protection of the Baltic Sea marine environment in a changing climate. Currently, the MAI are calculated under the assumption that the Baltic Sea environmental conditions are in a biogeochemical and physical steady-state (HELCOM, 2018), which is not likely to last with a changing climate.

With nutrient reduction targets to be reached and increasing water management difficulties, a need for a sophisticated hydrological model of the Nemunas River watershed arose, in order to assess hydrologic, sediment and nutrient dynamics with regards to climate change, agricultural practices and other factors. The created model should be flexible to be used for large-scale (entire watershed-wide) and medium (sub-basin) to small-scale scenario calculations, as well as it shall be applied in a coupled watershed-coastal area modelling framework.

2. Modeling framework

In this study, a script-based input generator coded in MATLAB (The MathWorks, Inc., Natick, Massachusetts, United States), was developed and used to setup the Nemunas River watershed SWAT (Soil and Water Assessment Tool) model and create the required input files from a set of homogenised datasets. A script-based approach provides the flexibility to overcome the difficulties related to inconsistent data structure and availability through the region (EU and non-EU datasets differ in data structure, accuracy and resolution), nutrient emission based data availability on administrative-level boundaries rather than sub-watersheds, inflexible and unpractical standard GIS tool functionality. The MATLAB was further used to post-process the model output data and to perform the statistical analysis.

As the modelled area is very large and the intent of the study is to provide opportunity to model landscape processes with sufficient accuracy, it was decided to split the modelled area into sub-models, each representing a sub-watershed of the main Nemunas River branch. Furthermore, to achieve better parametrisation, a separate sub-model represents the Nemunas and all smaller tributaries situated in the Belarus and Poland territories. The result of the sub-model division yielded the following configuration (Figure 1).

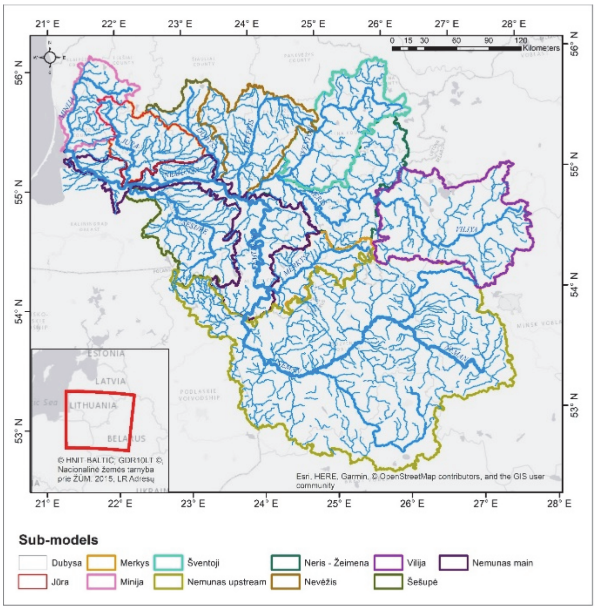

Figure 1. Nemunas River watershed modelling framework map

3. Model calibration and Scenarios

High-resolution sub-model calibration and validation were performed using manual calibration, by adjusting the parameters, associated with specific processes. This research is the first to utilize soft calibration techniques (Arnold et al., 2015) for a large case study with inter-connected models for hydrology and water quality, prior to the hard calibration against measured data. Both, visual analysis and statistical methods were used to evaluate the model performance. The Nemunas River watershed modelling framework performed well in reproducing monthly and daily flows and the sediment and nutrient loads for the days, when the measurements were available. Henceforth, the models used in this framework were deemed to be suitable to simulate long-term scenarios and assessing the hydrological and land-based sediment, nutrient and pollutant loads to the rivers.

Five sets of global 0.5° General circulation models (GCM) data were originally extracted from ISI-MIP5 (Inter-Sectoral Impact Model Inter-comparison Project) (Hempel et al., 2013). The GCM data for the scenarios had undergone a bias correction using statistical downscaling against the set of observed data using the Climate Change Toolkit (Ashraf Vaghefi et al., 2017).

Climate scenarios based on the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Representative Concentration Pathway (RCP) 4.5 and RCP8.5 (Collins et al., 2013) were defined for this study. Altered values for minimum and maximum daily temperature and precipitation data were forced, along with CO_2 concentration change, to produce the runoff, sediment and nutrient response of the modelled area. Other modelled processes, such as management practices, reservoir operations, groundwater nutrient concentrations were not altered, thus producing the “business as usual” conditions. The short term [2040 – 2050] and long term [2090 – 2099] outputs for flow, sediments, TN and TP loads of the scenarios were compared to the baseline scenario [2000 – 2010], which represents the current conditions.

4. Results

The annual average projections for the Nemunas River discharge show no clear pattern, with no trend detected by the Mann-Kendall (MK) test with 1% significance level (Henry B. Mann, 1945; Kendall, 1975). The variability among the GCMs is higher under the conditions of the RCP4.5. Although there are no clear trends in the projected mean annual flows, the variability between the GCMs becomes smaller by the end of the century, meaning that the outputs for GCMs under RCP4.5 and RCP8.5 are in agreement in the long-term period [2090 – 2099].

The interseasonal flow change in all scenarios suggests an increase in mid to late-winter flowrates (Figure 2), which coincides with the projected snow formation decrease in the entire watershed, meaning the increasing proportion of winter precipitation falling as rain.

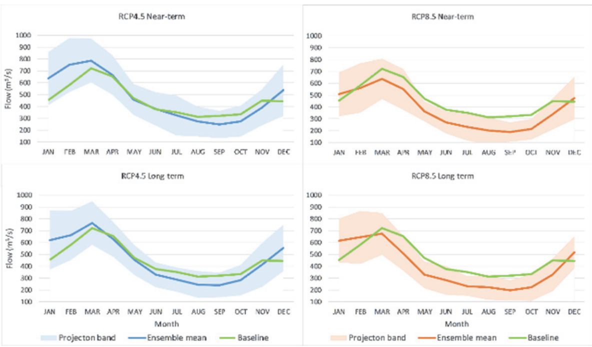

Figure 2. Interseasonal projected flow at the Nemunas – Smalininkai station compared to the baseline: top – near-term projections (up to 2050); bottom – long-term projections (up to 2100)

Possible future sediment and nutrient load projections strongly suggest that the use of nutrient reduction and retention measures is necessary and will remain such in the future if Lithuania strives to comply with the Baltic Sea Action Plan and reduce the nutrient loads. As the winter season is projected to get warmer in the future in all scenarios, the nutrient export from the watershed will strongly depend on the frequency of freezing and thawing cycles. The findings also show that most changes are likely to occur in January and February, thus the recommended action would be to target, assess and implement those nutrient retention measures, which are the most effective in winter.

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Assessing regional water flow changes and their drivers and implications for water quality

Georgia Destouni[1]

[1] Department of Physical Geography, Stockholm University, Stockholm, Sweden (georgia.destouni@natgeo.su.se)

1. Introduction

Assessment and attribution of water flow and quality changes are key challenges for Earth System science, in the Baltic region as in other parts of the world. This paper presents a data-driven multi-catchment comparative approach that can be used to meet these challenges. As a first step, the study uses and synthesizes Baltic and other comparative multi-catchment data (Bring and Destouni, 2011; Destouni et al., 2013; Asokan and Destouni, 2014; Levi et al., 2015; Destouni and Prieto, 2018) to assess large-scale changes and their relationships for the main water fluxes of precipitation (P), evapotranspiration (ET) and runoff (R) along with changes in surface temperature (T).

Through this approach, ET and R flux impacts of human land and water-use developments in the landscape and atmospheric climate changes in P and T can be distinguished and quantified. For these human and climate-driven R changes, important implications for water quality evolution are also identified and discussed based on recent theoretical-analytical advancements supported by Baltic catchment data (Destouni and Jarsjö, 2018).

2. Materials and Methods

The multi-catchment set used to assess P, ET, R and T changes comprise 30 variable-size catchments in the Baltic region compared with other parts of the world. Among these, 16 catchments are known to have been subject to major human disturbances of flow-regulation, agricultural expansion/intensification, and/or irrigation occurring between two main study periods, 1901-1954 and 1955-2008; no reports of such major human disturbances between the study periods have been found in the literature for the other 14 catchments. These disturbance conditions have been reported in and synthesized from a series of previous studies of these catchments (Bring and Destouni, 2011; Destouni et al., 2013; Asokan and Destouni, 2014; Levi et al., 2015; Destouni and Prieto, 2018).

For assessment of the water quality implications of human and climate-driven water flow (R) changes, this study further explores different dependences of waterborne nutrient and pollutant loads on such flow changes, as derived and found for Swedish catchments within the Baltic region by Destouni and Jarsjö (2018). Specifically, major flow-dependence differences are shown to prevail if subsurface legacy sources or currently active surface sources predominantly contribute to catchment loads, as explained and discussed further in the next section (3) in connection with the obtained results for water flow changes.

3. Results and Discussion

Two distinct relationships emerge consistently for the Baltic and other study catchments between the temporal changes of long-term average ET (and between those of R) and the corresponding P changes in catchments with and without known major human disturbances (red and green symbols and regression lines in Figure 1, respectively). For comparison, the commonly used Budyko relationship between actual and (mainly T-dependent) potential ET is not even close to explaining the ET changes in either the disturbed or the undisturbed catchments. On average among the undisturbed catchments, the observation based ET and R changes are around 75% (green line, Figure 1a) and 25% (green line, Figure 1b) of the corresponding P changes, respectively; for zero climate-driven change in P, the ET and R changes are also zero on average in the undisturbed catchments.

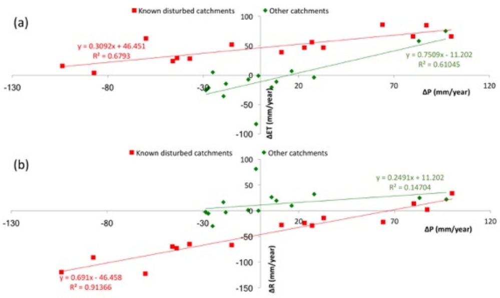

Figure 1. Water flux changes in the studied disturbed (red) and undisturbed (green) catchments of the Baltic and other regions. (a) Evapotranspiration change (ΔET) versus precipitation change (ΔP). (b) Runoff change (ΔR) versus ΔP.

In the disturbed catchments, the temporal change relationships are greatly shifted compared to the undisturbed conditions. The disturbed ET and R changes are around 30% (red line, Figure 1a) and 70% (red line, Figure 1b) of the corresponding P changes, respectively. Furthermore, even for zero climate-driven P change, the disturbed catchments exhibit an average ET increase of around 50 mm/year and a corresponding average R decrease of -50 mm/year.

These multi-catchment results for water flow changes imply a shift to overall smaller R for disturbed than for undisturbed catchments. The results of Destouni and Jarsjö (2018) further imply different dependences of waterborne nutrient and pollutant loads on such temporal shifts in water flow (R) if the loads are predominantly contributed from subsurface legacy sources or from currently active surface sources.

Destouni and Jarsjö (2018) have shown that dominant subsurface legacy sources tend to maintain a more or less stable average concentration level over time. Consequently, legacy source dominance implies a relatively simple linear regression relationship (red line, Figure 2) between the temporal variations in waterborne nutrient/pollutant load and average R; this since the load at each point in time is the product of the essentially temporally constant concentration level and the temporally variable R (water discharge normalized with the temporally constant catchment area). In contrast, dominant current surface sources lead to a dilution behavior of non-linear concentration decrease with increasing R. Consequently, dominance of such surface sources tends to maintain a stable average load level, more or less independent of R and its temporal variations and changes (blue line, Figure 2).

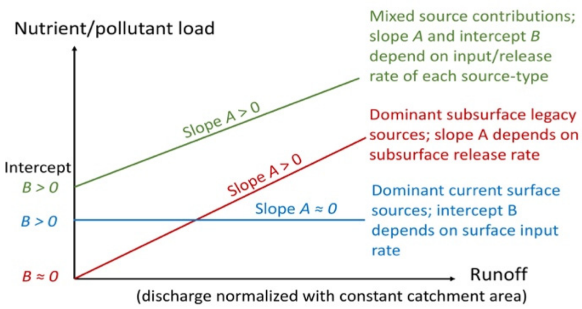

Figure 2. Schematic illustration of types of regression lines derived for and found to fit data-given temporal relationships between nutrient/pollutant load and runoff (discharge) for different conditions of subsurface legacy and current surface source contributions to the loads.

For Baltic catchments with possible dominant current surface sources, the climate and/or direct human-driven changes of water flow (R) should thus not much affect nutrient/pollutant loads (Figure 2: shifts along the blue line for different average R values do not change average load level). For catchments with dominant (red line, Figure 2) or significantly contributing (green line, Figure 2) subsurface legacy sources, however, human land and water-use disturbances that lead to smaller average R imply smaller nutrient/pollutant loads. Such nutrient load decreases have indeed been observed after major irrigation expansion with associated R decrease in the heavily disturbed Aral Sea catchment (Törnqvist et al., 2015) where significant subsurface legacy sources are found to have accumulated (Törnqvist et al., 2011). Furthermore, dominant contributions of subsurface legacy sources are also indicated by nutrient concentration data over the recent decade(s) for many catchments over Sweden (Destouni et al., 2017) and the whole Baltic catchment (Basu et al., 2010). These historic major human land and water-use disturbances have already decreased R relative to undisturbed conditions, and forthcoming climate change may instead increase future R and associated waterborne nutrient/pollutant loads from their current levels in these Baltic catchments (Bring et al., 2015).

4. Conclusions

Catchments in the Baltic region exhibit consistent behavior with that of other catchments over the world in terms of their ET and R responses to climate-driven P changes. The ET and R change responses are distinctly different between catchments with and without major human land and water-use disturbances. Change in P feeds into a greater change in ET (around 75%) than R (25%) under undisturbed conditions. For disturbed conditions, which elevate average ET (by around 50 mm/year on average in the studied catchments), the P change propagation is shifted, so that only around 30% of the P change feeds into ET change, while 70% feeds into change of R from an overall decreased average level (by around -50 mm/year on average).

Such decrease of average R has already occurred in disturbed Baltic catchments, making R considerably more vulnerable to forthcoming climate-driven P changes (from previously 25% to currently 70% of P change feeding into R change). In terms of water quality, this human-driven average lowering of R has so far also lowered (relative to undisturbed flow conditions) the subsurface legacy source contributions to the current waterborne loads of nutrients and pollutants into various water environments and ecosystems (streams, lakes, coasts). Forthcoming climate change, however, may mostly increase average R and associated nutrient and pollutant loads into Baltic water systems in the future. Overall, these shifts in water flow and nutrient/pollutant legacy source accumulation-release are essential Anthropocene signals and impacts that must be recognized and managed in the Baltic region and elsewhere around the world.

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Climate induced changes in runoff in the shared watershed of the Curonian and the Vistula lagoons (the Pregolya River catchment)

Dmitriy Domnin[1], Boris Chubarenko[1]

[1] Shirshov Institute of Oceanology of Russian Academy of Sciences, Moscow, Russia (chuboris@mail.ru, dimanisha@gmail.com)

1. Introduction

The Curonian and Vistula Lagoons should be considered as a part of one natural hydraulic system (Chubarenko et al., 2017), as they are connected via two branches of the Prgolya River (the proper Pregolya River and Deyma Branch). The catchment upstream the bifurcation point belongs to both lagoons and comprises 14% and 57% of the whole catchments of the Curonian and Vistula lagoons respectively. Approximately 36-40% and 60-64% of the runoff from this catchment discharges to the Curonian and Vistula lagoons respectively.

The climate change impact assessment for the Vistula Lagoon watershed was made using SWIM model (Hesse et al., 2015, 2015a) basing on 15 climate scenarios from the ENSEMBLES project, which projected a quite consistent increasing trend in precipitation for the Vistula Lagoon catchment. The simulated river discharge followed this precipitation pattern and was less sensitive to changes in air temperature or solar radiation. The conclusion was that river discharge and flood risk will probably increase in the Vistula Lagoon catchment.

The aim of the study was to verify this conclusion using another climate projections and modeling tool, namely the model HYPE.

2. Study area

The Pregolya River catchment is a transboundary catchment. The river flowing through the territory of the Kaliningrad Oblast (Russia) and its main tributaries (the Angrapa and Lava) originate in the Warminsko-Mazurskie and Podlaskie Voivodships of Poland. The catchment area is divided between Russia (Kaliningra Oblast) and Poland (Warminsko-Mazurskie and Podlaskie Voivodships) in approximately equal proportions – 49% and 51% respectively. In addition, a small part of the Pregolya River catchment (about 0.5%) is in the territory of Lithuania near the Vyshtytis Lake (Domnin et al., 2017).

3. Method

The set-up for the Pregolya River catchment extracted from the E-HYPE v3.1 (Lindström et al. 2010, Donnelly et al., 2010, Hundecha et al. 2016) was modified and calibrated using detailed local data for the Pregolya River catchment. Three separate model set-ups were prepared: the catchment area of the Pregolya River (13,100 km^2) upstream the division into two arms in Gvardeysk, the catchment areas of the Downstream Pregolya (1,100 km^2) and the catchment of the Deyma River (400 km^2) (Figure 1).

Calibration of the hydrological module of HYPE for Upstraem Pregolya was made (Domnin et al., 2017) for the period 1986-1996. Verification was performed for 2008–2009. The correlation coefficient and Nash Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) between measured and simulated discharges was 0.79 and 0.59 for calibration period and 0.85 and 0.55 for verification period respectively. Measured and simulated annual average discharge of the Pregolya River in Gvardeysk (before the river bifurcation in two branches) was 90 m^3/s and 89 m^3/s respectively, the same values for verification period were 76 m^3/s and 78 m^3/s.

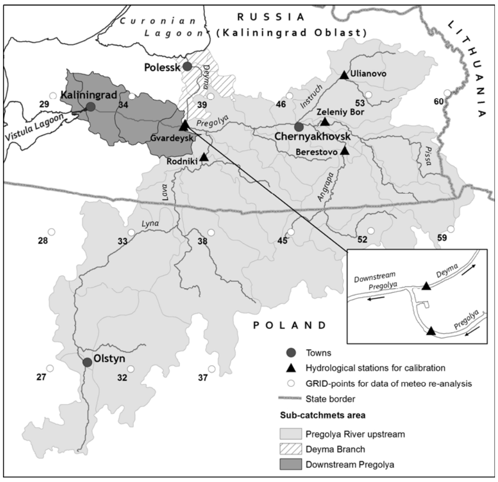

Figure 1. Scheme of branching of the catchment basin of the Pregolya River in the model installation: 1 – Upstream Pregolya , 2 – Downstream Pregolya, 3 – Deyma ((Domnin et al., 2017).

4. Climate projections

An assessment of the response in discharge of the Pregolya River to possible climatic changes was based on climate projections for the period of 1991-2100 for the scenario of greenhouse gas emission RCP8.5. Projections of precipitation and temperature for the 21st century were taken from a subset of models used within the framework of EUROCORDEX initiative (http://www.euro-cordex.net/). The choice of the subset of models was made to maximize the spread of possible mean temperature and precipitation changes over the southern Baltic Sea basin (Olesen et al., 2018).

Using climate projections for the period of 2041-2060, calculations of a possible response of hydrological characteristics have been made by Pregolya-HYPE model calibrated on 1991-2010 baseline period.

The responses to changes in the atmospheric impact (2041-2060) have been analyzed according to 4 climate projections: CanESM2_RCA4, CM5A-MR_WRF, CNRM-CM5_RCA4, MPI-ESM-LR_CCLM (from of EUROCORDEX initiative. Increases in temperature over the catchment area of the Pregolya River range from 1.2°C (CM5A-MR_WRF) to 2.1°C (CanESM2_RCA4), while precipitation increases range from 20 mm/year (MPI-ESM-LR_CCLM) to

200 mm/year (CNRM-CM5_RCA4) which mean an increase by 10-25% comparing to the baseline period.

5. Results

The uncertainty of changes in meteorological and hydrological characteristics for climate period 2041-2060 in comparison to baseline period 1991-2010 is described as following:

- the precipitation will increase, and the range of changes will be from +59 mm (+7%) to +216 mm (+27%);
- the mean annual air temperature will increase by 1.3 – 2°C;
- the projection for the mean annual discharge is not unambiguous, it may decreases by 7 m^3/s (-8%) or increases by 26 m^3/s (+31%);
- therefore, the mean annual specific run-off is not unambiguous, it may decrease by 23 mm (-10%) or increases by 62 mm (+28%).

Table 1. Main hydrological and meteorological characteristics for the catchment area of the Pregolya River for baseline period 1991-2010 and their absolute (Δ) and relative changes (%) with signs (+)/(-) obtained by modeling for climate projections for 2041-2060 (maximum range).

Para-meters	Base-line, 1991-2010	Climate projection, 2041-2061			
		Min		Max	
		Δ	%	Δ	%
Precipita-tion, mm	795	+59	+7	+216	+27
Tempe-rature, °C	7.8	+1.3	–	+2	–
Discharge, m^3/s	83.8	-6.7	-8	+26.3	+31
Runoff, mm	220	-23	-10	+62	+28

6. Discussion and conclusions

Two (out of the four) climate projections (CM5A-MR_WRF, CNRM-CM5_RCA4) project increases of discharge, while the other two (CanESM2_RCA4, MPI-ESM-LR_CCLM) project decreases. This suggests that the conditions in the Pregolya River basin are very sensitive to changes in evapotranspiration which is a result of the coupling of temperature and precipitation and thus is sensitive to climate model uncertainty. Once the simulation of evapotranspiration is a large uncertainty in hydrological models it should be taken into account when interpreting these results.

The increase in precipitation does not always lead to an increase in the river runoff from the catchment area. This nonlinearity is associated primarily with an increase in temperature, which leads to increased evapotranspiration from the catchment area.

The obtained results didn't coincide with similar ones (Hesse et al., 2015, 2015a) that supports the hypothesis that Pregolya River catchment is located at the belt where climate projections couldn't provide certain results about climate change tendency, therefore hydrological estimations have high uncertainty. Managers should consider both tendencies – increase and decrease in runoff.

7. Acknowledgement

Climate projection data were obtained from Swedish Hydrological and Meteorological Institute within the BONUS Soils2Sea Project 2014-2017 (www.Soils2Sea.eu), the data was bias-corrected to the WFDEI reference data using the DBS method. Simulations were supported within the same project. The analysis was made with support of State Assignment of FASO Russia (theme No. 0149-2019-0013).

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The complex and interdisciplinary study of water ecosystems of largest lakes of Europe (A Review)

Nikolai Filatov

Northern Water Problems Institute of the Karelian Research Centre of the Russian Academy of Sciences, Petrozavodsk, Russia (nfilatov@rambler.ru)

Abstract

The interdisciplinary study of the water ecosystems of Russia's largest lakes Ladoga, Onego realized by Northern Water Pproblems Ins. KarRC RAS with colleques from Institutes of the Russian Academy of Sc.: Limnology, Water problems, Numerical Mathematics, Oceanology, SPb Institute of Economy and Mathematica RAS and Institute of Earth Sc. SPb University for the last 10 years are presented. Estimates of the regional climate variability, hydrological characteristics, water balance elements and water level variations are given using long-term measurements and mathematical modeling. Diagnostic and forecasting calculations of atmospheric heat and moisture transport to the watershed of the studied lakes were performed with using the models.

Diagnostic and prognostic studies of the lake's ecosystems (hydrophysical processes, primary production, and biogeochemical flows of matter) of Lakes Ladoga and Onego were carried out using the created or adapted 3-D mathematical models developed in Russia (Rukhovets, Filatov, 2010). A marine biogeochemical model SPBEM developed for Baltic Sea (Savchuk&Gustafson, 2012; Vladimirova et al, 2018) has been adopted for studies of the Ladoga Lake eutrophication. In contrast to previously used models (Rukhovets, Filatov,2010) SPBEM describes nutrient dynamics both in the water body and bottom sediments (Filatov, Isaev, Savchuk, 2019). Also, special attention is paid to presentation and analysis of biogeochemical fluxes that drive and determine dynamics of concentrations and biomasses. Model was implemented for diagnostic (1996–2015) and prognostic (2016–2040) simulations of hydro-physical and ecosystem dynamics. Comparison of diagnostic simulated to scarce available observations showed a satisfactory match of the spatial-temporal dynamics of hydrophysical and biogeochemical characteristics. Possible changes in the hydro-physical processes, primary production, and biogeochemical nutrient fluxes in Lake Ladoga until 2040 under climate change scenario A1B are presented. This experience shows that the model can be used for projections of biogeochemical cycles that could occur in ecosystems of large stratified lakes under climate change and human impact.

Other new 3-D mathematical model previously developed for Caspian Sea (Ibraev, 2008) for the study of physical and chemical-biological processes in large lakes was constructed. The response of lakes Ladoga and Onego to possible climatic and human impacts were estimated by using this model (Zverev et al, 2016).

The traditional approach of models construction based on the solution of a system of non-linear partial differential equations is rather challenging. It possible alternatively to employed so-called cellular automata (CA), which enable modeling of complex non-linear processes, including self-organization, using relatively simple rules (Wolfram, 2002). The main task for this study was to describe the synergies of the physical, chemical, and biological processes. This, in fact, means that the “traditional” method of describing the ecological system through a set of differential equations (Menshutkin et al., 2016) is replaced by the concepts of discrete mathematics. Thus, the method of numerical solution of non-linear equations using cellular automata (CA) is a way in this direction. This method has been applied to the describing Lake Baikal biota (Afanasiev, 2012). Computer models of the distribution of persistent impurities, assessment of pollution and thermal regime of Lake Ladoga and Onego were built. It were developed several CA models: from a zero-dimensional vertical model of the lake's deepwater Area, two-dimensional model for the lake's longitudinal section and, finally, it was created three-dimensional model of the entire water body (Menshutkin, Filatov, 2016, 2017).

Under-ice complex studies of physical-chemical-biological processes of large lakes were look like a “blank spot” of limnology (Surter et al., 2012, Kirilin et al., 2012). The main reason for the lack of winter observations on large lakes which do not usually get fully ice-covered and have cracks, numerous fractures, thermal cracks, polynias and ice holes is a high risk to work on ice (Kouraev et al., 2017). The multidisciplinary Russian-Swiss international project “Lake Ladoga: life under ice – interplay of under-ice processes by global change” began in March 2015 on Lakes Onego (Onegskoe) and Ladoga (Filatov, Terzhevik, 2015). The research program was to survey both Lake Ladoga and Lake Onego, which belong to the system of European Great Lakes involved about 40 specialists from Russia, Switzerland, France, Germany, Sweden, and other countries under owing to the help of the ELEMO foundation (Lausanne, Switzerland), which allocated grant for 2015-2017 y. The basic assumption of the proposed work is that the winter regime, phytoplankton dynamics as well as other hydrodynamic and ecological processes of a large ice-covered lakes. The research program propose to investigate physical and biogeochemical dynamics on ice-covered Lakes Ladoga and Onego through interdisciplinary projects in seven sub-projects are conducted. The scientists would like to understand under-ice convections and its implication for ecosystem development. The radioactively-driven convection studies were realized on Lake Onega after snow disappeared from the ice surface, and the solar radiation penetrating through the ice warms the underlying water. In several sub-projects were measured physical, chemical and biological parameters simultaneously under-ice. The functioning of the ecosystem should be investigated by analyzing physical, chemical and phytoplankton, zooplankton and bacteria, as well as C transfer throughout the trophic system. The reconstruction of land use history and climatic changes in the catchment area will be explained using short sediment cores. The integrated surveys were set up on Lake Onego, which was fully ice-covered them northern part of Ladoga lacked the ice cover. The ice thickness at the measurement site on Lake Onego in March 2015-2017 was 30-40 cm, and the survey coincided with the onset of under-ice convection, which influences the distribution and transformation of the biota and matter in the lake. The principal aim of the multidisciplinary Russian-Swiss project is to carry out wintertime integrated field surveys of physical, chemical and biological parameters of the water in lakes Ladoga and Onego, including the water-ice interface, surface water layer, and ice itself, to investigate the structure and functional characteristics of aquatic organism communities in these systems, understand patterns in the formation of water quality, as well as study the effect of climate change on the lake ecosystems. Results of the interdisciplinary study were published in Special Issue of the SIL Journal Inland Waters "Life under ice in Lake Onego (Russia) – an interdisciplinary winter limnology study" (Wüest et al, 2019).

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Modeling system for heat and mass transfer in the system: catchment area – watercourse – water body

Kondratyev S.A.[1], Golosov S.D.[1], Shmakova M.V.[1], Zverev I.S.[1], Ivanova E.V.1, Shipunova E.A.[1]

[1]Institute of Limnology of the Russian Academy of Sciences, Saint-Petersburg, Russia (kondratyev@limno.org.ru)

A modeling system that quantifies heat and mass transfer in the system: catchment area – watercourse - water body was developed at the Institute of Limnology RAS. It also predicts consequences impacts of anthropogenic and climatic factors on the system in conditions of a lack of field observations data. The components of the simulation system can be used in any combinations depending on the conditions of the problem being solved, which significantly expands the possibilities of its practical application (Fig 1). A general description of system components is provided below.

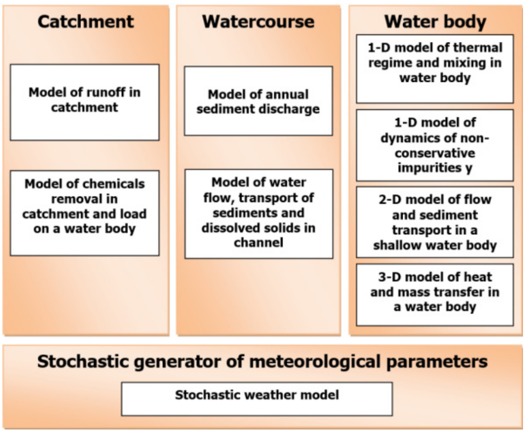

Figure 1 – Components of the modeling system of heat and mass transfer in catchment area – watercourse - water body

The model of runoff in catchment is intended for calculating hydrographs of melted and rainfall runoff in catchments, as well as water level in a water body. The model describes processes of snow cover and snow melting, evaporation and soil moisturizing of the aeration zone, the formation of runoff and runoff regulation by water bodies within a homogeneous catchment with characteristics assumed constant over its entire area.

The model of chemicals removal from catchment and load on a water body is designed to solve problems of quantitative assessment of nutrient load formed by point and diffuse sources of pollution. It also forecasts the load changes under the influence of possible anthropogenic and climatic changes. The model allows calculating matter removal from catchment taking into account an influence of hydrological factors and retention of nutrients by catchment and its hydrographic network.

The model of annual sediment discharge is based on using the compositional method of probability theory and the analytical equation for sediment discharge, which is a consequence of the basic equation of motion of water and solid matter. In this case, the calculated sediment discharge takes into account the contribution of both suspended and bed load discharges. Resistance parameters for river flows are determined in accordance with the size category of bottom sediments and being a function of a water content of the stream.

The model of water flow, transport of sediments and dissolved solids in free surface channel is designed to calculate characteristics of two-phase unsteady movement in a river bed. The model is based on mathematical representation of the forces acting in the system "water flow - bottom sediments – suspended matter." The model allows to detect a movement of suspended matter and dissolved substances along a channel and estimate particles deposition rate in case of decreasing in transporting potential of the flow.

The one-dimensional model of thermal regime and mixing in water body (Flake) was developed jointly by the Institute of Lake Science RAS, the Institute of Northern Water Problems RAS, the Institute of Fresh Water Ecology and Inland Fisheries (IGB) and the Meteorological Serves of Germany (DWD). The model designed to solve problems associated with calculation of thermal regime in the system "snow - ice - water - bottom sediments" and mixing conditions during the period of open water. This model is a basic tool for developing models of aquatic ecosystems functioning and models of formation of water quality in natural water bodies and artificial reservoirs.

The one-dimensional model of dynamics of non-conservative impurities in water body (FLakeEco) is able to describe an annual cycle of oxygen regime, a seasonal dynamics of nutrients concentration, primary production of phytoplankton and seasonal dynamics of total biomass of phytoplankton. The model is based on a parametric description of vertical distribution of dissolved oxygen concentration in the water body. The model is a continuation of the FLake model ideologically and structurally. In this case it acts as a hydrothermodynamic part of the FLake model.

The two-dimensional model of flows and sediment transport in a shallow water body allows to calculate a spatial structure of flows and paths of impurity distribution in water body with different wind effects and runoff from the catchment. It also allows to calculate the changes in morphometric characteristics of a bed of a water body. The model is based on a joint solution for shallow water equations in a two-dimensional formulation and analytical formula of solid discharge.

The three-dimensional model of heat and mass transfer in a water body is based on the hydrodynamic model for inland sea developed at the Institute of Numerical Mathematics of Russian Academy of Sciences. The model was adapted to lake conditions. The model allows to study thermal and ice regimes of large lake systems under impact of climatic atmospheric influences and with possible climatic changes. The model helps to estimate distribution of tributaries water in water bodies and corresponding changes in thermohydrodynamics of lakes.

The stochastic weather model is a unit for generating long series of meteorological elements, it provides a flow of meteorological information to the input of various deterministic models included in the modeling system. Thereat the orientation on meteorological observation data as a basis for deterministic-stochastic modeling is explained by the fact that for most cases the series of measured meteorological parameters are quite long. They are significantly longer than runoff series and series of measured values of impurities removal from the catchment and their transport in the water body.

The developed models have been tested and successfully used for complete practical tasks for the catchments of the northwestern and central regions of Russia, Finland, Slovakia and other countries, as well as for the largest European lakes (Ladoga, Onega, Chudsko-Pskovskoe) and other national and foreign water bodies (Golosov et al., 2007; Golosov et al., 2012; Kondratyev, 2007; Kondratyev et al., 2019).

As an example of models using, Fig. 2 shows the calculated phosphorus load on Chudsko-Pskovskoye lake located in the catchment of the Gulf of Finland and the following distribution of impurities in the water area.

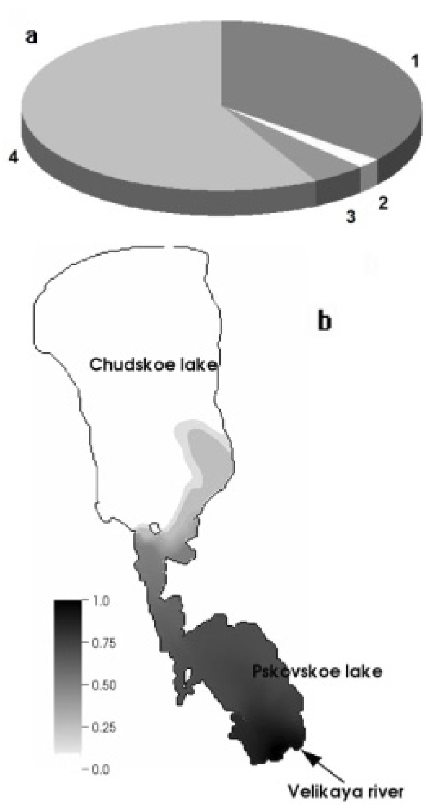

Figure 2 a - phosphorus load on Chudsko-Pskovskoye lake from Velikaya river catchment (1 – agricultural load, 2 – point load in catchment, 3 – direct outlets; 4 – land surface emission);
b - spreading of river inflow in aquatic area – decrease of concentration from 1.0 to 0.0.

The main load incoming into the lake with the runoff of Velikaya River is formed by emission of phosphorus from different types of underlying surface that are not used in agricultural activities. The water area of Pskovskoe lake is totally influenced by phosphorus load coming with river runoff. The flow path of river water in Chudskoe lake is spreading mainly along the east coast. A vertical thermal front prevents a penetration of polluted waters into the central part of Chudskoe lake. This front is caused by lower temperatures of the water masses in the deep-water part of the water body.

Prospects for the modeling development of mass transfer processes in the system: catchment area - watercourse – water body first of all include improvement of methods of deterministic estimation of runoff, removal of suspended particles and dissolved impurities from the catchment and streamflow, as well as mass transfer in a water body. Progress in this case depends on a significant restructuring and improvement of monitoring system of water bodies and providing special field studies for verification parameters of the models.

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Long-term monitoring of water chemistry in the Eastern Gulf of Finland

Alexander Korshenko

Marine Monitoring Department, State Oceanographic Institute, Moscow, Russia (korshenko58@mail.ru)

1. State monitoring System

Within a state water monitoring in the Eastern part of the Gulf of Finland including shallow Neva Bay the North-Western Division of Roshydromet takes water samples four times per year at about 40-50 stations (Fig. 1). Water samples from surface and near-bottom level are treated for standard hydrochemistry including nutrients, trace metals and several organic pollutants. Their content is compared with officially established in Russia Maximum Allowable Concentration (MAC). Some results from the last 16 years monitoring are presented in this paper.

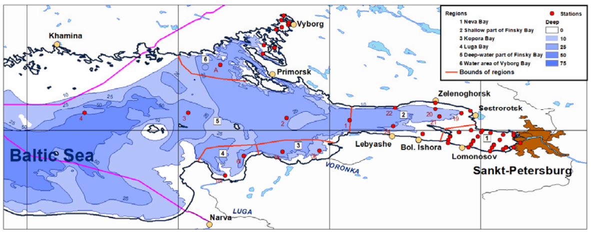

Figure 1. Stations of monitoring by Roshydromet in the eastern part of the Gulf of Finland including Neva Bay.

2. Nutrients

Annual averages of phosphorus of phosphates clearly indicate the highest values almost for all the years of observations in the deep waters of the eastern part of the Gulf of Finland (Fig. 2). The stations N1-4 are situated at transect, crossing central open waters. Concentrations here are about two times smaller than Maximum Allowable Concentration (MAC = 50 μg/dm^3), established in Russia. In contrast with that St.Petersburg Trade Port and Neva Bay in general show the lowest values especially for five last years. The average values exceed MAC only in Luga Bay case in 2009 at the station, which is close to the river estuary, due to a very high value of mineral phosphorus of 200 μg/dm^3 recorded at the surface layer. The total phosphorus in this sample reaches 240 μg/dm^3.

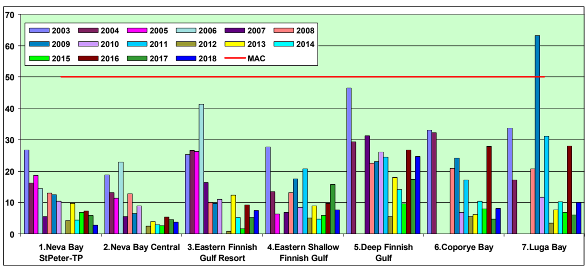

Figure 2. Annual average phosphates P-PO₄ concentration (μg/dm^3) in the different parts of the Eastern Finnish Gulf.

The maximum values of mineral phosphorus are rather high practically everywhere at the beginning of the observation period, including Neva Bay and StP-TP (Fig. 3). For last six years the maximal data exceeds MAC about two times mainly at the deep stations N1-4, where in the near-bottom layer phosphates concentration has a range of 36-95 μg/dm^3 and average value for this period is 77.5 μg/dm^3. In the surface layer of these four stations maximal values vary from analytical zero to 22.0 μg/dm^3 with average 8.0 μg/dm^3.

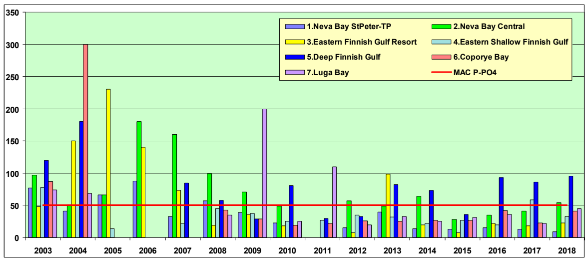

Figure 3. Maximal phosphates P-PO₄ concentration (μg/dm^3) in the different parts of the Eastern Finnish Gulf.

The total phosphorus concentration widely varies from analytical zero to 380 μg/dm^3 in 666 of 5992 treated samples from the whole period of observations. Maximum value is recorded in Coporye Bay in the beginning of October 2004 near the bottom at the depth of 24 m. The average is 21.0 μg/dm^3 for the whole studied area; and the main part is mineral phosphorus with average of 11.9 μg/dm^3. Among sub-regions of the eastern Finnish Gulf the lowest values are typical for Neva Bay (average is 15.0 μg/dm^3) and St. Petersburg Trade Port (18.8 μg/dm^3), and maximal numbers are at deep stations (37.0 μg/dm^3), Coporye Bay (29.9 μg/dm^3), Luga Bay (30.9 μg/dm^3) and Vyborg Bay (26.1 μg/dm^3). In the inner part of the Neva Bay close to the underwater outlet from the Northern WWTP the phosphates concentration in average is 14.6 μg/dm^3 and total phosphorus is 24.7 μg/dm^3. There is no evident long-term trend in the total phosphorus content. It could be noted that the highest values are indicated at 2003-2004 and 2011 (47.1, 36.5, 37.3 μg/dm^3) and are rather low for the last four years: 7.7, 18.0, 13.1 and 14.3 μg/dm^3.

The annual average ammonium concentration in the different parts of the studied area is significantly lower than MAC = 389 μg/dm^3 (Fig. 4). Considering the results form the stations the most affected was are the waters of St.Petersburg Trade Port and the Vyborg Port.

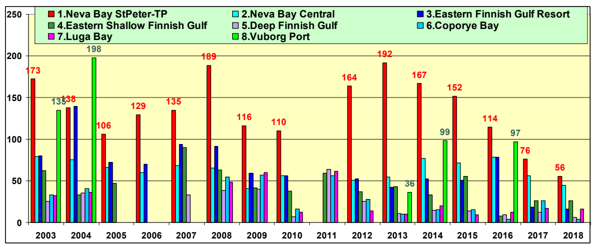

Figure 4. Annual average ammonium N-NH₄ concentration (μg/dm^3) in the different parts of the Eastern Finnish Gulf.

The maximum of ammonia content more often occurs in the central part and Trade Port in the Neva Bay. Only here the numbers exceed the MAC (Fig. 5). In other sub-regions it is usually much lower.

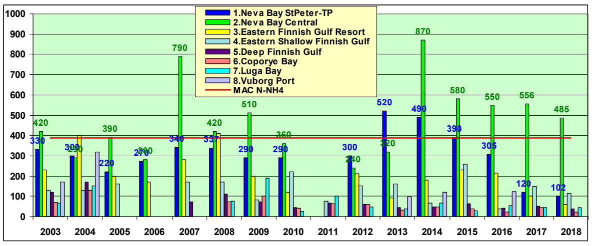

Figure 5. Maximum ammonium N-NH₄ concentration (µg/dm³) in the different parts of the Eastern Finnish Gulf.

Concentrations of other forms of nitrogen are significantly below the established norms with only few exceptions (Table 1). No difference between surface and near bottom layers can be mentioned for the eastern part of the Finnish Gulf: average $N\text{-}NH_4$ – 45.7/44.6; $N\text{-}NO_2$ – 4.3/5.0 µg/dm³; $N\text{-}NO_3$ – 110.6/102.2 µg/dm³; N_{total} – 614.6/574.1 µg/dm³. The same could be expected for the shallow Neva Bay: average $N\text{-}NH_4$ – 79.0/80.0; $N\text{-}NO_2$ – 9.0/9.7; $N\text{-}NO_3$ – 238.8/249.5; N_{total} – 717.2/712.5 µg/dm³. Seasonal variations of the different ingredients follow common trends. For instance, in the most investigated Neva Bay (4550 samples) the average ammonium concentration reaches the highest values in winter months – 82.5, 167.4 and 134.0 µg/dm³, but after spring phytoplankton bloom fall down to the range of 39.1-66.2 µg/dm³ up to the end of the year. In general, no significant changes in nutrients composition can be observed for last one and half decades, neither in Neva Bay, no in the eastern part of the Finnish Gulf. The area near the Northern WWTP in the Neva Bay has no significant features in nutrient composition in comparison with surrounding waters.

Table 1. Average and range of different forms of nitrogen in the Eastern Finnish Gulf.

N	Ingredient	Neva Bay		Finnish Gulf		MAC
		Mean	Maximum	Mean	Maximum	
1	Ammonia	77.4	1030	38.1	520	389
2	Nitrites	9.3	110	4.0	59	24
3	Nitrates	242.2	1130	94.9	550	9032
4	Ntotal	710	4002	559	2010	-

3. Trace Metals

Among the others the copper could be considered as the most poison due to crucial exceeding on established for fresh waters MAC = 1 µg/dm³ (Fig. 6). Last time the copper concentration in different parts of Neva Bay has value of about 3-6 MAC. In the beginning of observations the values are even higher and therefore decreased trend is clearly shown. The average of 4076 samples treated is 4.1 µg/dm³ and maximum is 40.0 µg/dm³.

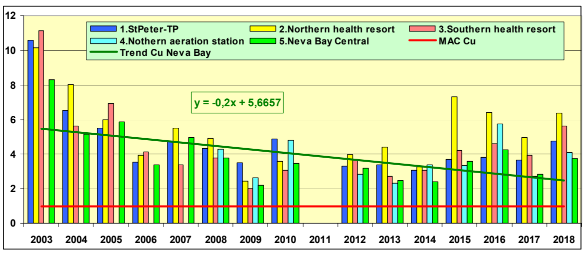

Figure 6. Average copper concentration (µg/dm³) in the different parts of the Neva Bay and long-term linear trend in the central part of the Bay.

In the eastern Finnish Gulf the situation is almost the same (Fig. 7). For the gulf waters usually considered as marine in Russia another MAC=5 µg/dm³ is used. Therefore the real data is not often higher than normal values, but real copper concentration even higher. For the last four years the copper content in the shallow resort area is significantly higher than in the other parts of the eastern Gulf. The average value of 1057 collected samples is 4.6 µg/dm³ and maximum is 76.0 µg/dm³. Looking on the permanent elevation of established standards for fresh and marine waters it could be possible to suggest the natural geochemical reason and practically absence of the relation between anthropogenic activity and copper content in the Finnish Gulf. It is clear that the state norms have to be changed to fit with local conditions of the Baltic region.

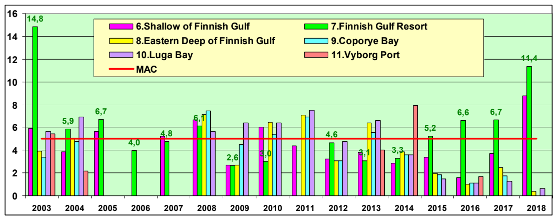

Figure 7. Average copper concentration (µg/dm³) in the different parts of the Neva Bay and long-term linear trend in the central part of the Bay.

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Near-inertial baroclinic waves in the horizontal shear flow records in the southeastern part of the Baltic Sea

Oxana Kurkina[1], Andrey Kurkin[1], Maria Kokoulina[1], Vladimir Gorbatskiy[2] and Irina Chubarenko[3]

[1] Department of Applied Mathematics, Nizhny Novgorod State Technical University n.a. R.E.Alekseev, Russian Federation (Oksana.Kurkina@mail.ru)
[2] The Krylov State Research Centre, St. Petersburg, Russian Federation
[3] Laboratory for Marine Physics, Atlantic Branch of Shirshov Institute of Oceanology, Kaliningrad, Russian Federation

1. Introduction

Inertial oscillations are one of the classes of intense mesoscale motions of water in the seas and oceans. The waves of such periods are often recorded in real measurements, see for example Kim et al. (2001), Magnell et al. (2005), Valipour et al. (2015), including observations in the Baltic Sea: Van der Lee & Umlauf (2011) and Lappe & Umlauf (2016).

We present the preliminary analysis of basic properties of stratified sea currents, which are the important component of hydrology, measured near the coast of the Curonian Spit in the southeastern part of the Baltic Sea. Records during summer season often show the structure, which is typical for near-inertial baroclinic waves.

2. Data of observations

The horizontal components of currents are measured during the years 2004 – 2010 using the ADCP device installed in the area with an average depth of 30 m. The data are collected with a temporal resolution of 3 minutes and with a vertical resolution of 1 m.

As an example of the observational data, Fig. 1 shows vertical profiles of zonal velocity versus time for four days in July 2010. This month was especially representative about the considered processes.

In Figure 1, one can clearly see, firstly, the pronounced inhomogeneous vertical structure of the flow velocity field, and secondly, inertial-scale oscillations. The meridional component is not shown here, however, there is a phase shift between the two components of the horizontal velocity, which is typical for waves in a rotating fluid.

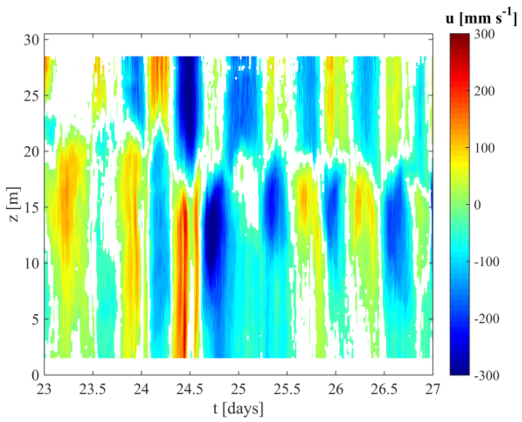

Figure 1. Typical example of a record of horizontal current velocity (eastward component) profile at the measurement point in summer (here for July 23-27, 2010). Zero contours of velocity are shown as white lines; z – distance from the bottom.

3. Vertical structure

Vertical profiles of both components of horizontal velocity at a fixed time are illustrated by Fig. 2. Figures 1 and 2 show, in particular, that the oscillations in the upper and lower layers of the water are in counterphase, since the vertical amplitude function changes the sign. Such a structure of vertical velocity profiles is characteristic of lower-mode baroclinic waves.

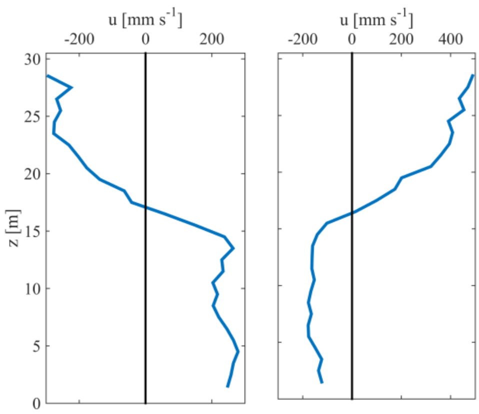

Figure 2. Examples of vertical profiles of horizontal current velocity (left panel - zonal component, right panel – meridional component) on July 24, 2010).

4. Spectral analysis

The typical frequencies/periods of the observed waves can be estimated from their amplitude spectrum shown in Fig. 3 (for time series of July, 2010). As expected, the most pronounced components of the wave field are near-inertial waves with frequencies close to $f_{in} = 2\ \Omega_E \sin\varphi$, where Ω_E is frequency of the Earth rotation around its axis, φ is geographical latitude of the measurement point (~55°N).

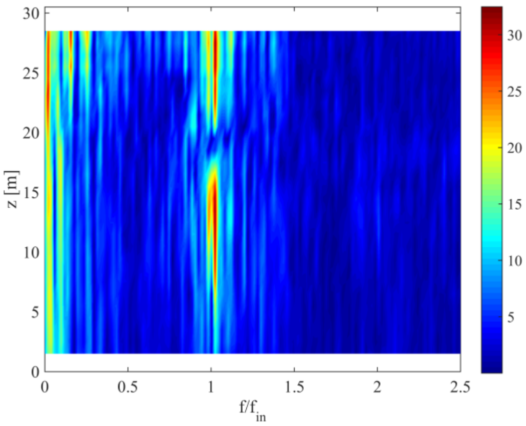

Figure 3. Contour plot in the vertical coordinate – normalized frequency domain for a single-sided amplitude spectrum (mm·s^{-1}) of the latitudinal component of horizontal velocity.

In vertical, these oscillations are localized in the upper layer with a thickness of about 10 m, as well as in the 10-meter layer below the pycnocline. They are still visible in the near-bed layer, though the peak amplitude is almost twice less here. The spectrum in Fig. 3 also shows lower frequency quasi-barotropic components with periods of 6-30 days.

5. Exceedance probability distribution

Exceedance probability distribution along vertical coordinate for horizontal velocity values over time is shown in Fig. 4 separately for positive (eastward) and negative (westward) parts of the current. Substantial asymmetry of negative and positive values of *u* as well as noticeable vertical inhomogeneity is demonstrated here. The weakest currents are observed in the vicinity of the pycnocline (at depths of 11 - 13 m). Maximum current velocities are reached near the sea surface; however, near-bed velocities are comparable in magnitude.

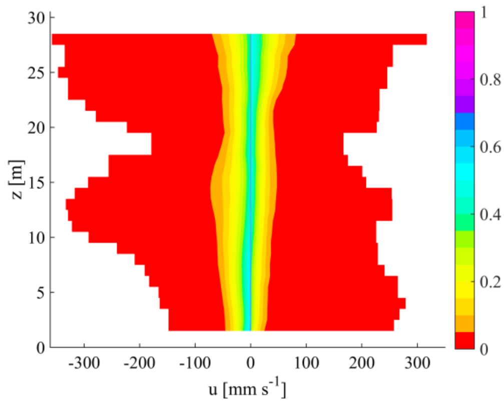

Figure 4. Exceedance probability (shown by colour) distribution along the vertical of the current horizontal velocity levels (positive and negative values correspond to eastward and westward components, respectively) in July, 2010.

Note that the probability distribution for negative velocities in Fig. 4 has a vertical structure very similar to the vertical distribution of amplitudes near the inertial frequency in the spectrum in Fig. 3. This suggests that the maximum speeds of the westward currents are caused mainly by inertial motions.

The observed meridional component of the horizontal velocity field has similar features.

6. Discussion and conclusions

High-resolution measurements of horizontal velocity profiles in the area of the Curonian Spit in the southeastern part of the Baltic Sea showed that in the summer seasons of 2004–2010, inertial baroclinic oscillations make up a significant part of the energy of stratified currents.

The maximum current velocities within the inertial wave field are 0.3 - 0.5 m·s^{-1}, and such waves can be considered as a factor of force impact on the sea bottom or hydraulic structures. If we talk about bending loads, then the loads can really be determining associated with the horizontal orbital velocities of the baroclinic waves, which (for the lowest baroclinic mode) are in the opposite phase above and below the pycnocline, or can have even more complex vertical structure for higher modes.

The results can also be applied to estimate the properties of the bottom boundary layer and the potential of current-induced sediment resuspension and seabed erosion processes.

7. Acknowledgements

The data were collected in frames of ecological industrial monitoring of Kravtsovskoye oil deposit (D-6), carried out by LUKOIL-KMN, Ltd. Support of the Sea Venture Bureau, Ltd., is acknowledged. The study was done with a support of the state assignment of IO RAS (Theme No. 0149-2019-0013) and grant of the President of the Russian Federation for state support of leading scientific schools of the Russian Federation (NSH-2685.2018.5).

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Runoff in small catchments in the Flysch Carpathians (Bieszczady Mountains)

Karolina Mostowik[1]

[1] Institute of Geography and Spatial Management, Jagiellonian University, Cracow, Poland
(karolina.mostowik@doctoral.uj.edu.pl)

1. Introduction

In Poland, a large part of freshwater resources originates in mountain areas in the south of the country – areas characterized by the highest precipitation supply. On the other hand, the groundwater resources of Polish mountain ranges built of flysch rocks are reported as quite low (Jokiel 1994). Moreover, due to steep topography and low retention capacity of thin slope covers, many regional studies assume the predominance of rapid surface river runoff in the Flysch Carpathians (Chowaniec 1998/1999, Małecka et al. 2007). On the contrary, presence of perennial, high–discharge springs with surprisingly stable water temperature and high storage capacity of reservoirs located in the upper parts of the Połonina Wetlińska Massif (Bieszczady Mountains) indicates that there exist conditions increasing groundwater resources and reducing surface runoff (Mostowik et al. 2016, Płaczkowska et al. 2018). Therefore, the research is focused on the identification of natural water circulation patterns in small catchments in a semi–natural, flysch mountain environment of the Połonina Wetlińska Massif in the High Bieszczady Mountains, Flysch Carpathians (Fig. 1).

2. Research significance

A quantitative determination of the water circulation components in selected catchments and the identification of the mechanism of water retaining in flysch rocks will make it possible to better utilize catchment resources and better manage them in the future. While the Bieszczady region is not strongly affected by human impact, effective water resources management is still important due to increased water requirements in the tourist season. Moreover, the significance of the proposed research work is not limited to the Bieszczady Mountains. Water storage potential of flysch rocks is an important subject for the entire Polish Carpathians, including densely populated foothill areas.

3. Study Area & Methods

The Połonina Wetlińska Massif (Fig. 1) is a typical flysch range built of sandstone and sandstone-shale members of the Silesian tectonic unit, where rocks are generally characterized by low hydraulic conductivity and low porosity. Land use is dominated by beech-fir forest on slopes and natural grassland covering the ridge elevated up to 1346 m a.s.l. The study area has been protected since 1973 by the Bieszczady National Park.

The key part of the research consists of the examination of water circulation in selected catchments based on temporal and spatial analysis of atmospheric precipitation and runoff collected by an own network of measurement and observation sites. The network includes 20 streamwater level gauges located around the Połonina Wetlińska Massif (7 monitoring sites with continuous measurements, 13 sites with periodic measurements) and 3 rain gauges. In order to determine rating curve, periodic discharge measurements are conducted by using a current meter. In the next step, analysis of recession limbs of hydrographs enables to assess groundwater storage capacity and distinguish recession phases in selected catchments, when streams are recharged by various water circulation mechanisms. The regional hydrological and meteorological background is given by the monitoring network of the Institute of Meteorology and Water Management. This research is the summary of the first year of measurements (November 2017 to October 2018).

Figure 1. Location of study area, the Połonina Wetlińska Massif (purple box) on the background of the Bieszczady Mountains and the Carpathians.

4. Results

The results obtained during the first hydrological year of fieldworks have revealed significant differences in total runoff between analyzed catchments. From regional perspective, year 2018 was an average one in terms of precipitation and total runoff. It was characterized by typical high runoff during the snowmelt season (March, April) and a long-term drought (August to October). Comparing the runoff volume from the Połonina Wetlińska Massif and the atmospheric precipitation over the region, it is necessary to underline that precipitation in the mountain ranges in the Bieszczady Mountains seems to be underestimated, especially in winter half-year (November to April).

Despite similarities in lithology, land use and average elevation in the studied catchments, average river runoff in 2018 varied surprisingly from 21 (Kindrat stream catchment) to 49 $dm^3 \cdot s^{-1} \cdot km^{-2}$ (Rzeka stream catchment) – Fig. 2. Average runoff values of 50 $dm^3 \cdot s^{-1} \cdot km^{-2}$ have been typical, thus far, for catchments in the Tatra Mountains and the Babia Góra Massif only. Regional differences in storage capacity of the catchments were also proved by groundwater runoff varying from 2 $dm^3 \cdot s^{-1} \cdot km^{-2}$ to 21 $dm^3 \cdot s^{-1} \cdot km^{-2}$ during a drought period.

The storage capacity estimated by recession curves analysis is much higher than can reasonably be expected considering the surface area of topographic catchments and indicates that at least some catchments must be experiencing groundwater influx from outside their catchments.

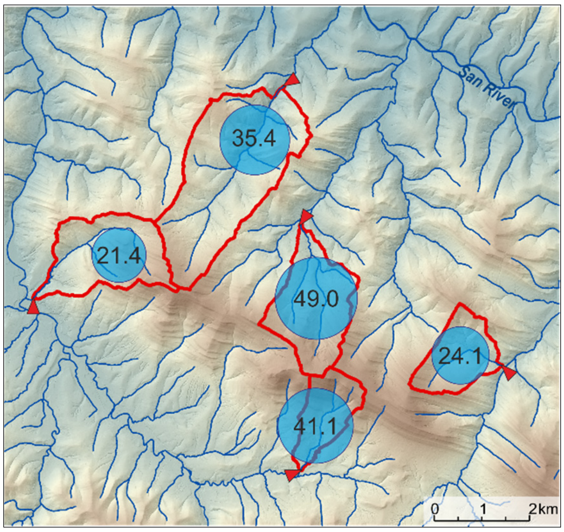

Figure 2. Average runoff in 2018 ($dm^3 \cdot s^{-1} \cdot km^{-2}$) in selected catchments of the Połonina Wetlińska Massif.

5. Conclusions

The results clearly indicate the diverse of water resources across the Połonina Wetlińska Massif. The study confirms greater capability of flysch mountain ridges to store water. In the area dominated by sandstone formations the tectonic structures (dip of rock layers, faults and fissures with weathering, releasing and tectonic origin) are crucial for runoff volume and regime. Subsurface tectonic features enable more precipitation to infiltrate and determine groundwater flow direction, changing significantly recharge areas of springs and rivers. Slow component of runoff have been underestimated in the Flysch Carpathians so far.

Acknowledgement

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Climate change influence on maximal runoff rivers of Baltic sea basin within Ukraine

Valeriya Ovcharuk[1], Eugene Gopchenko[1]

[1] Hydrometeorological Institute, Odessa State Environmental University, Odessa, Ukraine (valeriya.ovcharuk@gmail.com)

1. Introduction

The Baltic Sea basin covers about 20% of the territory of Europe, with about 85 million people living on the shores of the Baltic Sea. Within Ukraine, the basin is divided into two parts (the district of the Basin of the Dnister River) and consists of sub basins of the Western Bug and the San. The territory of the Vistula River basin district have the total catchment area of 12892 km2, which makes 2.13% of the territory of Ukraine, is located within two, the Lviv and the Volyn oblasts of Ukraine (Fig 1). Nevertheless, despite the fact that the rivers of the Baltic Sea basin in Ukraine makes rather a small part of the territory, the water resources of the Western Bug River, which are formed in the territory of Ukraine, are further used by the Republic of Poland and Byelorussia. Therefore, the study of the most high-water phases of the water regime in the rivers of the Vistula basin (spring floods and rain floods) is a topical task for further guidelines on the sustainable use of the study area and cross-border cooperation in water management.

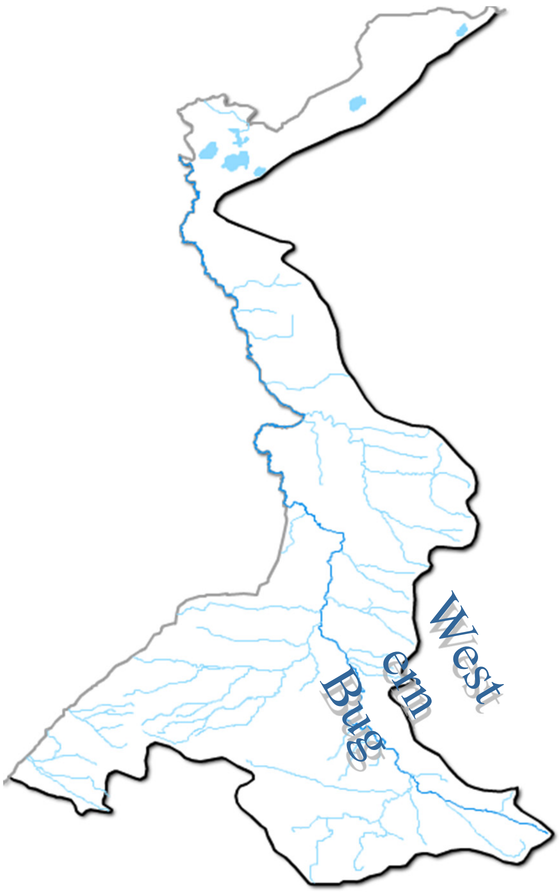

Fig. 1. The scheme of Vistula basin within Ukraine;

On another hand, an analytical review of the normative framework in the field of calculations of maximum runoff showed that despite the vast experience gained by scientists in this issue, the problem is still far from its solution due to the multifactority of the investigated phenomenon and regional features of the forming of maximum runoff on the rivers.

2. Methodology and data

For successful study implementation, was used perennial and modern materials of hydrological and meteorological observations of the state hydrometeorological network, obtained from the regime specialized publications and materials of the Ukrainian Hydrometeorological Center of the State Service of Ukraine for Extreme Situations, which are formed in the ARM-hydro (an automated system for collecting and processing hydrometeorological information for the Ukrainian part of the district in the river basin of Vistula River).

At the Odessa State Ecological University of the Ministry of Education and Science of Ukraine for 85 years there exists and is developed a recognized scientific school of 'Theoretical and Applied Hydrology', recognized in the country and abroad, which studies the processes of formation of floods and spring water with different probability of excess. A scientific school for research into this fundamental scientific problem was created by Prof. A.M. Befani and Prof. N.F. Befani and has been presently developed by Prof. Ye.D. Gopchenko (Gopchenko ,2015), as well as his followers - prof. Zh.R. Shakirzanova (Shakirzanova,2017), Dr. V.A Ovcharuk (Ovcharuk, 2018) and others. Depending on the natural conditions for the formation of river runoff, several theoretical submodels are suggested. It is on their basis of that it is possible to develop a normative base in the field of calculations and forecasting for the maximum runoff of rivers.

In proposed study is in the fact that for the first time in the framework of the original author's model, the procedure for taking account of the probable climate change in determining the maximum water consumption of various probability of excedence is documented methodically. For this purpose, regional coefficients and corrections will be made directly to the snowfall, precipitation and runoff factors for multi-modal climate change data for RCP 4.5 and RCP 8.5 scenarios.

3. Results

For time series of maximum water discharge spring and rain floods at the rivers of study area calculated statistical characteristics of the method of moments and the maximum likelihood.

In the context of regional and global climate change, it is necessary to explore possible trends in the characteristics of the runoff of rivers in its various phases. On the example of the Vistula River, it is shown that the characteristics of the runoff of spring water and rain floods have virtually no significant trends, but it should be noted that at individual stations there is a decrease in the maximum water discharges. The obtained the 1% probability values of maximum water discharges of spring and rain floods were compared. The discharges Q1% during the spring flood is 27% higher than the maximum discharges of rain floods. Nevertheless, in some cases, discharges of rain floods can to exceed the discharges of spring floods. Thus, the actual task of designing dams at the Vistula river basin is the development of reliable scientific and methodological recommendations for determining the characteristics of the maximum runoff of the rare probability of excess both for spring water and rain floods.

For the plain rivers of Ukraine was implemented of the variant of the calculated method for determining the characteristics of spring flood under climate change. Analyzing the received distribution of "climatic corrections", it should be noted that according to scenario RCP4.5 (model RACMO2, Fig.2a) for the period up to 2050, the forecast for the maximum runoff of spring flood is ambiguous. In particular, in the zone of mixed and broadleaf forests where almost completely situated Vistula basin, the coefficient is vitiated from1.0 to 0.9, that is, virtually no significant change is expected. A slight decrease in the maximal runoff modules of 1% probability of exceeding (by 10-20%) can be expected in the Polissya area.

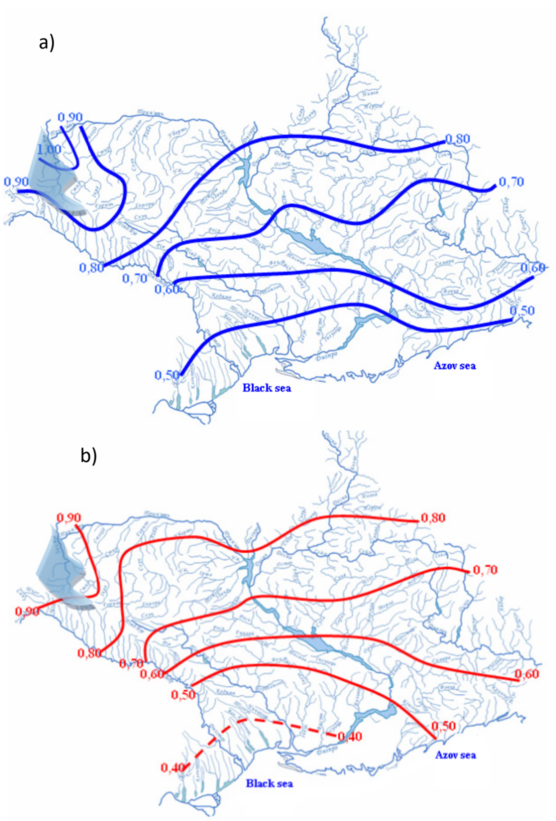

Figure 2. Distribution of the coefficients of influence of climate change on the maximum runoff of spring flood on the plain territory of Ukraine (model RACMO2, scenario RCP4.5 (a) and RCP8.5 (b)) for the period up to 2050, relative to 2010.

From north to south the value of the coefficients decreases, and accordingly the magnitude of the projected decrease in the maximum runoff of spring flood is increased. In general, in the whole territory of forest-steppe zone decrease of runoff are expected by 30-40% during springtime, and most of all (up to 50%) - for the steppe zone rivers. If using the more rigorous RCP8.5 scenario (Fig.2b), most results are similar, but for the Black Sea region, it is forecasted to reduce the runoff of spring flood to 60%. It should be noted here that reducing the flow of spring flood does not mean a corresponding reduction of water resources in general. Most likely, there will be a significant intra-annual redistribution of runoff, that is, due to a reduction in spring runoff, the minimal runoff may increase, as well as will expected the tendency to shift annual highs at earlier dates or increase in the number of cases of winter flood instead of spring flood. Verification of the modified methodic taking into account climate change has shown the possibility of its application for the assessment of changes in water content during the spring flood on the flat rivers of Ukraine, both in the framework of the basic scheme and in the form of separate calculations using climate data as an option for implementing the design scheme under climate change conditions.

4. Conclusions

During development and implementation method for calculation of maximal runoff for Vistula Rivers basin within Ukraine was received such scientific results:

• Description of natural conditions for the formation of the maximum runoff during floods and spring high waters within the Vistula River basin in Ukraine;

• Collection and analysis of information on flooding that occurred in the past and their consequences;

• Creation of a database for the monitoring of water regime (indices of water levels and discharges at hydrological stations) and the meteorological observations (indices of precipitation at meteorological and hydrological stations);

• Provision of scientific and methodological recommendations on the standardization of calculated characteristics of the maximum water discharges and the volumes of spring high water in the Vistula river basins with various probability of excess;

• Generalization of the information on climate change and its consequences in estimates of possible hydrological hazards.

The average accuracy of the calculation in two variants is ± 20.5%, with the accuracy of the initial information ± 21.4%, which allows recommending a technique developed for plan river of Ukraine, including Vistula basin, for practical application

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Topic bed load dependencies for the Baltic Basin Rivers based on minimum hydraulic information

Olga Petrovskaya

Channel Processes Department, State Hydrological Institute, Saint-Petersburg, Russia (riverchannel@yandex.ru)

1. Introduction

Bed load discharge and yield estimation is necessary for solving many environment protection and water management tasks. Nevertheless today there are comparatively few hydrologic stations where bed load measurements are conducted.

In this regard it seems helpful to use regional and topic bed load formulas (Barry et al. (2004), Sirdari et al. (2014)). Regional formulas are obtained by generalization of bed load measurements in rivers of a certain geographic-hydrologic region. Topic formulas generalize measurements performed in a specific hydrologic section. Obtaining such formulas requires long-term and detailed measurements of bed load and all main hydraulic characteristics.

In this paper we made an attempt to obtain approximate topic bed load dependencies in the absence of bed load measurements based on standard data of water discharge measurements (published in hydrologic bulletins) and data of bed composition in the section.

The dependency of bed load on water discharge $Q_b = f(Q)$ has been taken as a basic structure for topic bed load formula derivation.

2. Data

Three hydrologic sections in the rivers of the Baltic region: Tosna (Tosno), Luga (Kingisepp) and Shelon' (Zapol'ye) are chosen as the objects for derivation of topic bed load dependencies.

The following measurement data have been used: maximum annual water discharge, data of water discharge measurements (water stage, water discharge, flow width, mean and maximum depth of flow, mean and maximum flow velocity) and data of bed composition obtained during field survey.

3. Methods

Topic dependencies of bed load from water discharge are derived in the following way.

1. Maximum annual water discharge data are analyzed for entire observation period and three-five years with the highest water bearing are defined. Due to the fact that detailed data of water discharge measurements were published in hydrologic bulletins only until 1974, we could choose only among the years of this period.

2. In order to determine the degree of channel stability and stability of relations between hydrologic characteristics we built dependencies of water stage (Figure 1), flow width, mean and maximum depths and mean and maximum flow velocities on water discharge.

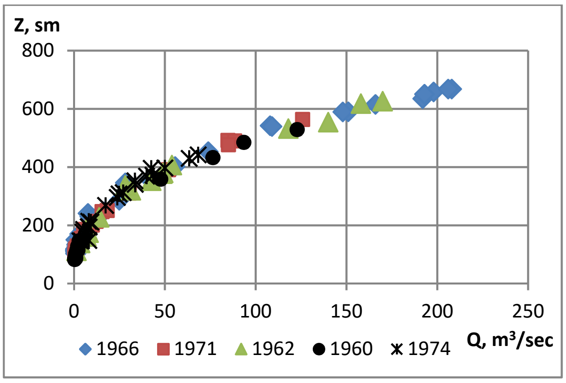

Figure 1. Dependency of water stage Z on water discharge Q in the section Tosno of river Tosna for the years of the highest water bearing.

3. If the relations are stable, the year of the highest water bearing with the most complete measurements is chosen for further calculations. For the chosen year the round number values of water discharge are assigned in its whole range. For the assigned values of water discharge the hydraulic calculations (presented below) are performed. The values of hydraulic characteristics (depth of flow, flow velocity, etc.), corresponding to a given water discharge, are determined from appropriate graphs.

4. Grain size distribution curve of the bed sediments of the given section is built and the weighted average grain size d is calculated.

5. For the assigned values of water discharge bed load discharge is evaluated. In this paper two methods were used.

- Via sand dunes characteristics:

$$q_b = 0{,}6 h_d C_d, \quad (1)$$

where q_b is bed load discharge per unit channel width in m^3/sec/m (bulk), h_d is height of sand dune (m), C_d is velocity of sand dune translation (m/sec). The last two variables are calculated according to the formulas by the State Hydrological Institute (SHI) (Kostyuchenko & Kopaliani (2006), Snischenko & Kopaliani (1978)):

$$h_d = 0{,}13H, \quad (2)$$

$$C_d = 0{,}019 V Fr^3, \quad (3)$$

where H is flow depth (m), V is flow velocity (m/sec), $Fr = \frac{V}{\sqrt{gH}}$ is Froude number, g – acceleration of gravity.

- G.I. Shamov's method (Shamov (1952)):

$$q_b = \alpha \sqrt[3]{\overline{d_{max}}^2} \left(\frac{V}{V_0}\right)^3 (V - V_0) \left(\frac{d}{H}\right)^{0{,}25}, \quad (4)$$

where q_b is in kg/sec/m, α is a coefficient depending on the ratio between fine and coarse sediment fractions, V_0 is marginal mean flow velocity at which bed load sediments stop moving (m/sec), $\overline{d_{max}}$ is mean diameter of the largest bed sediments fraction which is at least 10% of mobile part of bed sediments (m).

6. Evaluation of total bed load discharge Q_b is carried out by multiplying q_b by the flow width.

4. Results

The stability of channels and relations between hydraulic characteristics have been determined for all the sections. For the chosen highest water bearing years round number values of water discharge have been assigned, for which bed load discharge was calculated. The obtained dependencies are convenient to present in tabular form. In table 1 bed load discharge is in cubic meters per day.

Table 1. Dependencies of bed load discharge on water discharge for the rivers of the Baltic basin, obtained by the methods of the SHI and G.I. Shamov

Water discharge, m^3/sec	Bed load discharge, m^3/day	
	SHI	G.I. Shamov
Tosna (Tosno)		
25	22,7	15,8
50	25,6	15,6
100	50,2	31,7
150	93,8	62,6
200	138,5	93,8
Luga (Kingisepp)		
40	6,1	2,7
50	9,1	4,4
80	41,4	28,3
100	72,4	53,3
120	95,9	72,4
150	147	116
160	157	122
200	166	125
Shelon' (Zapol'ye)		
100	48,2	13,4
200	165	69
300	319	148
400	519	255
500	671	333
600	845	424
700	970	485
800	1189	599

The results obtained by the two methods differ on average by 34% for Tosna, 32% for Luga and 54% for Shelon'. The SHI method always gives higher values of bed load.

In view of the stability of channel and relations between hydraulic characteristics in the sections, the obtained dependencies characterize not only the year, for which they are derived, but the section over the whole period. They allow to calculate bed load discharge for any year by interpolation between the values used for the derivation (as long as the stability is preserved). It gives an opportunity to estimate bed load yield for different years and other periods.

5. Discussion and conclusions

According to the last studies (Petrovskaya (2018)) the calculation error of bed load discharge up to 60% is a good result. Due to the lack of bed load measurements in the described sections it is not possible to estimate the quality of the applied method completely. Though, due to the fact that the SHI bed load formula has been tested on the large set of field data obtained in plain rivers and is recommended for practice with the error no more than 60% (Samokhvalova (2012)), and Shamov's formula gave a close result, the current results altogether can be assessed as sufficiently reliable.

The applicability of this method is limited by stability of the channel and relationships between hydraulic characteristics in the section. In the case of stability absence the derived dependencies can only be applied to the periods they are obtained for.

Certainly the applied method is very approximate in comparison with ones based on bed load data (Barry et al. (2004), Sirdari et al. (2014)). Yet it can be successfully applied for a general estimation of bed load discharge and yield.

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The effect of sampling frequency and strategy on water quality modelling driven by high-frequency monitoring data in a boreal catchment

Mikolaj Piniewski[1], Paweł Marcinkowski[1], Jari Koskiaho[2] and Sirkka Tattari[2]

[1] Warsaw University of Life Sciences, Department of Hydraulic Engineering, Nowoursynowska 166, Warszawa, Poland
[2] Finnish Environment Institute, Latokartanonkaari 11, FIN-00790 Helsinki, Finland (jari.koskiaho@ymparisto.fi)

1. Background

With conventional water quality monitoring based on grab sampling, usually carried out once a month, it is quite challenging to obtain reliable sediment and nutrient loading estimates, which is a prerequisite for testing of water quality models.

Despite the growing availability of high-frequency water quality monitoring data obtained by using modern sensors, their use in the calibration of hydrological water quality models (HWQMs) is still limited.

2. Objective

The main objective of this study was to evaluate the continuous, 6-year-long, high-frequency water quality monitoring dataset as a source for the calibration and testing of the Soil & Water Assessment Tool (SWAT, Arnold et al. 1998) in a case study carried out in the Vantaanjoki river basin, which is a medium-sized (1680 km^2), boreal catchment in southern Finland (Figure 1).

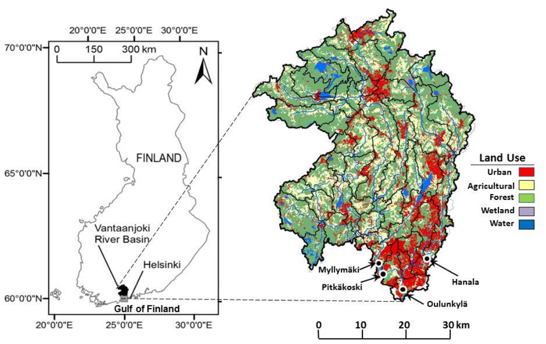

Figure 1. Location of the Vantaanjoki river basin and the Pitkäkoski monitoring station.

3. Material & Methods

SWAT is a process-based, semi-distributed, continuous-time model that simulates the movement of water, sediment, and nutrient compounds within a catchment with a daily timestep. The basic data sets required to develop the model input are (i) land elevation (topography), (ii) soil type, (iii) land-use, (iv) point sources and (v) weather (daily precipitation, air temperature and humidity, wind speed and solar radiation). SWAT computes the processes associated with water and sediment movement, plant growth, nutrient cycling etc. using these input data. SWAT uses spatial units called HRUs (hydrological response units) which are combinations of land use, soil, and slope within each sub-basin. The land-phase water balance components, land erosion and nutrient fluxes are computed separately for each HRU, aggregated at the sub-basin level and then routed through the river network to the main outlet. Sensitivity analysis, calibration and validation were conducted in SWAT Calibration Uncertainty Procedures (SWAT-CUP, Abbaspour (2008)) using the SUFI-2 algorithm (Sequential Uncertainty Fitting Procedure Version 2, Abbaspour et al. (2004)).

An automatic water quality monitoring station was established at Pitkäkoski (Fig. 1) in the autumn of 2010. The Pitkäkoski station captures roughly 75% of the total loading carried by the River Vantaanjoki (all except that of the eastern tributary, River Keravanjoki). The station is equipped with s::can nitro::lyser sensor (www.s-can.at/products/spectrometer-probes), which measures NO_3-N, turbidity and organic carbon with hourly time step. The functioning principle of the s::can sensor makes it possible to record NO_3-N and carbon concentrations simultaneously with turbidity. The measuring path length of the sensors is 5 mm. The measuring range is for NO_3-N 0.1-50 mg l^{-1} and for turbidity 5-1000 FTU. Turbidity correlated highly with total suspended solids (TSS) and total phosphorus (TP) (R^2=0.88 and 0.76, respectively) and was thus used as a surrogate of these two water quality parameters. The measuring path and the windows of the sensor are cleaned with compressed air before each measurement. In addition, on average once every two months the sensors are taken up from the river and cleaned manually.

The 6-year-long (2011-2016) continuous dataset recorded by the s::can sensor was used to calibrate (2011-2013) and validate (2014-2016) the model as a "benchmark" for three sub-sampling scenarios:

- Flow-proportional sampling with 26 samples per year (FP-26)
- Flow-proportional sampling with 12 samples per year (FP-12)
- Regular sampling with 12 samples per year (R-12)

We developed these scenarios to mimic different water sampling strategies and frequencies. The data for the scenarios was "sampled" from the continuous dataset and then calibrated and validated similarly as the "benchmark". In calibration and validation process, the Kling-Gupta efficiency (KGE, Gupta et al. 2009) was used as the objective function. The closer the KGE is to 1, the better the goodness-of-fit. Additionally, the percent bias (PBIAS) that measures the average tendency of the simulated data to be smaller or larger than their observed counterparts, was also tracked.

4. Results

The goodness-of-fit (KGE) of the model calibrated against the continuous, high-frequency data ("benchmark") for the daily loads of three water quality parameters (see Fig. 2) ranged between 0.76–0.83 (calibration) and 0.69–0.73 (validation). Overall, the model calibrated against the sub-sampled low-frequency data of the three scenarios performed worse than the ”benchmark” for each of the studied water quality parameters (Fig. 2).

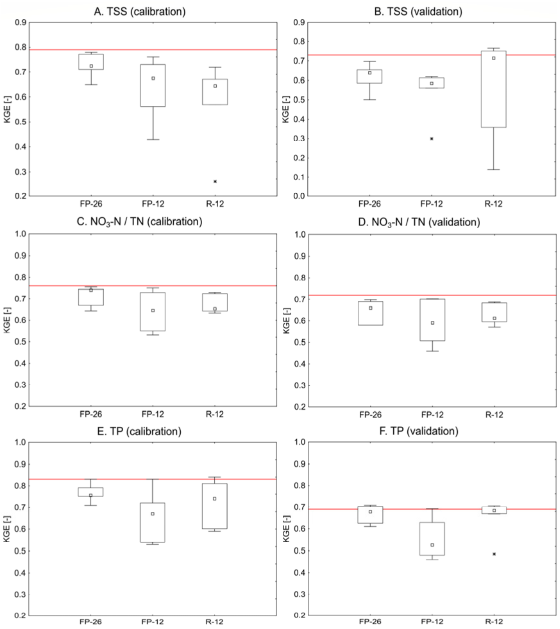

Figure 2. Comparison of the model performance in calibration (A, C, E) and validation (B, D, F) periods for total suspended solids (TSS), nitrogen (coupled results of NO_3-N and TN) and total phosphorus (TP), expressed by KGE values between different sub-sampling scenarios FP-26, FP-12 and R-12. The red lines show the KGE values obtained with the "benchmark" model. Box plots illustrate variability across six realizations of sub-sampling scenarios.

The results showed that increasing the sampling frequency from 12 to 26 samples per year leads to a clear improvement in the model performance, particularly for TSS and TP loads. In contrast to the sampling frequency, the evidence for the effect of the sampling strategy on the model performance was much weaker.

5. Concluding remarks

- The model performance as quantified using KGE and PBIAS indices was generally good for all of the studied variables
- Increasing the grab sampling frequency of the observational data leads to an improvement in the model performance, particularly for TSS and TP loads
- In contrast to the sampling frequency, no evidence for the effect of sampling strategy on the model performance was found
- This study corroborates earlier studies demonstrating the value of high-frequency data as a calibration source for HWQMs
- More attention should be paid to the calibration data as a source of uncertainty in model predictions, either by wider adoption of modern sensors providing high-frequency data, or increasing the grab sampling frequency
- The risk of uncertain loading estimates is particularly high in rivers with flashy flow regime, such as the River Vantaanjoki.

Acknowledgements

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Hydrological modeling of spatial long-term forecasting of maximum water discharge of spring flood using the example of the rivers of the Baltic region

Shakirzanova Zh. R.[1], Dokus A. A.[1]

[1]Odessa state environmental university, Odessa, Ukraine, angel.dokus@gmail.com

1. Introduction

Hydrological modeling of river flows is a priority in the field of hydrological calculations and forecasts (World Meteorological Organization, 1994). The rivers of the Baltic region belong to the flat type of predominantly snow feeding and are characterized by the formation of maximum water discharge during the spring flood.

The article is concerned with analysis of the processes of formation of spring floods of lowland rivers and the development of a methodological framework for spatial long-term forecasting of the maximum water discharge of spring floods for more reliable regulation of the reservoirs water regime and the implementation of protective measures during the passage of the highest floods (for example, the rivers of the Zapadnaya Dvina/Daugava basin).

Hydrological modeling in order to predict runoff is usually carried out for rivers that have systematic observations of river runoff. The maximum water discharges are usually formed most quickly on small rivers, on which there are no data on water runoff measurements.

Unlike runoff depths, maximum water discharge during spring flood cannot be generalized for different rivers of the territory, since they comply with reduction under the influence of changes in river catchment areas and other morphometric characteristics of the basins.

The proposed hydrological model solves the problem of predicting the maximum ordinate of spring floods with a long lead-time and in real time for rivers with any dimensions of catchment areas and under different physiographic conditions for the formation of river runoff (Gopchenko et al., 2005).

Also an important issue in the context of modern climate fluctuations and the presence, in connection with this, of temporary decreasing trends in maximum water discharge of spring floods of lowland rivers, is the assessment of their values (long-term average and various exceedance probability) for a long period in the future. For the rivers of the Baltic region, there are current trends shifting the dates of maximum discharges from melting of snow to earlier dates (Blöschl et al., 2017).

2. Research methodology

The basis of the hydrological model of the forecast scheme are the regional dependences of the maximum water discharge on the values of the maximum water supply in the snow on the catchment presented as their modular coefficients $k_m = f(k_S)$ (Gopchenko et al., 2005, Shakirzanova et al., 2017; Dokus et al., 2018).

Taking into account the different character of development of spring flood processes in different years, the predicted dependencies are differentiated into three categories of flood heights – high, medium and low.

For such a separation of the available time series by maximum runoff, a discriminant analysis apparatus was used, the predictor vector of which included the main hydrometeorological flood factors: maximum water supply in snow, autumn or spring moistening of the soil, depth of freezing, characteristics of thaws in winter and snowmelt processes in spring.

The main factors forming the maximum river runoff were selected within the allocated regions, homogeneous according to the conditions of spring flood formation, using the methods of factor and cluster analysis (Gopchenko et al., 2005).

The forecast of maximum spring flood discharges is issued as of 1 March in each year, and is also updated on 15 March and the date of the maximum snow storage on the catchment. The forecast is issued in real time using an automated software package developed by the authors (Gopchenko et al., 2006, Shatokhin et al., 2018). The lead-time for forecasts for different dates of their release averages 50 to 30 days or less.

The spatial forecast is presented in the form of annually compiled distribution maps of the maximum modular coefficients across the territory k_m. The transition to the predicted values of the maximum runoff modules q_m is carried out when determining the average long-term maximum runoff modules of the spring flood q_0.

If there are series of observations, the average multi-year maximum modules are determined by statistical methods. If they are absent, a modern operator model for the formation of the maximum river runoff is proposed for calculation q_0 (Ovcharuk et al., 2018). This model allows you to calculate and generalize all the initial parameters of the calculation scheme, including those obtained from observational data and those that are not measured by the hydrometeorological network, but are calculated numerically by the model.

In addition, the operator model allows to assess possible changes in the maximum runoff of spring floods due to future climate changes by introducing "climate corrections" calculated according to the models and scenarios of the Intergovernmental Panel on Climate Change (IPCC, http://ipcc-data.org).

The hydrological model of spatial long-term forecasting also allows to determine the forecast probabilities of the maximum water discharge of spring flood in a multi-year period. As a base, a three-parameter gamma distribution was used (with the coefficients of variation of the maximum water discharge C_v specified as a map and the fixed ratio (C_s / C_v) = 2.5). The forecast probabilities are summarized across the territory based on annually compiled maps of water supply.

A hydrological model for spatial long-term forecasts of maximum spring floods has been implemented and estimated using data from 13 rivers of the Zapadnaya Dvina/Daugava river basin with a hydrometeorological observation period of 21-44 years.

3. Methodology evaluation

Evaluation of the effectiveness of the proposed hydrological model for predicting the maximum water discharge of spring flood was carried out in two stages. At the first stage, according to the Fisher criterion, the reliability of the separation in the discriminant analysis of the totality of cases (years) into flood groups is established – high, medium and low. At the second, the model is evaluated according to the quality criterion S/σ (where S – the mean square error of the verification forecasts, σ – the acceptable error) and availability of acceptable error of verified forecasts (statistical correctness of forecast) – $P\%$. For the rivers of the territory under consideration, a criterion for the quality of the forecast methodology was obtained in different calculation options for the discriminant function with a different set of flood factors in the predictor vector. At the same time, the values of the quality criterion S/σ vary from 0.55 to 0.76, and the availability of acceptable error is from 81 to 66%, respectively.

A decrease in the quality of the methodology for forecasting the maximum water discharge of spring flood is observed in those areas where, by the main date of the forecast (1 March), maximum water supply in the snow have not yet formed and their subsequent accumulation is observed. In this case, it is recommended to issue clarifying forecasts on 15 March, and then necessarily on the date of the maximum water supply in the snow.

The acceptable forecast error in the presence of series of observations of the maximum water discharge is determined by the probable deviation of the value from the average long-term value, and if they are absent, it is estimated from its dependence on the catchment area proposed in the work.

4. Conclusions

The hydrological model presented in the work is recommended as a methodological basis for the compilation of spatial long-term forecasts of the maximum water discharge in spring floods of lowland rivers. The forecast scheme proposed in this work can be used directly for long-term forecasting of the maximum water discharge of spring flood on the rivers of the Zapadnaya Dvina/Daugava basin, not only in individual points where there are long-term series of observations, but also in general for rivers of the territory with different catchment areas and in different physical and geographical conditions for the formation of river runoff.

The model allows to evaluate the possible changes in the maximum runoff of the spring flood of the rivers in connection with future climate changes by introducing "climate corrections" to their average long-term values.

A forecast is presented in the form of two maps – modular coefficients of maximum water discharge and their forecast probabilities over a multi-year period.

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The effect of nutrient river loads on the nitrogen and phosphorus balance in the Gulf of Finland based on model data

Oksana M. Vladimirova[1], Tatiana R. Eremina[1], Alexey V. Isaev[2], Vladimir A. Ryabchenko[2] and Oleg P. Savchuk[3,4]

[1] Russian State Hydrometeorological University, Russia (3256767@gmail.com)

[2] P. P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, Russia

[3] Institute of Earth Sciences, St. Petersburg State University, Russia

[4] Baltic Nest Institute, Stockholm University Baltic Sea Centre, Sweden

1. Introduction

The Gulf of Finland has the status one of the most eutrophic water area in the Baltic sea [Assessment, 2016; Pertillä et al., 1996]. The eutrophication of the Gulf of Finland is determined by the supply of nitrogen and phosphorus directly from the catchment area of the gulf, water exchange with the Baltic Sea, as well as the transport of the substance between different areas of the gulf, internal chemical and biological processes. One of the main reasons for the bay eutrophication is the input of organic compounds with river runoff. It is well known that with the mineral forms of nitrogen and phosphorus, their organic compounds comes to the aquatic environment in a significant amount at the same time In most existing ecosystem models [Eiola et al., 2009; Savchuk et al., 1996; Fennel, 1995; Neelov et al., 2003; Savchuk, 2000] of the Baltic sea organic matter is represented only as suspended organic matter. Such a formulation of the problem implies the use of a bioavailability factor for organic matter entering with the river runoff. Organic loads are lumped together in detritus and availability coefficients differ from model to model. In the result, there are large differences between actual nutrient inputs prescribed in different models, especially for phosphorus [Meier et al., (2018)]. For instance, even historical loads differ more than two times.

2. Model

To to find out if the explicit description of dissolved organic nutrients is necessary for modeling St.Petersburg Baltic Eutrophication Model (SPBEM-2) were used. The model consists of two modules – hydrodynamic and biogeochemical, full description and verification is given in [Vladimirova et al., (2018)].

Simulation domain covers the Gulf of Finland. Horizontal resolution of the spherical grid is about 2 NM along both meridian and parallel, and vertical resolution is 3 meters.Period of the simulations – 2009-2014 years.

3. Results

Due to explicit description of labile and refractory components of dissolved organic nutrients it is possible to estimate full budget for phosphorus and nitrogen. Analysis of average annual components of phosphorus budget shows that the pelagic system sources of phosphorus are the output from the sediments and external loads. Phosphorus sinks are sedimentations and boundary exchange. Despite the insignificant export of total phosphorus from the gulf (tab. 1), the exchange across the border occurs due to the export of inorganic phosphorus, and the import of bioavailable dissolved organic phosphorus.

Table 1. The average annual values of the phosphorus balance according to various sources, 10^3 tons / year.

Export from the GoF	External loads	Burial	Sources
5,4	9	3	Gustafsson et al., 2017, 1980-2014
1,8	8,6	11,1	Liu et al., 2017, 1971-1999
1,3	7,1	5,8	Savchuk, 2018, 2005-2014
4	5,6	3,8	SPBEM-2, 2009-2014

The nitrogen cycle, in contrast to the phosphorus cycle, includes such additional processes as nitrogen fixation and denitrification. Analysis of the average annual values of the components of the nitrogen balance shows that the main contribution is made by the external load, as well as the exit from bottom sediments and nitrogen fixation. The removal of nitrogen from the water system occurs due to the process of sedimentation, exchange at the open border and denitrification. In the water column, nitrogen losses due to denitrification are negligible. As for phosphorus, the outflow of total nitrogen from the gulf to the Baltic Sea occurs through the open border (tab. 2). The distribution of the fluxes of various nitrogen fractions shows that the exchange at the boundary occurs mainly due to the receipt of a labile fraction of dissolved organic nitrogen and in small quantities in the form of suspended organics. Nitrogen is removed from the Gulf of Finland in the form of a stable fraction of DON and in a slightly smaller amount in mineral form.

Table 2. The average annual values of the nitrogen balance according to various sources, 10^3 tons / year.

Export from the GoF	External loads	Burial+denitrification	Sources
59	158	105	Gustafsson et al., 2017, 1980-2014
1	124	125	Liu et al., 2017, 1971-1999
64	129	65	Savchuk, 2018, 2005-2014
27	107	139	SPBEM-2, 2009-2014

4. Conclusions

The results of the nitrogen and phosphorus balance does are comparable with the previously published results of numerical modeling. Thus, according to [Gustafsson et al., 2017; Savchuk, 2018; Lui et al., 2017], total nitrogen and phosphorus are removed from the bay to the Baltic Sea (Tables 4.3, 4.4). Since different years of averaging were used, the average annual external load (river load + atmosphere) differs from calculation to calculation. Nitrogen and phosphorus is exported from the Gulf of Finland as mineral forms, while it is imported as dissolved organic nutrients.

It seems that accounting for dissolved organic matter in the modeling of the Baltic Sea eutrophication is really necessary for both: reliable prescription of the external inputs and their possible changes and realistic simulation of nutrient transports and transformations

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Participants

Akstinas	Vytautas	Lithuanian Energy Institute	Lithuania	vytautas.akstinas@lei.lt
Alekseev	Ivan	Saint Petersburg State University/Arctic and Antarctic Research Institute	Russia	alekseevivan95@gmail.com
Azarova	Diana	Russian State Hydrometeorological University	Russia	diana.azarova97@gmail.com
Babkin	Aleksei	State Hydrological Institute	Russia	Abav@mail.ru
Babkin	Vladimir	State Hydrological Institute	Russia	Vladimir-babkin@mail.ru
Borzenkova	Irena	State Hydrological Institute	Russia	irena_borzen@mail.ru
Čerkasova	Natalja	Klaipėda University	Lithuania	natalja.cerkasova@apc.ku.lt
Chebykina	Ekaterina	"Eco-Express-Service" LLC	Russia	e.maximova@ecoexp.ru
Chibrikova	Evgeniya	Saint Petersburg State University/Arctic and Antarctic Research Institute	Russia	zchibrikova@mail.ru
Chubarenko	Boris	Shirshov Institute of Oceanology of Russian Academy of Sciences, Atlantic Branch (Kaliningrad)	Russia	chuboris@mail.ru
Cretaux	Jean-François	Legos/ CNES	France	Jean-francois.cretaux@legos.obs-mip.fr
Destouni	Georgia	Stockholm University	Sweden	georgia.destouni@natgeo.su.se

Dokus	Anhelina	Odessa State Environmental University	Ukraine	angel.dokus@gmail.com
Domnin	Dmitriy	Shirshov Institute of Oceanology of Russian Academy of Sciences, Atlantic Branch (Kaliningrad)	Russia	dimanisha@gmail.com
Filatov	Nikolai	Northern Water Problems Institute, Karelian Research Centre of the Russian Academy of Sciences	Russia	nfilatov@rambler.ru
Georgievsky	Dmitriy	State Hydrological Institute	Russia	dmivlge@gmail.com
Grek	Elena	State Hydrological Institute	Russia	grek-elena90@yandex.ru
Gustafsson	David	Swedish Meteorological and Hydrological Institute, Norrköping	Sweden	david.gustafsson@smhi.se
Kazakov	Eduard	State Hydrological Institute	Russia	silenteddie@gmail.com
Kondratyev	Sergey A.	Institute of Limnology of the Russian Academy of Sciences	Russia	kondratyev@limno.org.ru
Korshenko	Alexander	Marine Monitoring Department, State Oceanographic Institute, Moscow	Russia	korshenko58@mail.ru
Koskiaho	Jari	Finnish Environment Institute	Finland	jari.koskiaho@ymparisto.fi
Kurkin	Andrey	Nizhny Novgorod State Technical University n.a. R.E. Alekseev	Russia	aakurkin@gmail.com
Kurkina	Oxana	Nizhny Novgorod State Technical University n.a. R.E. Alekseev	Russia	Oksana.Kurkina@mail.ru
Kurochkina	Liubov	State Hydrological Institute	Russia	plathanthera@gmail.com

Mamaeva	Maria	State Hydrological Institute	Russia	mamaeva.maria.anatolyevna@gmail.com
Mikheeva	Elena	Helmholtz-Zentrum Geesthacht, Institute of Coastal Research	Germany	elena.mikheeva@hzg.de
Mostowik	Karolina	Institute of Geography and Spatial Management, Jagiellonian University in Kraków	Poland	karolina.mostowik@doctoral.uj.edu.pl
Naumov	Lev	Russian State Hydrometeorological University	Russia	levnaumov96@gmail.com
Nazarova	Alina	"Eco-Express-Service" LLC	Russia	a.v.nazarova@yandex.ru
Nowikov	Matwey	Russian State Hydrometeorological University	Russia	m_nowikov@rambler.ru
Ovcharuk	Valeriya	Hydrometeorological Institute, Odessa State Environmental University	Ukraine	valeriya.ovcharuk@gmail.com
Petrovskaya	Olga	State Hydrological Institute	Russia	riverchannel@yandex.ru
Piniewski	Mikolaj	Warsaw University of Life Sciences, Department of Hydraulic Engineering	Poland	
Reckermann	Marcus	International Baltic Earth Secretariat, Helmholtz-Zentrum Geesthacht	Germany	marcus.reckermann@hzg.de
Safonova	Ksenia	Russian State Hydrometeorological University	Russia	ksenisaf@gmail.com
Serova	Olga	Russian State Hydrometeorological University	Russia	OlgaSerova1995@gmail.com
Shakirzanova	Zhannetta	Odessa State Environmental University	Ukraine	jannettodessa@gmail.com
Slizyte	Ramune	Vytautas Magnus University Agriculture Academy	Lithuania	ramuneslizyte@gmail.com

Tattari	Sirkka	Finnish Environment Institute	Finland	sirkka.tattari@ymparisto.fi
Timofeeva	Larisa	Russian State Hydrometeorological University	Russia	tilarisa@gmail.com
Varentsova	Natalia	FSBI Central Administration for Hydrometeorology and Ecological Monitoring	Russia	efrnatalie@gmail.com
Vladimirova	Oksana	Russian State Hydrometeorological University	Russia	3256767@gmail.com
Vuglinsky	Valery	State Hydrological Institute	Russia	vvuglins@mail.ru
Yahlakov	Boris	State Hydrological Institute	Russia	boris.ya.workggi@yandex.ru
Zadonskaya	Olga	State Hydrological Institute	Russia	ov-zadon@yandex.ru
Zhuravlev	Sergey	State Hydrological Institute	Russia	s.zhuravlev@hydrology.ru
Zinchenko	Vadim	Saint Petersburg State University	Russia	vdmzinchenko@gmail.com

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