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ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ ОБРАЗОВАТЕЛЬНОЕ УЧРЕЖДЕНИЕ ВЫСШЕГО ПРОФЕССИОНАЛЬНОГО ОБРАЗОВАНИЯ «РОССИЙСКИЙ ГОСУДАРСТВЕННЫЙ ГИДРОМЕТЕОРОЛОГИЧЕСКИЙ УНИВЕРСИТЕТ»

СОВРЕМЕННЫЕ ПРОБЛЕМЫ В ГИДРОЛОГИИ

Материалы международной научно-практической конференции 23–24 апреля 2014

РГГМУ

Санкт-Петербург
2015

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Современные проблемы в гидрологии: материалы международной научно-практической конференции 23–24 апреля 2014. — СПб.: РГГМУ, 2015. — 106 с.

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В сборнике представлены материалы международной научно-практической конференции «Современные проблемы в гидрологии». Исследования посвящены вопросам управления водными ресурсами, гидроэкологии водных объектов, моделированию гидрологических процессов, вопросам лимнологии, гидрометрии и гидравлики.

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Foreword

23th of April 2014 a scientific conference «Modern problems of Hydrology» was in Russian State Hydrometeorological University. The conference was held within the framework of the cooperation agreement between RSHU (St. Petersburg, Russia) and the Faculty of Biology and Earth Sciences UMK (Torun, Poland).The conference was scheduled event. Such an international conference was held in Poland in 2011 in Nikolaus Copernicus University.

Themes of all presentations were matched with the stated subject. Themes of presentations of participants from Poland were dedicated to the problems of water management, hydroecology of water bodies of Poland and exploitation of roads in the winter period. Subjects of the presentations of participants from RSHU cover a wide variety of topics hydrology and hydroecology. The issues of modeling of hydrological processes, hydrometry, limnology, hydraulics were considered. Invited participants presented papers on the impact of deforestation on the regime of rivers and evaluation of the carbon content in the rivers of Eastern Siberia.

In conclusion, summarizing the results of the conference were marked a high enough level of the majority of reports, their engineering direction and the relevance of declared topics. Among the most interesting reports should note the following works: «The spatial analysis of overgrowing the lakes – on example of the Wielkopolska Lake District»; «Removal of carbon from the Arctic runoff of the rivers»; «Modeling of pollutant spreading in watercourses»; «Estimating the statistical parameters of unstudied lakes on the example of lakes of Northwest of Russian Federation».

Skomorokhova E.

THE INFLUENCE OF RIVER BED AND FLOOD PLAIN INTERACTION EFFECT ON DEPOSIT TRANSPORTATION

An analysis of the deposits transportation problem was performed with regard to estimation the influence of river bed and flood plain interaction effect. Based on field data and data obtained from a physical model of river channel with a unilateral floodplain, influence of the effect of river channel and floodplain flows' interaction on hydraulics of the channel flow and sediment transportation was revealed.

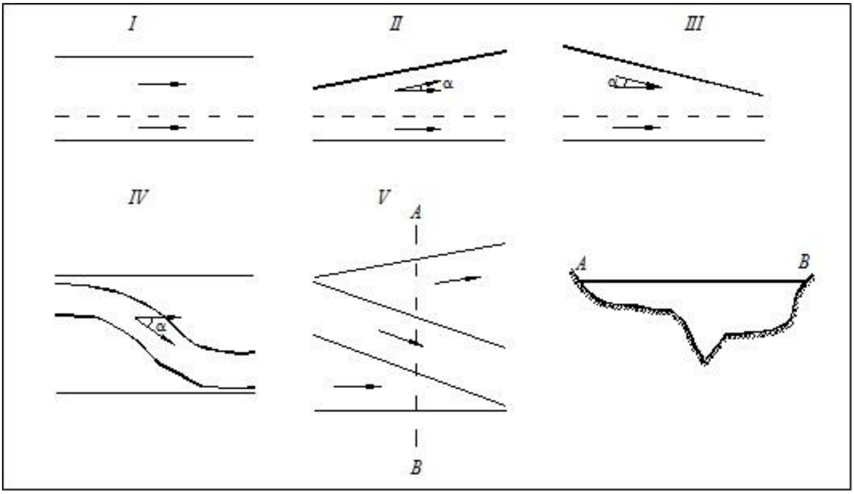
Key words: river bed, interaction effect, flood plain, deposits transportation.

The subject of deposit transportation provided the greatest motivation for the growth in hydrological studies in twentieth century. An expansion of hydrological measurements of deposit transportation was driven largely by needs for the evaluation of water resources and any hydrological construction.

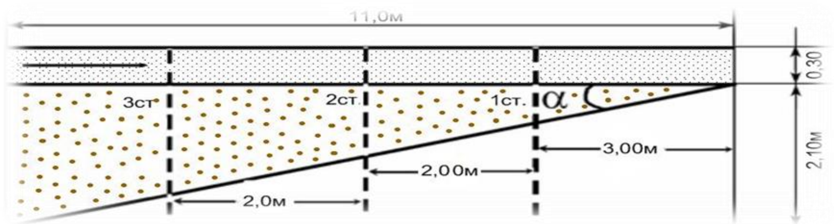
As it is known in recent years, a considerable number of works have appeared on various problems of stream routing. However, no detailed information is so far available on the phenomenon of river bed and flood plain interaction effect which is very important for any quantification of the volume of deposits transported by river stream. In my research work I have tried to develop the technique of consideration this effect studied on the basis of numerable experiments carried out in the laboratory of hydrometry chair at the Russian State Hydrometeorology University.

This picture demonstrates types of river bed and flood plain interaction. As it is shown the type of interaction depends on position of stream axis.

Picture 1 demonstrates the scheme of experimental model of river with flood plain with all the geometric sizes and roughness. The experiments were carried out under two conditions of flood plain roughness – gravel 2 and 1 cm. In process of experimental work the measurements of water stage (level) and stream depths have been made in using a small type of staff gauge with accuracy 1 mm.



Picture 1. Types of river bed and flood plain interaction



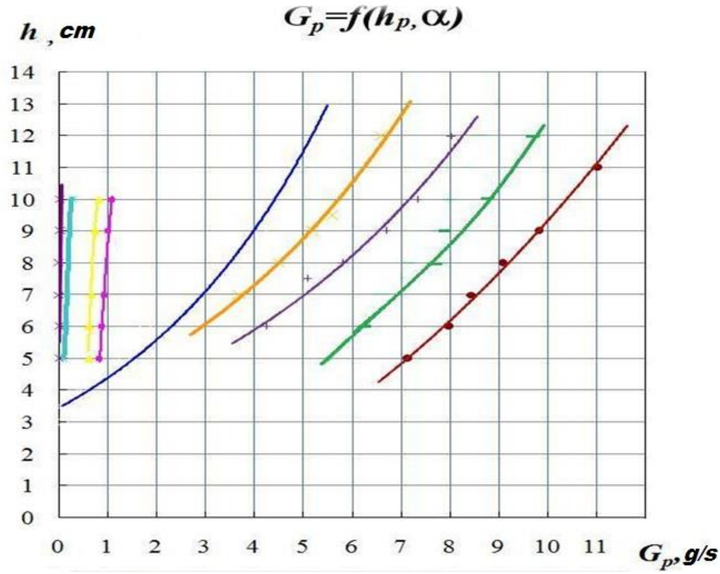
Picture 2. Scheme of experimental model of river bed and flood plain

The most direct method of obtaining a value of discharge to correspond with a stage measurement is by the velocity-area method in which the river velocity is measured by small current meter at selected verticals of known depth across a measured section of the stream.

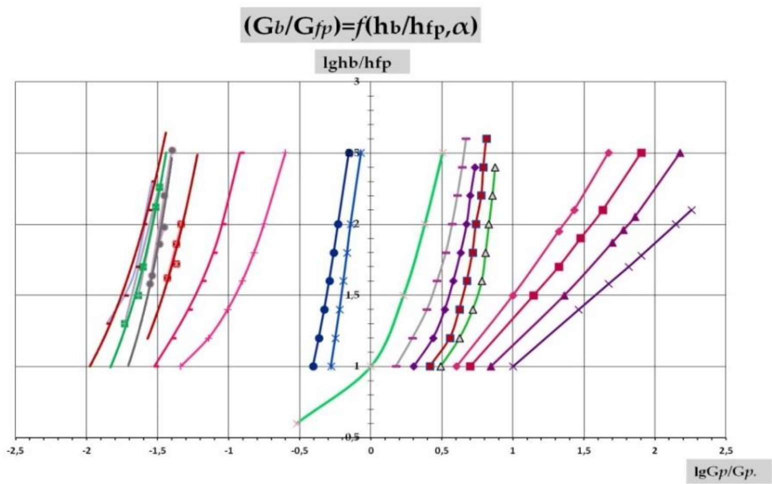
The weighting of sand masses transported by the stream has been done after each experiment. The sand pass was maintained according to transportation capacity of the stream.

The experiments have been made under conditions of slow flow also called subcritical flow as defined by dimensionless Froude number below one. Deposits were transported in wave forms, which have been made possible to calculate the wave velocities.

To find out the process essences the comparison method has been used, which means that each experiment were done at first under conditions of insulated stream flow and after then repeated under conditions of interaction.



Picture 3. Dependencies between transportation capacities, depths of the stream and α angle



Picture 4. Summary graph of dependencies between deposit transportation and α angle

Consequently the dependencies between transportation capacities, depths of the stream and alpha angle for smooth flood plain and gathering axis and for rough flood plain and coming apart axis were constructed. The insulated stream is represented in full line.

Graph 2 demonstrates the summary graph of all experiments made. The central curve shows the insulated stream. The right group of curves represents the coming apart axis interaction conditions, which means that deposits transportation grows greatly due to effect of interaction between flood plain and river bed. The greater angle between dynamic axis (the rightmost curve) the greater value of a physical quantity of deposits transported by river channel flow. The opposite is true for the left group of curves, which demonstrates the conditions of gathering dynamic axis.

To sum up it could say that the first stage of investigation was done, which made possible to set the dependencies between transportation capacities and flood plain and river bed geometry and also to expose the influences of morphometric characteristics on the deposits transportation capacity.

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Marchenko A., Naumenko M.

APPLYING OF LAKE NUMBER FOR ESTIMATION OF VERTICAL STABILITY OF LAKE LADOGA

Vertical water density distribution in a large lake is important for understanding of energy and mass exchange in water masses, mixing processes. Basically the water density is determined by nonlinear relationship between the temperature and the density. Water temperature varies during the annual course of climatic parameters. The mean annual surface temperature cycle depends on the lake geographical placement and depth distribution in the lake. Morphometric differences in the limnic regions determine the specific conditions for heat accumulation and loss during the annual cycle, the time of the beginning and end of hydrological seasons, and their duration. Formation of temperature (and hence density) stratification as well as estimation of their degree are the fundamental for limnological investigation. The objective of this paper is to present calculations of Lake Number on the base of average temperature distribution for deep part of Lake Ladoga and discuss results of applying it to limnological investigations.

Determination of Lake Number

The main characteristic of lake stability is the vertical density gradient $G_d = \frac{d\rho}{dz}$, where ρ is water density and *z* is depth. If $G_d = 0$, the stability is neutral, when $G_d < 0$, then the stability is unstable. The stable stability of water masses is characterized by $G_d > 0$. Mberger and Patterson [8] suggest to take into account the lake depression form and seasonal variation of thermocline depth. In the end of twentieth century they constructed so-called Lake Number (LN) which widely use in limnological practice at present time and is Schmidt stability evolution in fact. It is known that Schmidt [7] stability represents the work to be performed in order to mix entire water body until uniform condition ($\frac{d\rho}{dz} = 0$). Formula LN [9] is defined by

$$\mathrm{LN} = \frac{gS_t\left(1 - \frac{z_t}{z_m}\right)}{\rho_{\mathrm{sur}} u^{*2} \sqrt{A_{\mathrm{sur}}\left(1 - \frac{z_g}{z_m}\right)}}, \qquad (1.1)$$

where $$\mathrm{St} = \frac{1}{A_{\text{пов}}} \int_0^{zM} (z - zg) A(z)(1 - \rho(z) dz, \qquad (1.2)$$

S_t is stratification stability; Z_g is height of center of volume above the lake bottom;

$$u^{*2} = 1{,}56 \cdot 10^{-6}\, u_{10}^{\;2}, \qquad (1.3)$$

u^* is water friction velocity; $A(z)$ is lake area at height z; A_{sur} is lake surface area; z_t is height of thermocline above lake bottom; ρ_{sur} is water density at surface; $\rho(z)$ is water density at height z; u_{10} is wind speed at 10 m above water surface; g is gravitational acceleration.

Center of volume of a lake can estimate as

$$s_0 = \frac{\int_0^H zF(z)dz}{V(H)} = H - \frac{\int_0^H V(z)dz}{V(H)}, \qquad (1.4)$$

where $V(H)$ – total volume of the lake.

It is necessary to calculate water density with precise accuracy by Chen-Millero equation (1986).

Equation of state for freshwater was proposed by Chen and Millero which is valid over the range appropriate to most freshwater lakes: 0–0,6 salinity, 0–30 ^{0}C, 0–180 bars [4].

$$\rho = \rho_o / (1 - P/K),$$

$$\rho_o = 0{,}9998395 + 6{,}79147 \cdot 10^{-5}\, t - 9{,}08947 \cdot 10^{-6}\, t^2 + 1{,}01717 \cdot 10^{-7}\, t^3 - 1{,}28467 \cdot 10^{-9}\, t^4 + 1{,}15927 \cdot 10^{-11}\, t^5 - 5{,}01257 \cdot 10^{-14}\, t^6 + (8{,}1817 \cdot 10^{-4} - 3{,}857 \cdot 10^{-6}\, t + 4{,}967 \cdot 10^{-8}\, t^2) S, \qquad (1.5)$$

$$K = 19652{,}17 + 148{,}113\, t - 2{,}293\, t^{2+}\, 1{,}256 \cdot 10^{-2}\, t^3 - 4{,}18 \cdot 10^{-5}\, t^4 + (3{,}2726 - 2{,}147 \cdot 10^{-4}\, t + 1{,}1287 \cdot 10^{-4}\, t^2)\, P + (53{,}238 - 0{,}313\, t + 5{,}7287 \cdot 10^{-3}\, P)\, S, \qquad (1.6)$$

where ρ is density of lake water at P(bars) pressure, t is temperature in ^{o}C, ρ_o is density of lake water at sea level, S is salinity.

Calculation of Lake Number requires temperature profiles data, wind velocities above the water surface and morphometric characteristics of the lake depression.

Study area and data

Largest European Lake Ladoga is about submeridionally elongated and situated between 60 ° and 62 ° N of North-West Russia. The Lake Ladoga takes 18 place on area and 14 volumes among the largest lakes of the world. The southern part has shallower bottom with 5–20 m depth, whereas the northern area of the lake is rather deeper with depth 100–200 m. Maximum depth is situated in this region and reaches 230 m. Altitude above sea level is 5,1 m. Water level fluctuates by an average of 0,7 m each year, but year-to-year magnitude of level range can vary to 1,1 m. River Neva flows from Lake Ladoga with mean discharge about 2500 m^3/s. Dimictic Lake Ladoga is located in the boreal temperate zone. The surface water temperature twice a year passes the value of 4 °C that is the temperature of maximum density. This results in total vertical water mixing from the surface down to the bottom. Average annual air temperature equals 3,4 °C. Ice cover commonly exists during five months. The mean annual lake-wide averaged water temperature is 3,7 °C. Lake Ladoga has the mean lake temperature less than temperature of maximum density of water. Mean residence time is about 11 years. Basic parameters of Lake Ladoga are presented in the Table.

Basic morphometric variables of Lake Ladoga

Altitude above the sea level, m	5,1
Drainage area, km^2	258 600([2])
Total lake area, $S_{tot.}$ km	18 135
Lake area, km^2	17 765,4
Islands, km^2	456,6
Area index *	0,06
Volume, km^3	847,8
Mean depth, H_{mean} , m	48,3
Median depth, m	41,6
Std. deviation, m	39,9
Maximum depth, H_{max}	230
Maximum length, km	219([3])
Maximum width, km	125([1])
Relative depth **	0,15
Direction of major axis	NW-SE
Shoreline length *L*, km	1570([3])
Shore development ***, ξ	3,28
Capacity factor, H_{mean} / H_{max}.	0,21
Form factor, *K* ****	0,38
Retention time, years	~11

* Lake area / drainage area; ** maximum depth/mean diameter; *** $\xi = L/2(p\ S_{tot})^{1/2}$; **** ratio of mean width to length; ([1]) – by Baranov (1962) [2]; ([2]) – Alekin (1984) [1]; ([3]) – by Chern'yeva (1966) [3].

Lake Ladoga depth-area and depth-volume relationships were calculated with 1–5 m depth interval by using of digital bathymetric model of the lake (Naumenko, 2013) [6] (fig. 1).

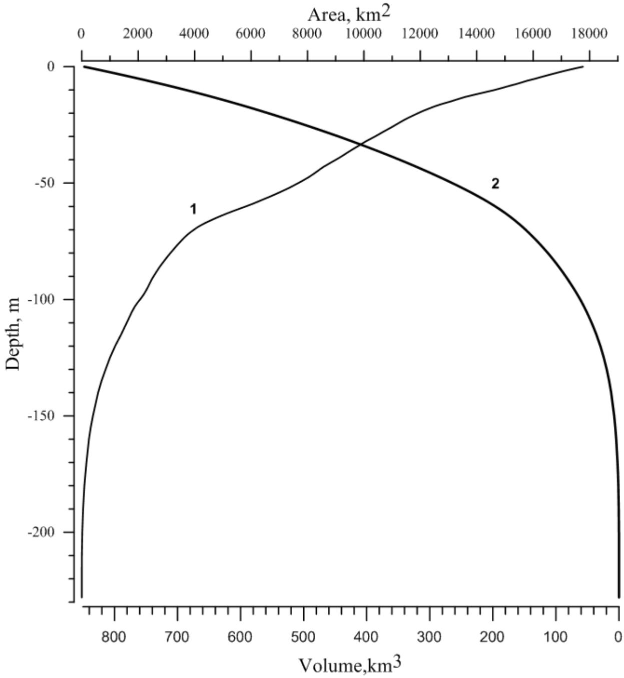

Fig. 1. Lake Ladoga depth–area (curve 1) and depth-volume (curve 2) relationship

We use the curve 2 for estimation of Lake Ladoga volume. Height of the center calculated from hypsographic curve is 200 m above bottom.

The quantitative analyses of a seasonal course of water temperature for the regions in connection with their depths have been made (Naumenko, Karetnikov, 2002b) [5]. It was found that the climatologically averaged temperature cycle for the annual period of Lake Ladoga can be accurately estimated by ten-days averaging with lag 5 days, which has allowed to smooth high-frequency temperature fluctuations (fig. 2).

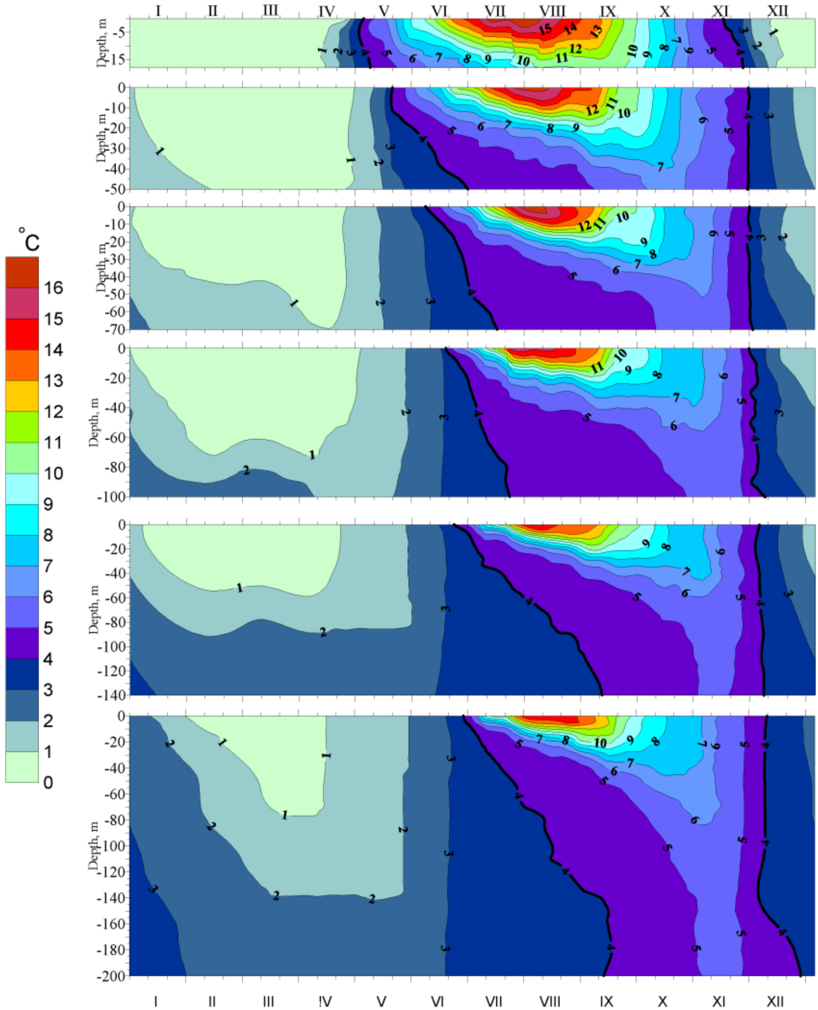

Fig. 2. Time-depth annual course of temperature for six limnetic regions of Lake Ladoga

We apply this information for calculation of 10-days mean temperature for the whole water body of Lake Ladoga from May to November. Wind velocities were got from meteorological yearbooks.

Results and discussion

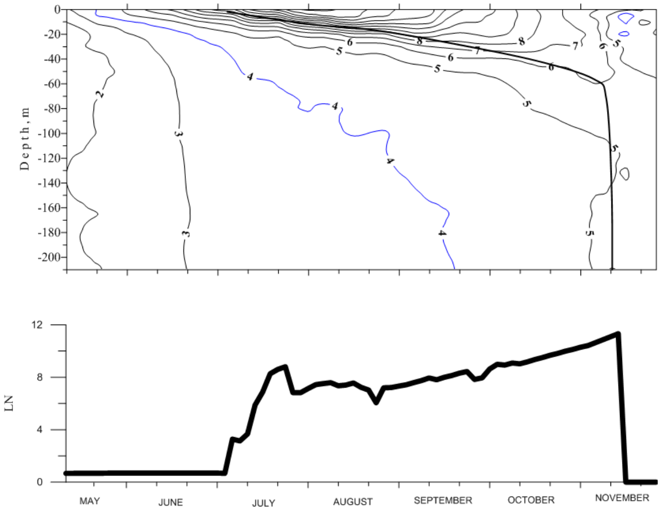

Fig. 3 Graph of seasonal trend of temperature and Lake number

Figure 3 (top) depicts the lake-wide average vertical distribution of temperature for open water period of a year. Vertical resolution of the image is 5 m and temporal step is 2,5 days. For the first time we present Lake Ladoga seasonal cycle of Lake Number (fig. 3, bottom). While surface water temperature is less 4 °C the stratification is unstable and free convection exists. When $\frac{d\rho}{dz}$ become positive, LN begins to increase by value. Wind action and temperature stratification have "mortal combat" during summer and autumn months. In fall when surface temperature drops, and convective mixing keeps an upper layer at uniform temperature throughout named mixed layer. The mixed layer deepens with subsequent heat loss until the temperature is uniform over the entire depth. In that way the heat moves at bottom depth and bottom maximum temperature becomes equal the surface temperature. In this time the depth of thermocline increases and reaches the bottom at last. For Lake Ladoga it means that the downward penetration occurs and the first fall turnover exists when the surface water temperature reached 5,8 ± 0,2 °C in the deepest region at the beginning of November.

Therefore, calculation of dimensionless Lake Number for Lake Ladoga stability investigation is a very useful tool and can be applied for various limnological tasks and comparison of different lakes. It should be noted that for different regions of Lake Ladoga the free convection and stable stratification periods begin in the different dates and exist various duration (fig.2). It shows a next step for new conclusions.

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Piasecki A., Skowron R.

THE STATE OF WATER AND WASTEWATER MANAGEMENT IN CITIES IN POLAND

In the paper the author analyses and assesses water and wastewater management in 17 largest cities in Poland (over 200 000 residents) in the years 1995–2012. As a result, an increase in the length of water supply network by more than 33 % and sewerage by 54 % was found out. It was found that in individual cities the increase in the length of both networks was very diverse. In the case of wastewater network, it ranged from 4 % in Sosnowiec to more than 186% in Toruń. With respect to the water supply the difference was much smaller and ranged from 18 % in Wrocław to 81 % in Gdańsk. The effects of the expansion of the researched infrastructure was an increase in its saturation as well as accessibility for the residents. Furthermore, a significant increase in the share of treated wastewater, while also improving the degree of their purification, was indicated.

In conclusion, it was found that the extent of the investment made in water and wastewater management in the analysed cities is satisfactory. The expanded and modernised infrastructure meets most of the qualitative and quantitative requirements contained in the Water Framework Directive (WFD). Undoubtedly, the living standards of the urban population were significantly increased, while the pressure on the environment was significantly reduced by limiting the amount of pollution.

Key words: wastewater, water use, water supply, sewerage.

From the earliest times water and wastewater systems have constituted basic elements in the functioning of every major urban system. From the physiological point of view the primary need of the population has been the supply of drinking water. For this reason, since ancient times cities have taken steps to build water supply systems.

The desire to improve the living conditions influenced the developmental milestones of urban centres. A manifestation of this desire has been the construction of sewage disposal systems.

The first comprehensive sewerage project in the Polish lands was developed for Gdańsk in 1869 [2]. In the era of rapid urban population growth, especially in the second half of the twentieth century (Szymańska, 2013), the construction of water supply and sewage system had a huge impact on the quality of urban centres.

For many years of the second half of the twentieth century stagnation in the development of water and wastewater management, especially in terms of the sewer section, was observed in Poland. Both in the post-war period and in the times immediately preceding the political transformation, investment in this type of infrastructure was insignificant [6]. Most often, it only focused on expanding the system to enable supply of drinking water. The consequence is a disparity, observed especially in rural areas, between the water supply and wastewater network [4].

Poland's integration with the European Union resulted in the need to adapt the national law to the requirements of the EU legislation, including in particular the Water Framework Directive (WFD) [7]. As a result, the new law has created a number of favourable conditions for changes in the water supply and sewage disposal [1]. What seems important is the fact the Water Law has introduced the requirement of simultaneous solving the problems of water supply and wastewater disposal [5]. Thus, to meet the new legal requirements, for many years the projects related to the construction and modernisation of sewage treatment plants as well as water supply and sewerage system in the entire country have been carried out. One of the priorities was to provide the adequate infrastructure in major cities, mainly due to the amount of wastewater produced by urban centres.

Materials and methods

The paper presents the analysis and assessment of water and wastewater management in the 17 largest cities in Poland (over 200 000 inhabitants) in the years 1995–2012 (Fig. 1). The following indicators were determined:

- saturation with the water supply and wastewater network (expressed as the ratio of the length of both networks to the surface area of the city);
- dynamics of change in the length of the water and wastewater network5
- the share of treated wastewater5
- access to sanitation and water supply.

The Local Data Bank of the CSO was the source of the information and data.

Figure 1. Location of the largest cities in Poland (over 200 000 inhabitants)

Results and discussion

Since the late 1980s a growing trend of investments related to water and sewage infrastructure has been observed in Poland. In the surveyed cities the increase in the length of the water supply network in the 22-year period was over 33%. In the case of the sewerage network, this increase was even higher and amounted to 54 %. Despite a greater increase in the sewage system, there still remains a distinct disproportion between the sewage and water network (Fig. 2).

In the years 1995–2012 there was a significant decrease in water consumption and wastewater generation in the surveyed cities. It was caused by many factors, but one of the most important was the socio-economic transformation that occurred in Poland in the early 1990s. It forced the closure of many unprofitable factories. In the case of households an important factor limiting water consumption was widespread metering of the tap water use and a significant increase in its price. The decrease in water consumption resulted directly in reducing the amount of wastewater.

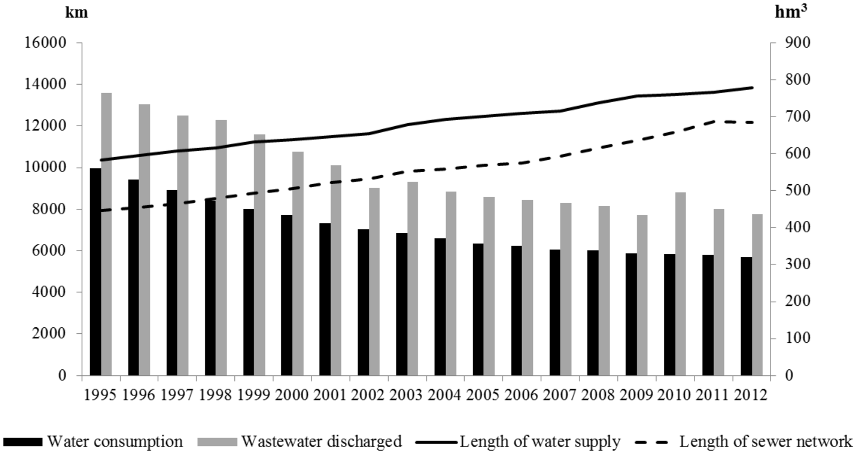

Figure 2. Basic rating parameters of the development of municipal infrastructure

Among the studied cities the largest increase in the length of the water supply system occurred in Gdańsk (81 %), and the sewerage system in Toruń (186 %). It should be emphasised, however, that there were significant differences in the dynamics of changes in both elements of the infrastructure in individual cities. The range of extreme values of this ratio with respect to the wastewater system was 182 percentage points (pp) and to water supply system – 70 pp.

The most extensive water supply network (over 2 100 km) and sewage (approx. 2 000 km) is in Warsaw, which results mainly from the fact that it is the largest city in terms of the area and the number of inhabitants (tab. 1).

With the increase in the length of the networks in question, the saturation index with both elements of the infrastructure also changed. The highest value of the indicator for both the water supply system and sewage is now in the city of Białystok. This is due to the relatively small surface area of the city – over 102 km^2, and a relatively large number of people – about 300 000. The opposite situation is observed in Szczecin, which has almost three times larger the surface area (over 300 km^2) and the population of about 400 000.

Table 1

The basic rating parameters of the development of municipal infrastructure

City	Rate of growth		Density of the water supply network		Density of the sewerage network		Relationship between the length of sewer network water supply	
	water supply network	sewerage network						
	1995-2012		1995	2012	1995	2012	1995	2012
	%	%	Km	km	km	km		
Warszawa	30,45	40,30	314,91	410,81	271,53	380,95	1,16	1,08
Kraków	41,91	66,31	284,37	403,55	243,82	405,50	1,17	1,00
Łódź	26,09	55,00	352,14	444,00	243,86	378,00	1,44	1,17
Wrocław	16,03	20,19	381,13	442,22	250,68	301,30	1,52	1,47
Poznań	21,40	28,48	281,65	341,92	230,15	295,71	1,22	1,16
Gdańsk	81,12	55,92	220,34	399,08	218,09	340,04	1,01	1,17
Szczecin	40,12	58,83	178,80	250,53	120,80	191,86	1,48	1,31
Bydgoszcz	30,22	95,27	266,97	347,66	195,60	381,94	1,36	0,91
Lublin	39,07	39,64	288,78	401,62	276,96	386,76	1,04	1,04
Katowice	54,13	75,82	265,82	409,70	167,45	294,42	1,59	1,39
Białystok	35,32	67,31	421,22	570,00	277,33	464,00	1,52	1,23
Gdynia	46,62	43,94	235,96	345,96	213,01	306,62	1,11	1,13
Częstochowa	19,59	86,52	306,56	366,63	184,50	344,13	1,66	1,07
Radom	20,80	102,60	364,82	440,71	192,59	390,18	1,89	1,13
Sosnowiec	10,50	4,24	474,95	524,84	318,46	331,98	1,49	1,58
Toruń	55,75	186,09	194,83	303,45	140,69	402,50	1,38	0,75
Kielce	44,90	59,93	207,55	300,73	191,73	306,64	1,08	0,98

What seems also interesting is the correlation between the two elements of the infrastructure, which in the study period showed significant changes in several cities. In 1995, the length of the water supply network was significantly larger, which resulted in the value of the said indicator of more than 1,4 in ten of the surveyed cities. This means that in these cities the water supply network was more than 40 % longer than that of the sewage network. This indicates a significant underinvestment in sanitation, and indirectly – on the attitude to the environmental issues related to appropriate management of wastewater disposal. In subsequent years, the value of the analysed indicator in most cities dropped significantly and now stands at an average of 1,15. It is worth emphasising that in 2012 in Toruń, Bydgoszcz and Kielce the length of sewerage network exceeded the water supply network.

As already mentioned, the volume of wastewater generated by the analysed cities decreased in the period considered. At the same time, the share of the treated wastewater increased. Currently, more than 93 % of wastewater produced in the examined cities is treated (in 1998 it was below 70 %). This seems extremely important due to the purity of Polish rivers, which are the main wastewater receivers. Unfortunately, still the biggest part of untreated sewage is discharged to the Vistula by the capital city of Warsaw (about 25 %) (Tab. 2).

Table 2

Share of treated wastewater and its treatment manner

City	Share of treated wastewater		Treated wastewater					
			mechanically		biologically		with increased biogen removal	
	1998	2012	1998	2012	1998	2012	1998	2012
	%							
Warszawa	46,2	74,7	0,0	0,0	100,0	0,5	0,0	99,5
Kraków	55,5	100,0	99,3	0,0	0,7	1,7	0,0	98,3
Łódź	99,7	100,0	60,9	0,0	39,1	0,0	0,0	100,0
Wrocław	99,6	100,0	0,9	0,0	84,8	29,2	0,0	70,8
Poznań	100,0	100,0	99,9	0,0	0,1	0,3	0,0	99,7
Gdańsk	76,3	100,0	0,0	0,0	14,0	0,1	86,0	99,9
Szczecin	17,4	100,0	97,0	0,0	3,0	0,7	0,0	99,3
Bydgoszcz	28,0	100,0	0,0	0,0	83,4	0,0	16,6	100,0
Lublin	100,0	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Katowice	90,1	91,4	1,3	0,6	77,4	10,1	21,3	89,3
Białystok	99,4	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Gdynia	99,9	100,0	0,0	0,0	0,0	0,0	100,0	100,0
Częstochowa	99,7	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Radom	96,4	100,0	0,0	0,0	100,0	0,0	0,0	100,0
Sosnowiec	71,2	99,8	7,6	0,0	86,6	0,8	5,8	99,2
Toruń	37,2	100,0	4,5	0,0	0,0	0,8	95,5	99,2
Kielce	88,6	100,0	0,0	0,0	100,0	0,4	0,0	99,6

It should be noted that besides the quantitative growth of treated sewage, the degree of its purification also increased. This is mainly thanks to the modernisation of the existing wastewater treatment plants, as well as investments in new objects of this type. In the mid-1990s only Bydgoszcz had a wastewater treatment plant which used the technology for a better level of nutrient removal. In other cities mechanical and biological treatment of wastewater dominated. Now, thanks to the said investment in the researched infrastructure, in all the surveyed cities wastewater treatment with an increased degree of nutrient removal dominates.

Intensive development of the tested infrastructure increased the accessibility to it by the residents of various cities. If all the cities are considered, the growth was relatively small and amounted to 1 pp in the case of water supply and 3 pp for sewerage system (Fig. 3). In individual cities, however, these values were much larger. The largest increase in the share of population using the water supply occurred in Kraków – by 6 pp, while in wastewater system in Toruń – by over 7 pp. Despite a threefold larger growth of the share of people using the sewage system, it is still much smaller than in the case of the water supply network. The main reasons are economic and technical factors. Construction of water supply is far cheaper and shows lower technical requirements when it comes to supplying water. In the case of sewage system, a cheaper and often used solution in the case of dispersed settlement is the construction of septic tanks or individual biological wastewater treatment plants.

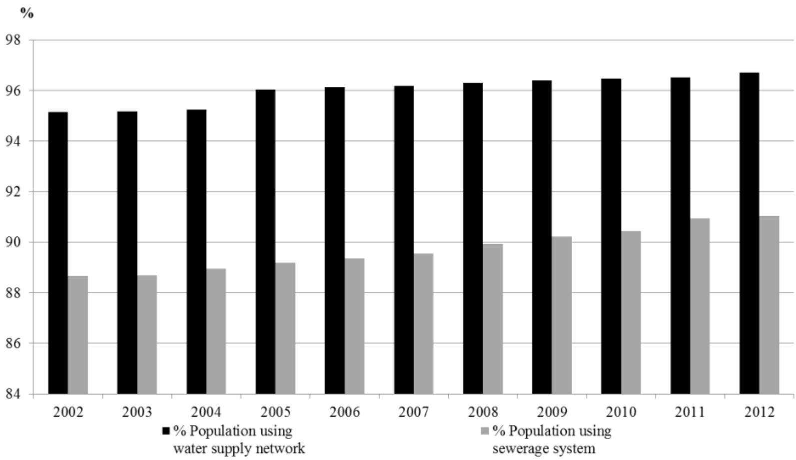

Figure 3. Population using sewage system and water supply network

As already mentioned, one of the main factors influencing such a dynamic development of the studied infrastructure was the requirements of the EU in the field of environmental protection. At the same time the EU supplied substantial funds under the pre-accession and post-accession programs to the expansion and modernisation of water and sewage infrastructure in Poland. With these measures such fast and comprehensive development of individual objects and water and wastewater components was possible. It should be emphasised that the cost of construction and modernisation of the infrastructure is very high and many cities would not be able to carry them out using only their own resources. Among the researched cities the biggest financial resources for this purpose were spent by Warsaw. In this city there were also the largest gaps in the analysed infrastructure, the best proof of which was over 50 % of untreated sewage produced by the capital until 2005. The total investment in the past few years in this city exceeded 3,1 billion PLN. More than half of this amount was covered from EU funds (mapadotacji.gov.pl).

Table 3

Value of the projects financed by the EU

City	Value project [mln zł]	EU grant [mln zł]
Warszawa	3155,3	1759,7
Kraków	574,3	341,9
Łódź	606,9	303,4
Wrocław	335,1	191,1
Poznań	814,2	352,5
Gdańsk	357,8	164,4
Toruń	447,9	260,8
Bydgoszcz	905,7	550,0

Summary Changes in the water and wastewater management began in Poland at the start of the socio-political transformation system in the early 1990s. Previously little attention was paid to environmental protection and thus many rivers and lakes were polluted with municipal and industrial wastewater. Poland's integration with the EU forced a series of changes in both legal and infrastructural spheres. The obligation to adjust the water and sewer systems to the requirements of the Directive rested mainly on local authorities.

In the years 1995–2012 in the major cities, a number of investments in the water and sewage infrastructure were conducted. In total, over 7 700 km of water supply and sewerage networks were built. The average growth rate of the sewage network was greater by half than that of the water supply network.

Dynamic expansion of water and sewage infrastructure was accompanied by a simultaneous modernisation of the existing one. A particularly noteworthy is the construction of new sewage treatment plants and modernisation of the existing ones. As a result, almost all surveyed cities have at least one treatment plant with the increased nutrient removal scheme.

Despite such large investments in terms of the analysed infrastructure, there is a simultaneous decline in the amount of water consumed and wastewater produced. The current problem is the exploitation of the existing infrastructure, which was designed and constructed for other technical parameters. As a result, it now shows more frequent failures and faster wearing out [3].

The scope of the investment in the water and wastewater management in the analysed cities should be regarded as satisfactory. The expanded and modernised infrastructure now meets most of the qualitative and quantitative requirements of the WFD. Thanks to that, the standard of living of the urban population has been raised, and the negative impact of anthropopressure on the environment reduced. Undoubtedly, most of the investments were only possible thanks to financial support of the EU. The financial aid in adapting to the requirements of the WFD seems to be extremely important.

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Kuptz K.

WINTER PROTECTION OF ROADS IN THE AREA PUCK

Transport and the ability to move in today's world are becoming increasingly important. There is a guarantee of socio-economic development. Proper infrastructure and passability help to provide people with adequate mobility, significantly improving their standard of living. However, in the winter when there are temperatures below zero and there are snowfalls and ice phenomena traffic situation worsens. The paper will be presented workflow in winter seasons in the most northern Polish county area.

Resources

The basis for the creation of the article are materials obtained from the District Road in Sławoszyno contained in the "notebook reports" performing duty, materials obtained from the Board of County Road for Puck and Wejherowo, materials from the website of the General Directorate for National Roads and Motorways and literature.

Characteristics of the District roads Puck

The total length of roads administered by the Board is 186,116 km. In the area of research, there are four provincial roads. Provincial road number 213 is a road linking Celbowo from Słupsk, the road is 109 km in length. It runs through the four administrative districts: Puck, wejherowski, lęborski and Słupsk and the six municipalities: Puck, Stepped, Choczewo, Wicko Główczyce and Słupsk. In the area the road runs through the following towns: Połczyno, Werblinia, Starzyno, Sulicice, Minkowice, Stepped, Żarnowiec, Wierzchucino. Another way is to Provincial Road number 215, which is of a total length of 22,3 kilometers, it connects the seaside resort of Władysławowo to the Sulicice. The road connects the municipality of Władysławowo and Stepped Municipality. On the stretch of the Jastrzębia Góra-Chłapowo is maintained even paved surface, which is in terrible condition, which is an additional problem when it comes to its winter maintenance, in this section there is a large number of traffic events, not only in the winter. Towns located on the route 215 are Władysławowo, Chłapowo, Roze

Figure 1. Way of the Pomeranian Region (source GDDKiA)

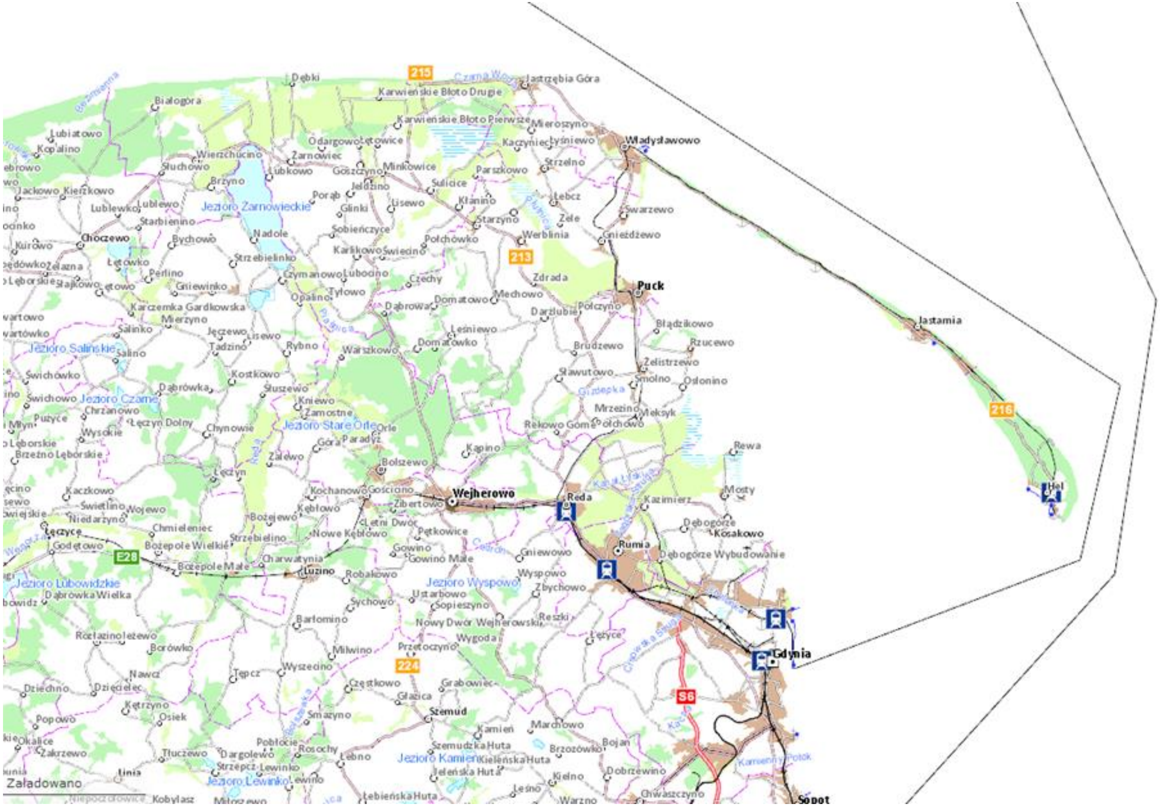

Figure 2. Dear District Puck (source geoportal.gov.pl)

wie, Jastrzębia Góra, Karwia, Karwieńskie Mud First, Sławoszynko and Sulicice. In Sulicicach road that connects with the National Road number 213 on the test area there is also present Provincial Road number 216, that lies at the junction of two districts: Wejherowo and Puck. It is very important because it connects the Tri-City agglomeration of the northern part of the province. This route is 56 kilometers long and runs from Reda to Hel. The road is characterized by a very large number for the provincial road traffic, especially in the summer. It runs through the village Reda, Ciechocino, Rekowo lower, upper Rekowo, Widlino, Sławutówko, Celbowo, Puck – bypass, Swarzewo Władysławowo, Cottages, Jastarnia, Smithy, Downtown Jastarni - bypass, Jurata, Hel. Provincial Road 218 runs from number Krokowa to Gdansk People at Tri-City Bypass, its length is 58 km. Proceeds by steps (and there connects with the Provincial Way No. 213), Piaśnica great, Wejherowo (where it intersects with the National Road No. 6), Gałęźną Górę (where the borders of the Provincial Way # 224), Nowy Dwór Wejherowski, Bieszkowice, Koleczkowo , Bojano, Dobrzewino, Chwaszczyno (where it intersects with the National Road No. 20), Gdańsk Osowa. Winter road is maintained according to specified by the General Directorate for National Roads and Motorways standards. The Board of County Road Puck sets 9,564 km of roads of III standard, 70,693 km – of IV standard, 78,657 km – of standard V, and 24,569 km – of other standards.

Summary of the characteristics of the natural environment

According to the Polish division into regions, natural Kondracki, Puck County lies within the Embankment Kashubian, Koszalin and the Hel Peninsula. This includes its borders Kępa Oksywska, Kępa Swarzewska, Kępa Puck, Kępa Ostrowska, Kępa Sławoszyńską, Kępa Starzyńska, Kępa Żarnowiecka the northern edge of the Clumps Gniewowskiej, the north-eastern part of Kępa Osiecka, part Glacial Valley Kashubian and Reda-Leba, Glacial Valley Płutnicy, Plain blot littoral eastern section of the Curonian Kashubian and all the Hel Peninsula. The most striking feature of this area is the presence of young glacial forms, especially the extensive moraine plateaus, cut through the glacial valley. The height difference between the two characteristic forms of the area dates back to several tens of meters (see Figure 3).

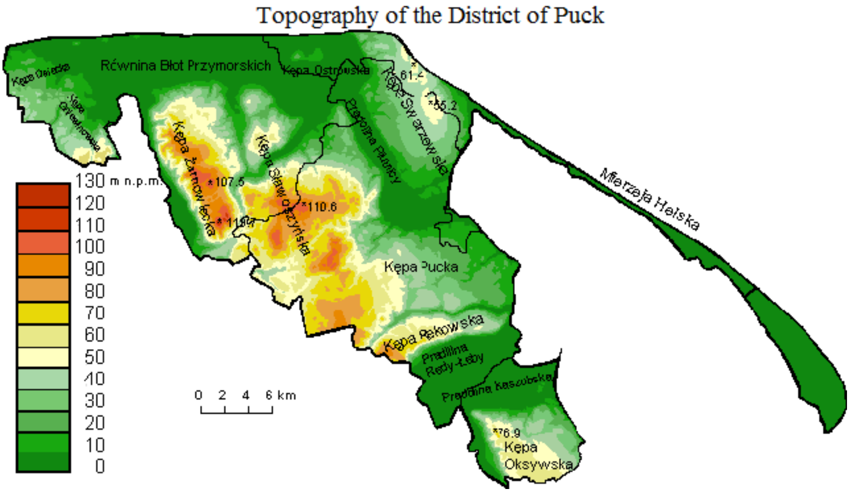

Figure 3. Topography of the District of Puck

The district is dominated by wavy sculpture, hilly and flat. In terms of shape there are the most diverse upland edge zones, which highlight the interesting sculpture of a deep cut erosion. Describing the topography of the county Puck from the south to the north we see at first Kępa Oksywska. It is slightly wavy morainic plateau, separated from the adjacent areas of the big bend in the glacial plateau Kashubian and sloping toward the sea cliff of 20–30 m. In the west area Kępa rises to a height of 76,9 m above sea level. In the western part of the valley, there is erosion, among others. Kosakowska is the longest valley, which formerly flowed water from the northern part of the Clump.

A detailed analysis of the weather with particular regard to the snow and icy roads.

It is characterized by its location advantage of the characteristics of the sea. It belongs to the temperate climate zone. The proximity of the Baltic Sea, and the impact of air masses of oceanic and continental make the climate of these areas very variable and has characteristics of transience. The above-mentioned influence of the Baltic Sea has a range of about 30 km inland and contributes to the occurrence of late cool spring and serene autumn. In contrast, winters are less troublesome and summer is less hot. Average temperatures range from 7,2 ° C to 8,0 °C. The coldest month is February: –1,6 ° C and the warmest one is

July: 17,3 °C. The average annual temperature in the Puck is 7,6 °C. Average annual atmospheric pressure in the vicinity of the puck is 1015hPa. The highest value takes in March and November, and the lowest one in January and July. During the year, we can observe more than 100 days of Frost, below 0 °C, the temperature drops about 30 times a year, usually in the month of February. Puck county area, especially the coastal belt, has also increased humidity compared with the areas lying in the hinterland. The air has an increased content of iodine and a considerable amount of sea spray. Area county rarely has rains. The reason for this is the location of the area in the so-called "Drop shadow" Pomeranian Lake District. Average rainfall varies between 550–600 mm. The most "wet" month is July, in which there has been a more than 80mm. The least abundant in the rain month is March, in which there has been a little over 21mm. During the year, we observe approximately 140 days of rain – they are quite common, but poor and usually do not exceed 5mm.

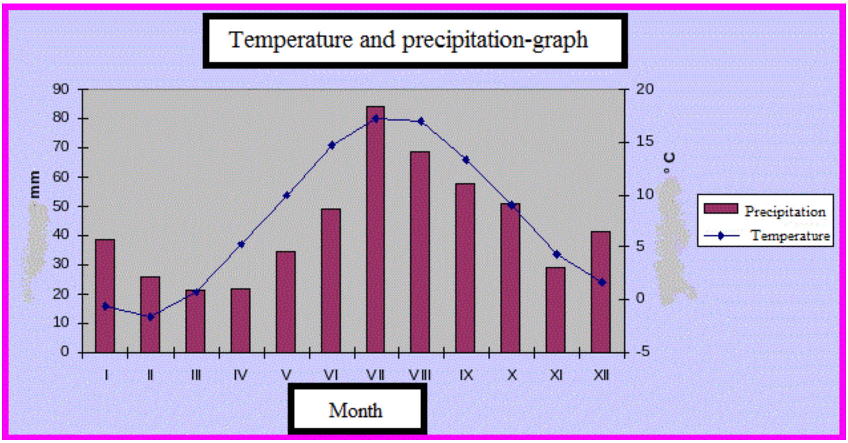

Figure 4. A comparison of average temperatures and rainfall for the District of Puck

Technical measures used for winter road maintenance

The Puck district uses a blend of sand and salt 33%, and pure sand. Including plans assumes the use of a mixture of 500 tonnes (200 tonnes in the last quarter and 300 tonnes in the first quarter of the year) and the use of 1,500 tons of clean sand (700 tons in the last quarter and 800 tonnes in the first quarter of the year). Reports are issued about The

Circuit Road. It contains information on the location of measurement, time, air temperature, rainfall, wind blowing, which sections of roads are closed and some sections of roads which are at a standard maintenance and technical data of the active maintenance of roads: the amount of equipment used for snow removal, the amount of equipment used to remove ice, and the number of employees in a given day for winter road maintenance.

The impact of local conditions on road maintenance

Local conditions have a huge impact on the maintenance of roads, terrain as well as its use affect the quality of living. There are snowstorms and blizzards in places most exposed to clumps occurring in the area of research. The use of agricultural areas mainly affects the movement of the snow and the additional difficulties on the road.

Conclusions

The work has been characterized 15 winter seasons from 1999/2000 to 2013/2014. Such a long period of observation allowed to notice that winter seasons were the longest, how intense it was winter road maintenance. And hence that the season could be the most expensive for GDDKiA. This work shows how to maintain the road in a very specific way, because it is the most northern region of Poland. The data obtained allow to observe how individual proceeded winter seasons, the temperature occurred as roads were excluded from the traffic and how many people and equipment were involved in the campaign in winter (Figure 5).

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Data	Godzina	Stan pogody			Zamknięte drogi w km	Sprzęt użyty do odśnieżania	Sprzęt użyty do usuwania gołoledzi	Ilość pracowników do ZUD
		Temperatura	Opady	Wiatr				
25.11.13r.	07:00	2°C	deszcz	słaby	-	-	-	1
26.11.13r.	07:00	1°C	śnieg z deszczem	słaby	-	-	1	3
27.11-05.12.13r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
06.12.13r.	07:00	0°C	deszcz	silny	-	-	6	9
07-08.12.13r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
09.12.13r.	07:00	1°C	brak	brak	-	11	-	12
10.12.13r.	07:00	-2°C	brak	słaby	-	-	6	7
11.12.13r.	07:00	4°C	brak	słaby	-	-	-	1
12.12.13r.	07:00	3°C	brak	brak	-	-	-	1
13.12.13r.	07:00	2°C	mżawka	brak	-	-	-	1
14-30.12.13r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
31.12.13r.	07:00	0°C	brak	silny	-	-	2	4
01.01.14r.	07:00	-1°C	brak	słaby	-	-	3	6
02.01.14r.	07:00	0°C	brak	słaby	-	-	-	1
03.01.14r.	07:00	4°C	brak	słaby	-	-	-	1
04.01.14r.	07:00	3°C	mżawka	słaby	-	-	-	1
05.01.14r.	07:00	2°C	brak	słaby	-	-	-	1
06.01.14r.	07:00	2°C	brak	słaby	-	-	-	1
07.01.14r.	07:00	7°C	deszcz	słaby	-	-	-	1
08-12.01.14r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
13.01.14r.	07:00	-4°C	brak	słaby	-	-	6	8
14.01.14r.	07:00	-2°C	brak	umiarkowany	-	-	6	8
15.01.14r.	07:00	-1°C	brak	słaby	-	-	1	3
16.01.14r.	07:00	-2°C	brak	słaby	-	-	-	1
17.01.14r.	07:00	-3°C	śnieg	słaby	-	-	6	10
18.01.14r.	07:00	-5°C	brak	umiarkowany	-	-	4	5
19.01.14r.	07:00	-5°C	brak	umiarkowany	-	-	6	9
20.01.14r.	07:00	-5°C	brak	silny	-	-	6	9
21.01.14r.	07:00	-6°C	brak	umiarkowany	-	-	-	1
22.01.14r.	07:00	-6°C	brak	umiarkowany	-	-	-	1
23.01.14r.	07:00	-7°C	śnieg	umiarkowany	-	-	2	3
24-26.01.14r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
27.01.14r.	07:00	-9°C	śnieg	silny	-	6	-	10
28.01.14r.	07:00	-6°C	śnieg	umiarkowany	-	7	-	9
29.01.14r.	07:00	-9°C	śnieg	silny	-	11	-	13
30.01.14r.	07:00	2°C	śnieg	silny	-	12	-	14
31.01-02.02.14r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
03.02.14r.	07:00	1°C	brak	słaby	-	-	-	1
04.02.14r.	07:00	-5°C	brak	słaby	-	-	6	9
05.02.14r.	07:00	-6°C	brak	słaby	-	-	-	1
06.02.14r.	07:00	-3°C	brak	słaby	-	-	-	1
07-11.02.14r.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
12.02.14r.	07:00	0°C	brak	słaby	-	-	4	5
13.02.14r.	07:00	-1°C	brak	słaby	-	-	6	9
14.02.14r.	07:00	0°C	brak	słaby	-	-	-	1

Figure 5. Winter season 2013/2014

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Churyulin Ye. V.

PERIODOGRAM ASSESSMENT OF WATER FLOW VELOCITIES

Phenomenon of low-frequency fluctuations of velocity in free-surface flows was discovered in the middle of XX century. Their period was in the range from several minutes up to dozens of minutes with regard to hydraulic characteristics of the flow in measurement section. Relationship of occurrence of low-frequency fluctuations in rivers justifying phenomenon of low-frequency fluctuations was established more than 30 years ago. In brief, an essence of the discovery lies in the fact that the periodic low-frequency fluctuations of velocity are solutions of equations of one-dimensional hydraulic idealization, not simply Saint-Venant's system (it does not have such solutions), but their modification.

The latter comes down to that hydraulic resistance factor λ (or related Chezy's factor *C*) is considered as an equivalent variable along with average velocity and depth in the cross-section, rather than considered as a specified factor. It has been shown that resistance factor λ $\left(\lambda = g / C^2\right)$ depends on the acceleration (*dU*/*dt*) and the frequency (ω). Consideration of this circumstance results in having an advanced system instead of classical Saint-Venant's equations. The number of variables has increased.

The purpose of the study is to detect number of variables in series of measured velocities of the flow. According to Takens' theorem one variable bears information about all the variables of the system being considered. Fractal diagnostics helps to define the number of variables in the series of one element. But, first of all, one should learn how to process series of velocities and detect periods of low-frequency fluctuations. Therefore the purpose of my study is to develop a method (algorithm) to calculate periods of fluctuations and estimate periodograms of velocity series of the flow.

4 experiments each comprising 3 tests have been performed. Each test lasted 3000 seconds and values of *velocity pulsation* were recorded every second. Experiments were performed in different states of water flow.

Schuster's method

Periodogram, which was first developed by Schuster in 1898, is one of the most well-known and most important tools used in cycles study. This periodogram searches for cycles, analyzing data in a form of a table. Available data are classified in columns in chronological sequence, whereas number of used columns equals length of a cycle being searched. A separate periodogram has to be built for every searched cycled of specified length. For example, we have a data series for 135 years and we want to check, if 12-year cycles are available, then we have to split data into 12 columns and 11 rows and the rest is neglected.

Then sum and mean value is calculated for every column. If 12-year cycle is available in data, then mean value for one column will show a significant maximum, whereas for another column – a significant minimum. If 12-year cycle is not available, then mean values for the column should practically coincide. Factors in Fourier expansion a_T and b_T, which are comprised in formula used to define amplitude A_T, should be also calculated. After amplitude calculations a diagram is plotted where periods are shown on X-axis and amplitudes of respective periods are shown on Y-axis. That is a periodogram.

Maximum values on a periodogram show possible periods, characterizing relations of this series. If a limited number of data is expanded in Fourier's row, maximum values for periods may be obtained, which are not intrinsic for this series, so called false periods. Their main difference is that they tend to the maximum in a periodogram, which remains constant.

Besides Schuster's method, a program in MATLAB, based on the use of transformation of Fourier's rows, was written.

On the first stage periodograms was estimated as follows: mean, maximum and minimum values were defined for data series. RMSD was also calculated for the series. The periodogram was estimated. In case of deviation of maximum and minimum from RMSD+mean and RMSD+mean was the biggest, then this period was taken as a reference. All the calculations were performed with the help of programs written in MATLAB.

We tried to find an equation for a series of observations based on established relation. For that purpose we wrote a program, *which ena-*

bles performing these actions. Polynominal value is the most important value for selection of equation.

In order to use this equation for the series being studied a correlation dependence was established. Correlation made 0,325. Unfortunately we are not able to use this basic equation as design equation so far, but we will keep working on that.

Thus, as a result of the work performed we have developed an algorithm how to process velocity series of the flow, which enables defining periods of fluctuations, and we have developed software, not depending on characteristics of the series and processed experimental velocity series of the flow.

Isaev D.I., Tarasov A.I.

LABORATORY STUDIES OF UNDERFLOW AT THE RIDGE MODE OF SEDIMENT MOVEMENT

Water flow under alluvial channel is poorly studied. The Series of experimental studies on underflows at ridge mode of sediment movement were done in 2012–2013. For studies of underflows was used crystal of potassium hypermanganate ($KMnO_4$).

Results show that underflow rates have oscillatory behavior. A underflow changed its rate and direction. Velocity vectors changed depending on crystal position relative to ridge body.

The River Hydraulics mainly studies underflows under a dam. Due to the large water level difference these flows can reach considerable power and threaten the safety of the structure. By far water flow under alluvial channel is poorly studied. The Series of experimental studies on underflows at ridge mode of sediment movement were done in 2012–2013.

Experiments were realized in the Water Surveys Laboratory, Russian State Hydrometeorology University. Length of laboratory glass pan is 6 m versus 0,11 m width. (Figure 1). The pan was filled inequigranular sand with prevailing granularity 0,25 mm. Histogram of granulometric composition is shown on the Figure 2. Ridge movement of sediment was formed after water delivery to the pan.

Figure 1. General pattern of laboratory pan for studies underflow

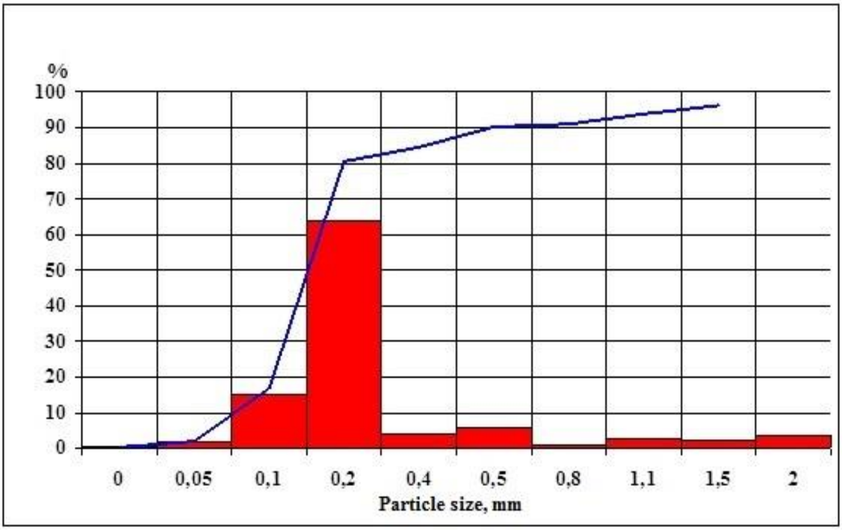

Figure 2. Granulometric composition of sediment in experiments

During the experiments water depth and average rate of flow were 0,1 m and 0,25 m/sec consequently. At given mode, ridges are formed on the bed with length being 0,1 m, average bed depth 3 cm, and rate of the movement along the bed 0,04 cm/s. Detailed characteristics of hydraulic elements are shown in the Table 1.

Table 1

Main characteristics of flow and bed ridges

Q, m³/s	*H*, cm	h_{sand}, cm	*F*, m²	*V*, m/s	*L*, cm	Δ, cm	tgα	*C*, cm/s
0,003	9	2	0,012	0.247	10	3	0,15	0,038

Crystal of potassium hypermanganate ($KMnO_4$) was put in the basement of ridge near glass wall. Crystal was rapidly submerged under layer of sediments (Figure 3, 4). By showing spot contour changes of potassium hypermanganate we could say of flow behavior within a ridge. Movement of color spot was fixed by the camera.

Figure 3. Crystal $KMnO_4$ in the beginning of the experiment

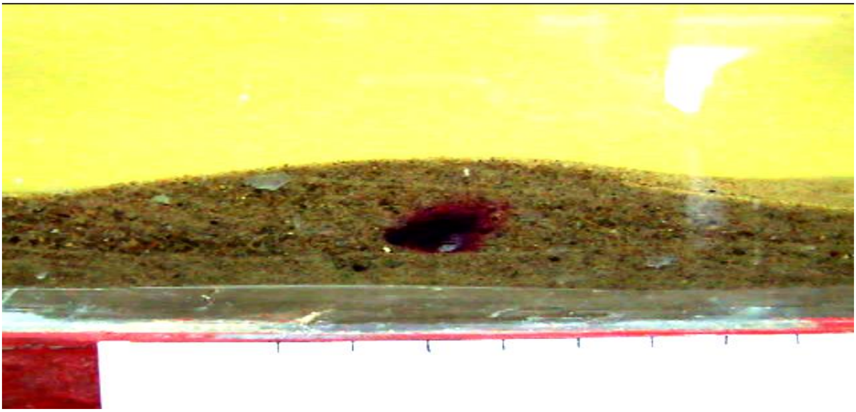

Figure 4. Color spot in the body of ridge

In result of the series of experiments some features of underflow with ridge mode of sediments were found out. So rate of color spot movement varied from 0.005 to 0.04 cm/s depending on which part of the ridge passes over the potassium hypermanganate spot at that moment. Maximum underflow rates were observed under a discharge slope of the ridge, minimum – under crest and near basement. As a ridge moved a underflow changed its rate and direction. Vertical current prevailed under ridge basement. Flow as though pressed in alluvial bed.

As result of processing of photographic material we managed to take flow structures within the ridge (Figure 5).

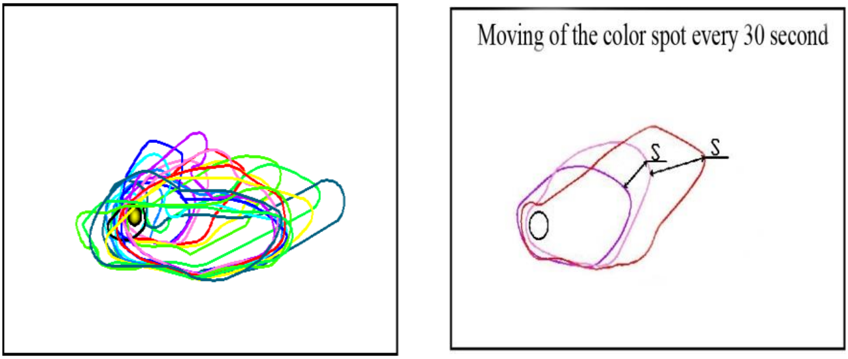

Figure 5. Color spot contours over serial time intervals

Results of calculations show that underflow rates have oscillatory behavior. This figure (Figure 6) show it clear.

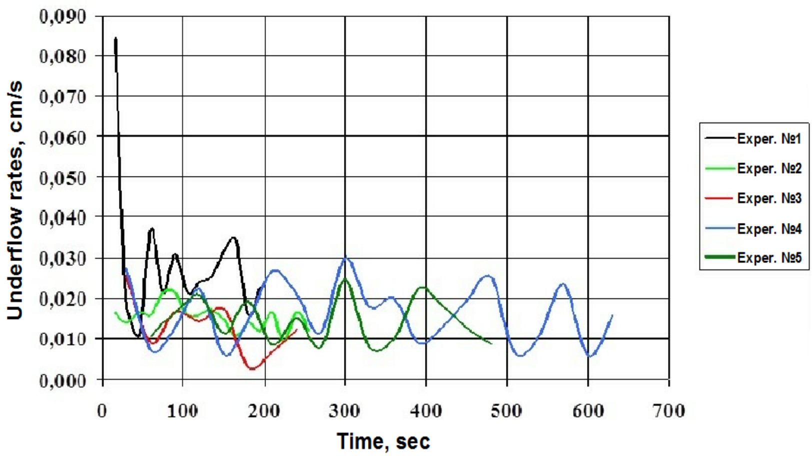

Figure 6. Graph of the change in the propagation velocity of color spot inside the ridge

As were shown by the experiments a underflow changed its rate and direction. Velocity vectors changed depending on crystal position relative to ridge body. General regularities of underflow direction in ridge body are represented on the Figure 7.

Figure 7. Diagrammatic representation of the motion direction
in the body of the ridge every 30 seconds

Water flow rates in sand-bed were significantly less than those in channel and ridge movement ones. In all cases the same pattern type of different oriented currents under body of the ridge were observed. The currents pattern well conforms with pressure curve received by Raudkivy for hard material ridge (Figure 8) [1].

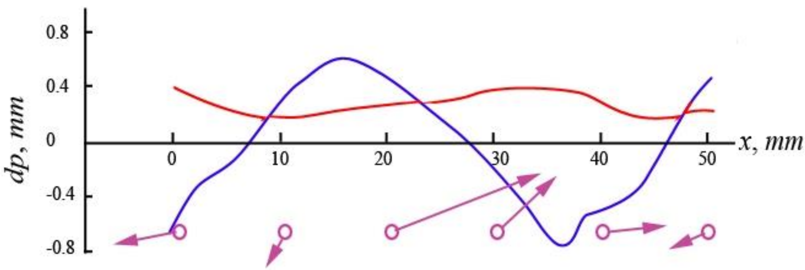

Figure 8. Comparison of Raudkivy`s pressure curve above ridge
and current structures from RSHU`s study

The series studies of underflow under active layer of sediments that take part in ridge movement were done in the end 2013. According to previous results circular vertical water drifts in soul column prevails in this layer.

The obtained experimental results allow to specify theoretical views of the origin and epigenetics of the bed ridges.

It is also required to redefine Lorentz`s law for alluvial channel, because for such channels a flow rate at the bottom is nonzero.

It should also consider different orientation of underflows when constructing oil-and-gas pipelines.

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Baryshnikov N. B., Subbotina E. S., Ovseyko P.P.

THE ROLE OF RIVERINE SHAFTS IN THE RIVERBED AND FLOODPLAIN FLUXES VELOCITY FIELD FORMATION

The riverine shafts influence upon the formation process of the riverbed and floodplain fluxes velocity fields was analysed. It was pointed, that interaction effect between riverbed and floodplain fluxes reducing under riverine shafts impact. Riverine shafts influence on the velocity field formation, fluxes capacity, especially upon riverbed part of flux.

The formation process of riverine shafts is determined by several parameters. The main one is incoming water masses of riverbed fluxes, sediment saturated, to the floodplain. Herewith, the velocity of such fluxes significantly decreases due to abrupt depth decreasing. It is accompanied by sediment accumulation at the riverine part of the floodplain. More over, the further water masses velocity decreasing and sediment sorting are observed. At first, one of the largest particles accumulate, which form the base of shafts, and then the smaller one and warp too. Generally, the last one accumulates at the intermane lowlands of floodplain, leveling its relief.

Chalov R. S. think: “The floodplain genesis is connect with sediment congestion accumulation (stray, axis), representing the shape of itself moving. During water horizon vary from flood (high water) to mean water, separate parts of riverine shallows are rising and it can cover by vegetation. One of the highest one, formed at the high water years, doesn’t flood at the further mean water years. This fact is contributes to vegetation growing. Further process of crest increasing happens due to sediments accumulation by vegetation” [1, p. 146].

These points of view are close to each other. However, Popov I. V. takes shore ridge as a shore shaft foundation, and Chalov R. S. – stray or axis. At the same time, stray and axis are different forms of the band ridge, however not always moor and doesn’t form the floodplain.

The majority of scientist have the common opinion that peculiarities of floodplain formation occur due to riverbed flux process at the given part of the river.

The last one can proceed in large quantities can be placed on the floodplain, not only through deep holes, but through riverine shaft crests, especially , if the angle between riverbed and floodplain fluxes crossing is close to 90° or larger than it. This fact is confirmed by observation data of floodplain array of river Ob in Barnaul city during the flood period of 1970 year, closing to 1% frequency.

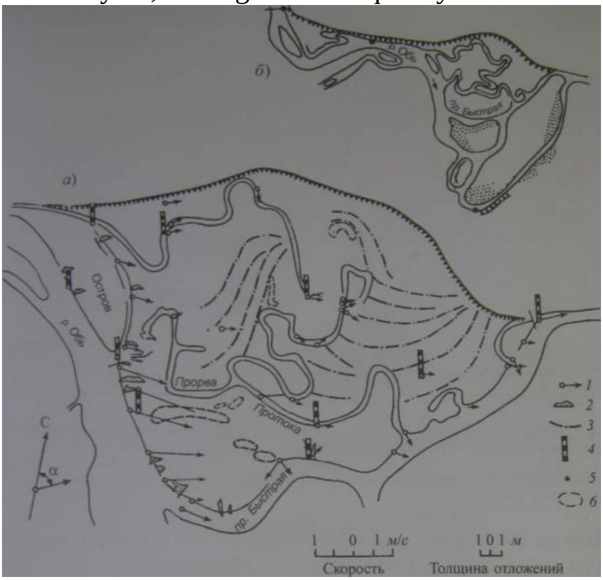

Fig. 1 Plan of array floodplain (a) and location of all areas river Ob in Barnaul (б)

On fig. 1, one can see that the riverbed was full of bottom sediments at the fluxes crossing area. Those sediments proceeded from areas, located upper due to vortex area formation. Wherein, the main role (according to Goncharova V. N. terminology) played floodplain flux. At first bottom sediments proceeded to floodplain array through riverine shaft lowlands (deep holes), and then, attached to further depth and level increasing at the floodplain, above the riverine shaft, – directly through it. At that, the process is attended by sediments sorting. One of the largest fractions suspended the riverine shaft directly, increasing the height.

Thus, riverine shafts sort of separation of riverbed and floodplain fluxes. Herewith, its interaction occurs through the deep holes at first. The last one could be as a natural origin as anthropogenic [3].

Due to riverine shafts significant height, overgrown trees, the riverbed and floodplain fluxes interaction significantly runs down. As the real information analysis shows, in the presence of high levels two fluxes could be formed. The riverbed one is more powerful and the another one – floodplain is weaker, though sufficiently pronounced. These fluxes are separated above the riverine shaft and flux velocity becomes is 3–5 times smaller than riverbed one and 2–3 times smaller than floodplain flux. According to this, riverine shaft has a significant impact not only upon the fluxes velocity fields, but the passing ability of riverbeds and floodplains also.

Simultaneously, at the number of rivers, especially of the 5-th type, role of the riverine shaft in the fluxes interaction (according to Barishnikov N. B. typification [2]) is not considerably. For example, the data of river Nesterovka of Taloviy patrol can be represented.

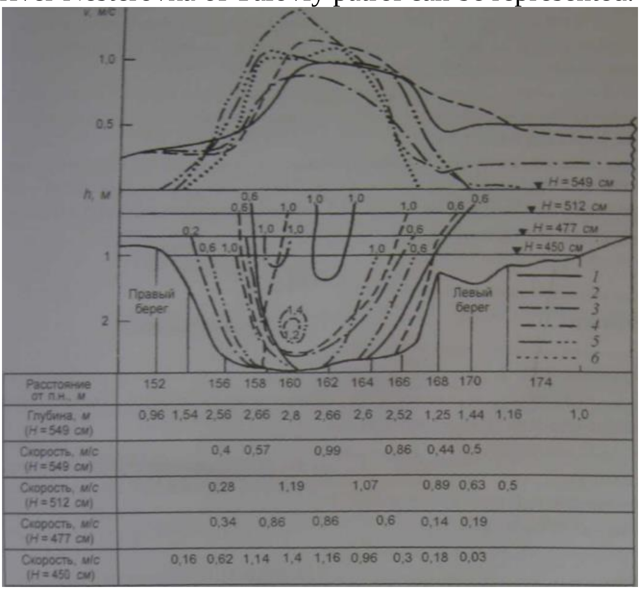

Fig. 2 Profile of cross-section with isotachs distribution curves and average speeds on verticals across the width of gauging stations p. Nesterovka (patrol Taloviy).

As it shown on fig. 2, the curve of mean distribution on verticals velocities along the flux width at the maximum levels smoothly transfer to the similar velocities of the floodplain flux, without any bends above the riverine shaft.

It is necessary to point, that the author of this paper have observation data only of Roshydromet hydro alignment, where usually the grass is mown and the trees are cut off. The areas, where we can neglect the anthropogenic parameter, the role of riverine shafts significantly increasing. However, even in these conditions, the riverine shafts height and the power of its vegetation growing can significantly vary due to watercourse. This leads to the fact, that the interaction effect of riverbed and floodplain fluxes and its influence upon velocity fields formation, especially riverbed flux, vary along its the length.

At the same time, in the various papers [2] the mark of the riverine shaft crest is a reference point and can be used as a basis of observation data on different rivers to represent the data in relative coordinate system. So, the accuracy of mean values of riverbed flux components determination during its interaction with the floodplain one depends on the accuracy of riverine shaft mark determination. And so, the the accuracy of maximum (especially catastrophic) water flow according to the data of the maximum levels and morphometric characteristics of settlement area.

The following conclusions was done as a result of the analyzing.

The riverine shaft is the reference value, allowing to represent the hydraulic characteristics of riverine fluxes riverbeds and floodplains morphometric characteristics in relative coordinates. This fact allows to compare and to evaluate observation data of different objects to detect the regularities of its vary.

The accuracy of riverine shaft mark determination depends on horizontal and vertical shooting scale. To increase it, it is necessary to conduct field survey work.

To estimate the influence shafts height changes along the length of calculated area on riverbed hydraulics and floodplain fluxes and to estimate their interaction effect experimental, natural, laboratory researching must be performed.

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Bobrova O.N., Fedorova I.V., Chetverova A.A., Potapova T.M.

ESTIMATION OF CARBON CONTENT IN THE EAST SIBERIAN ARCTIC RIVERS BASED ON HISTORICAL AND FIELD DATA

In this paper historical data from Roshydromet stations on carbon dioxide, hydrocarbons content, and permanganate oxidation were analyzed to understand temporal variability of carbon content in some Arctic rivers (Yana, Indigirka and Lena) and its relation with water discharge. The relation of permanganate oxidation and dissolved organic carbon was studied based on field data of expedition Lena 2013.

An estimation of the dissolved carbon formation and runoff to the Arctic Ocean by rivers is one of the important aims of the permafrost hydrology. To understand the time variability of carbon content and its relation with water discharge, the historical data from Roshydromet polar station could be used. These data contain the values of permanganate oxidation (PO), concentration of hydrocarbons and carbon dioxide content.

Nowadays the main characteristic of the carbon content is dissolved organic carbon (DOC). Permanganate oxidation is close to the DOC concentration, but they are not equal. Some studies to compare PO and DOC were done in 2012 and 2013 on Samoylov Island.

Materials and methods

To calculate the volume of runoff and flow rate of carbon were used the data from the hydrological yearbooks [3] for the years 1948-1975 concerning permanganate oxidation, the content of dissolved hydrocarbons and carbon dioxide from four stations (Lena River – Kusur and Kachyug, Yana River – Verkhoyansk, Indigirka River – Indigirskoye).

Total carbon content was calculated as sum of organic and inorganic carbon. Organic carbon content was assumed equal to permanganate oxidation value [4]. Inorganic carbon was calculated as sum of carbon in carbon dioxide and hydrocarbons using following formulae:

$$C_{inorg} = C_{CO_2} + C_{HCO_3},$$

where $C_{CO_2} = 0,27\ [CO_2]$; $C_{HCO_3} = 0,2\ [HCO_3]$.

The investigations of dissolved organic carbon (DOC) and permanganate oxidation were carried out in the Lena River Delta (Figure 1) in 2012 and 2013 on the delta channels, lakes of the third terrace, ice-complex of Kurungnakh Island and on the watershed of the Fish Lake on Samoylov Island in Lena River delta.

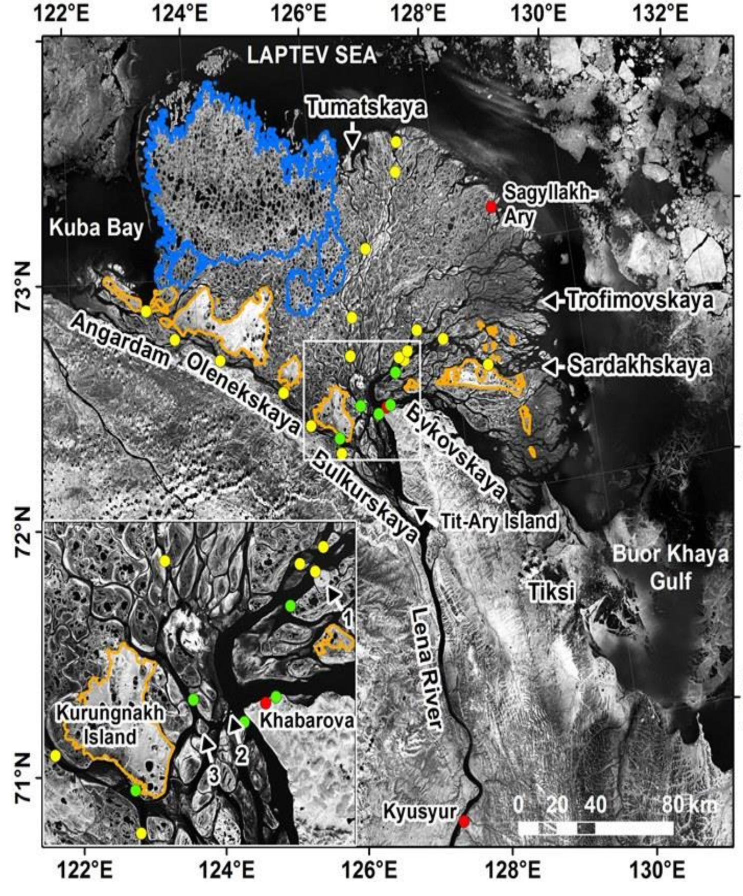

Figure 1. Lena River Delta and delta terraces (orange outline: Ice Complex deposits (third terrace); blue outline: late Pleistocene fluvial sands (second terrace). 1: Sardakh Island; 2: Stolb Island; 3: Samoylov Island) [5]

In 2012 Samples for DOC were analyzed in the field using a Spectro::lyser probe. The measures are based on the water absorption of radiation at wavelengths from 220 to 790 nm at intervals of 2,5 nm. In 2013 measurements were completed on Shimadzu TOC-L, which uses catalytic oxidation method.

For the measurements of permanganate oxidation was used Kubel's method [1].

Results and discussion

Long-term observation data are summed up in Table 1. It can be noticed that for Lena River mean values of hydrocarbons content and permanganate oxidation are higher than the same values for Yana and Indigirka Rivers. Total carbon flow rate for these rivers is three times smaller than carbon flow rate for Lena River.

Table 1

Long-term observation data

River – point	$C_{CO2,}$ mg/l	$C_{HCO,}$ mg/l	P_O, mg/l	TC, g/m^3	Volume (TC), Mt	Flow rate, *t*/year·km^2
Lena – Kusur	1,9	11,9	10,3	24,1	12,7	5,22
Lena – Kachug	1,1	23,4	9,3	33,8	0,10	5,52
Indigirka – Indigirskoye	1,7	3,9	5,2	10,7	0,14	1,71
Yana – Verkhoyansk	1,3	4,1	7,3	12,7	0,06	1,36

Carbon dioxide

Carbon dioxide values have significant difference inside the year (Figure 2), and maximum values are mentioned for the end of freezing period. Concentration of carbon dioxide is decreasing during the flood due to dilution of river water with melt waters. In the beginning of freezing values are growing again which could be explained by decreasing of expense on biological production.

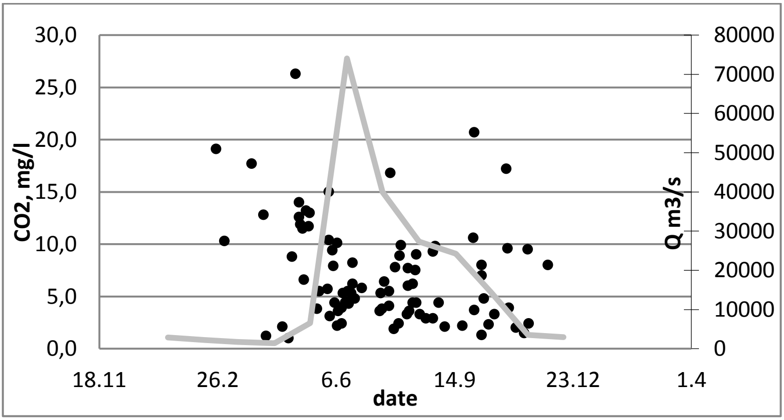

Figure 2. Carbon dioxide content (black circles) and water discharge (grey line) for station Kusur on Lena River

Hydrocarbons

The concentration of hydrocarbons is decreasing rapidly in the flood period because of the low-mineralized melted waters input in the river. That decrease was shown most significant for station Kusyur on Lena River (Figure 3).

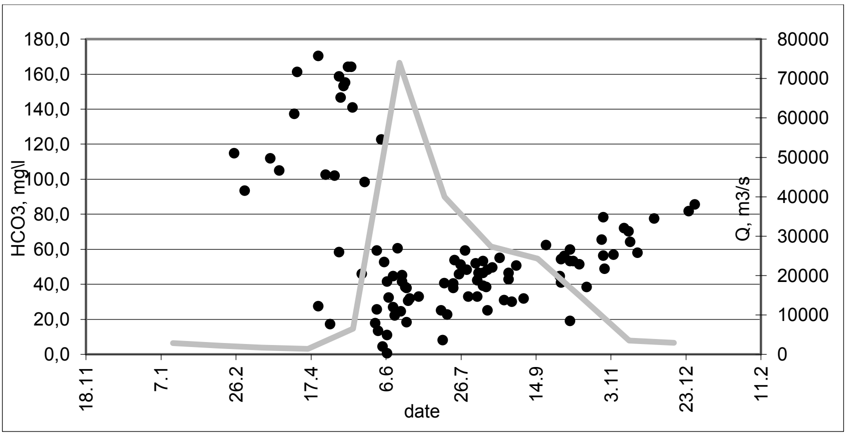

Figure 3. Hydrocarbons content (black circles) and water discharge (grey line) for station Kusur on Lena River

For the other studied stations that relation between concentration and water discharge was not so expressed, and maximum values of hydrocarbon were smaller.

Permanganate oxidation

According to historical data a mean PO value for the Lena River for 1948–1975 in Kachyug station (upstream of the river) is 9,3 mg/l, in Kusur station (downstream) – 10,3 mg/l, for the Yana River in Verkhoyansk station (upstream of the river) – 7,3 mg/l, for the Indigirka River in Indigirskiy station – 5,2 mg/l. The values for Lena River are similar to results presented by G. Cauwet and I. Sidorov [2] where the mean annual concentration of organic carbon is 10 mg/l.

The values of PO have a significant difference inside the year (Figure 4). There are many sources of organic carbon in river water and the within-year variability makes it difficult to estimate the origins of this carbon.

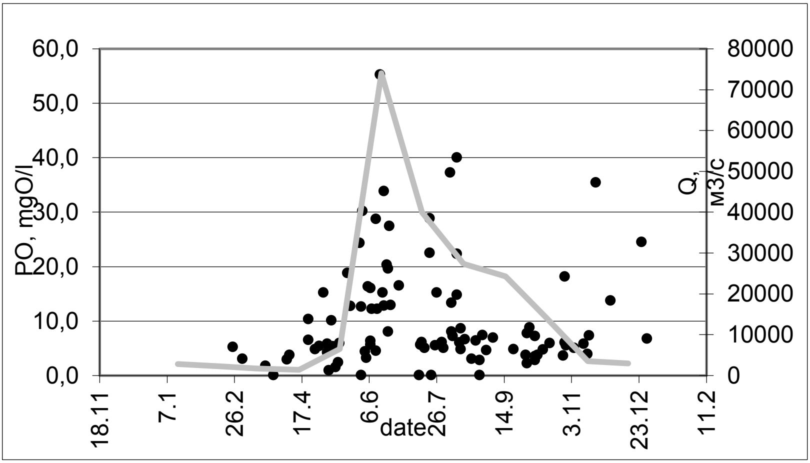

Figure 4. Permanganate oxidation (black circles) and water discharge (grey line) for station Kusur on Lena River

The maximal values are occurred in the flood period, which could be explained by the input of the organic material from the river basin with melt waters and by cutting of the banks by ice drift.

According to field data value of the permanganate oxidation was 15–22 mg/l for the delta channels and the lakes on Samoylovsky island

and 45–48 mg/l for the pore waters on Fish Lake catchment. This result for delta channels is substantially higher than the values for Lena River from Roshydromet stations.

Organic and inorganic carbon content

The ratio of total inorganic carbon (TIC) and total organic carbon (TOC) in relation with water discharge was studied for station Kusyur on Lena River. For the flood (discharge > 50 000 m^3) this ratio is mainly exceed 1 which means that inorganic carbon prevail in this period (Figure 5).

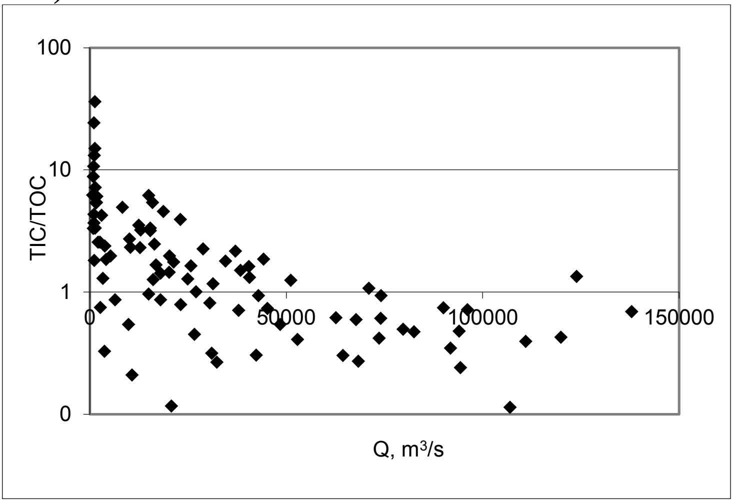

Figure 5. The ratio of total inorganic carbon (TIC) and total organic carbon (TOC) depending on water discharge

Dissolved organic carbon (DOC) and permanganate oxidation (PO)

Nowadays the main value which shows carbon content in water is dissolved organic carbon. As on the Roshydromet stations permanganate oxidation was measured, the comparison of this to values is need to relate modern and historical data.

The results of measurements done in expedition Lena-2013 are presented on Figure 6.

For the most part of the samples DOC concentration is higher than permanganate oxidation but the difference is less than 20 % (with the inaccuracy of DOC analysis of 10 %), which means that this two characteristics are relatively close and could be equally used for the estimation of organic carbon content.

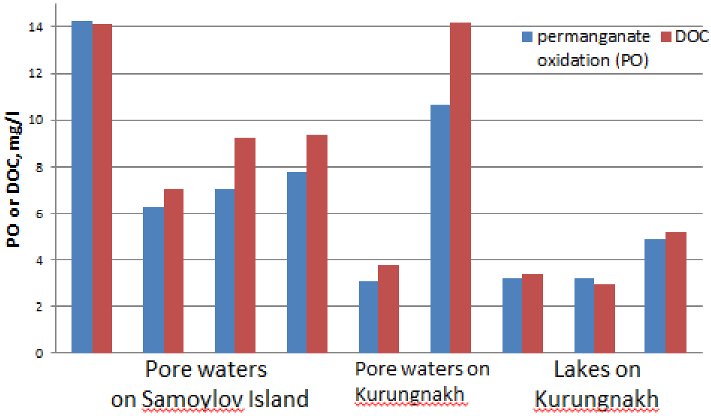

Figure 6. Permanganate oxidation and dissolved organic carbon in water objects of different types

Due to small quantity of samples this measurements should be considered as preliminary, and for more accurate result additional measurements are needed.

Acknowledgements

The field work was performed as a part of project "Samoylovsky Island research station" of the program "Laptev Sea system" and as preparation for the Russian-German project about carbon in permafrost (CarboPerm), which started in October, 2013.

Many thanks to Antje Eulenburg for the help with lab analysis.

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Skowron R., Piasecki A.

SPATIAL ANALYSIS OF PLANT OVERGROWTH OF THE LAKES IN THE WIELKOPOLSKIE LAKELAND

The genesis of the lakes in the northern part of Poland is related to the last Weichselian glaciation. These lakes constitute approximately 0,9 % of the country's area. The analysis covered the lakes located in the Wielkopolskie-Kujawskie Lakeland, one of the three lakelands in northern Poland. These lakes have rather small areas and are of smaller depths. The examination of cartographic materials of 256 lakes from various periods made it possible to analyse the changes in the degree of plant overgrowth of the lakes over the period of the last sixty years. As a result, the areas of the lakes were found to have declined by 0.6% (from 28 152.6 ha down to 27 983.7 ha). Simultaneously, the area covered by emerging plants was observed to have increased by 1,7 %.

Key words: Poland, lakes, plant overgrowth.

In the Holocene history of the lakes several development stages of their basins can be distinguished. According to Niewiarowski (1978, 1987), several factors were of a significant role, such as: diversified pace of dead ice melt-out, short and long-term climatic changes, different time when the lakes entered the system of the surface run-off, deforestation of lake basins (both total and direct), hydrotechnical treatment (from the mid-18th century) and land irrigation and drainage.

The evolution of post-glacial lakes took place mainly in the Allerød, more rarely in the Bølling, and showed varied intensity of processes which brought about different changes. The pace of lake basin transformation since the formation till the present time has fluctuated considerably. Two factors have been decisive, namely: changes in the level of lake waters (lowering) and accumulation of biogenic and terrestric deposits in the lake basin.

Although the lakes have undeergone several stages of evolution, they are currently in the various phases of the development of their basins. The processes, which involved the melt-out of dead ice lumps, played a significant role in the formation of the lake basins. The melt-out pace varied. The Holocene development of many lakes in Poland (lakes: Biskupińskie, Gościąż, Weneckie, Gąsawskie, Pakoskie, and

Gopło) revealed various water levels, influenced most frequently by climatic conditions.

The average degree of disappearance of lakes related to the Weichselian glaciation equalled 67.4 %. However, according to Choiński (2006), as many as 2 215 lakes disappeared in the Polish Lowland over 70 years of the 20th century (i.e. 11.2 % of their area). The changes undergoing in the lake basins have been presented in numerous works.

The influence of anthropopressure upon the formation of the water table in the lakes began in Poland, similarly to other countries, in the Middle Ages. This activity was related to the construction of water mills. That process lasted even over hundreds of years, and finished with the closure of water mills in the mid-19th century. From the mid-18th century a different stage of the evolution of lakes was intensified by large-scale irrigation and drainage works, as well as by the regulation of river channels. The lakes are thought to have disappeared mainly due to natural causes. These causes include, among others: plant overgrowth, filling lake basins with deposits, and seasonal decline in water supply. From the 18th century, and particularly in the 19th and 20th centuries, there was violent increase in anthropopressure resulting in the acceleration of lake disappearance or increasing pace of lake eutrophication. These processes were most conspicuous in the areas predestined for the development of farming. In the years 1871-1914 the total area of 420 000 ha was ameliorated. The decline in the water table level in numerous lakes by 0,5–0,7 m led to a considerable decrease in their areas, sometimes even by 25–30 %.

The undertaken agrotechnical procedures resulted in the decline of the water table level in many lakes in Poland. The analysis of the lake percentage in 15 catchments of the Baltic Coastland over a hundred years showed a negative trend. The number of lakes fell by 16.2% and their area by 3,9 %. The analyses of bathymetric plans of the lakes located in the lakelands of northern Poland leads to a conclusion that over the period of 60–70 years of the 20th century their areas declined by several percent, whereas their volume fell by dozens of percent. Many lakes were found to have their isobaths changed – more towards the middle of the lake from the shore. New peninsulas or islands were formed, and in some cases a lake was found to have divided into several smaller ones. Similar situations were observed in the other regions of the Polish Lowland. The analysis of aerial photographs of smaller lakes in the southern part of the Wielkopolskie Lakeland exposed considerable succession of littoral and floating plants.

These changes are also very substantial in the Wielkopolsko-Kujawskie Lakeland. According to Choiński (2007), plant overgrowth is one of the effects which prove the processes of shallowing and disappearance of lakes. These process are favoured by the increasing inflows of biogenic substances which are effects of disadvantageous changes undergoing in land management structure and the decline in the buffer zone of the direct catchment of the lakes. The calculations conducted by Kowalczyk (1993) on nearly 900 lakes located in North Poland showed the mean coefficient of emerged plants equalled 4.1%, whereas it was 10.4% in the WIelkopolsko-Kujawskie Lakeland. The main factors favouring plant overgrowth also include a big share of the littoral zone. Therefore, studying this problem thoroughly is more purposeful after over 60 years from the initial measurements and observations of plant overgrowth of the lakes.

Within the lake basins an extensive or only a fragmentary zone of shallow water (the littoral zone) can be distinguished. In this belt several zones of plants can be differentiated:

- a zone of reed beds – exists at the border of a land and water, includes mainly helophytes;
- a zone of Schoenoplectus – emerged aquatic plants which grow to the depth of 1 – 2 m;
- a zone of floating leaf plants – root plants which grow to the depth of 3 m;
- a zone of submerged flower or flowerless plants – root plants at the depth of 3–6 m.

The research objective is to show spatial changes in plant succession in the lakes located in the Wielkopolsko-Kujawskie Lakeland as an essential factor, which leads to the changes in the lake area and the gradual process of lake disappearance.

Research materials and methods

The analysed lakes are located in the Wielkopolsko-Kujawskie Lakeland, the region stretching between three rivers: the Oder, the Vistula, the Noteć and the limit of the maximum extent of the Weichselian glaciation (Fig. 1). The central and western parts of the study area are located in the River Oder watershed, while the eastern part belongs to the watershed of the River Vistula. This area is characterized by relatively small height differences. It has been considerably transformed by human activity for the last three centuries. The hydrographical network is poor, mainly due to smaller supply of precipitation. There are 1 347 lakes of a total area of 42 053.1 ha. The landscape is dominated by small lakes (1 154) of the area below 50 ha. There are also 98 lakes of the area of over 100 ha, and only 2 lakes of the area of over 1000 ha. The mean depth of all the lakes in the Wielkopolsko-Kujawskie Lakeland is 5.7 m.

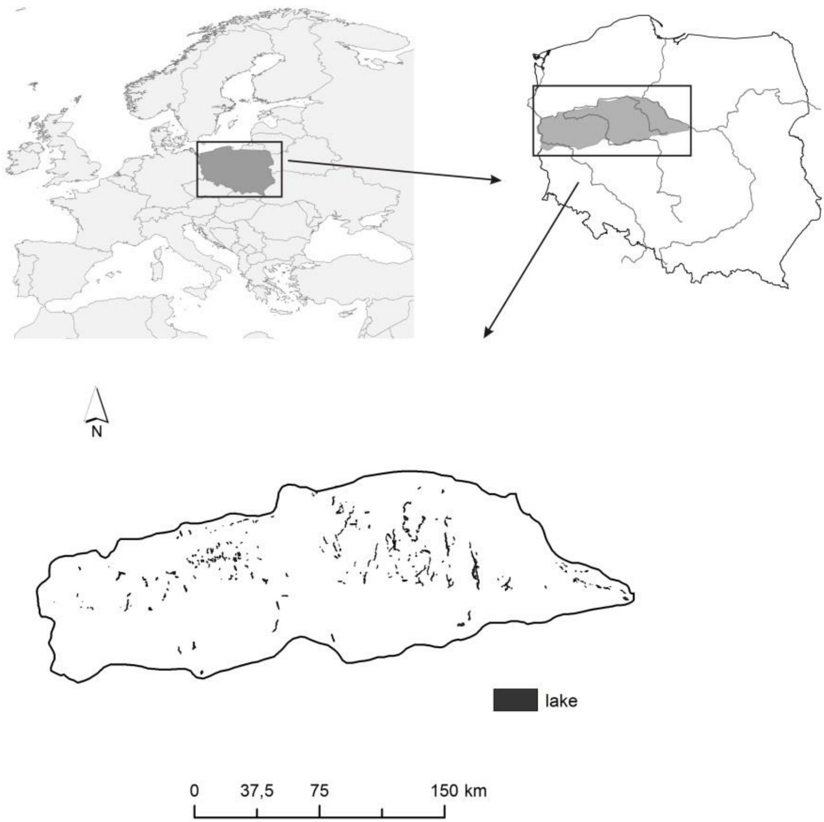

Figure 1. Location of the study area

Overgrowth changes were presented using two indicators. The first one is a plant overgrowth coefficient understood as a percentage share of the area covered by emerged plants in relation to the lake's total area. The other parameter is the shoreline overgrowth indicator, defined as the ratio of the area covered by emerged plants (excluding the area of islands) to the shoreline length, and expressed in ha/km.

The study was based on two types of data. The main source of data came from bathymetric plans from the mid-20th century made by the Inland Fisheries Institute in Olsztyn and the up-to-date aerial photographs in the form of an orthophotomap (2009–2011). The research involved digitizing all the data (for 256 lakes) concerning the lines of the lakeshores and islands, the extents of emerged plants, the areas of plant islands, and land plants and the lengths of the shorelines. The scale of the source material made it possible to determine the above mentioned parameters precisely, and to account for among others: single plant islands, breaks in the belt of reeds, water bridges, or concrete waterfronts. Digitization was carried out at a scale of 1: 1 500.

Another stage involved collecting the obtained information and developing a database in a tabular form. Owing to this, it was possible to carry out further calculations and analyses, and determine the basic statistical parameters.

Analysis of the material and discussion of the results

The analyzed area concerns the WielkopolskoKujawskie Lakeland which covers approximately 27 567 km^2. Postgalcial lakes of varied areas and depths are a characteristic feature of the landscape. According to Choiński (2006), there are 1 347 lakes of a total area of 42 053.1 ha. Small lakes of the area below 50 ha dominate in the landscape (there are 154 such lakes). There are 98 lakes of the area of over 100 ha, whereas only 2 lakes of the area of over 1000 ha (Lake Gopło and Lake Powidzkie). The mean depth of all the examined 490 lakes in the Wielkopolsko-Kujawskie Lakeland is merely 5.7 m. The deepest lakes are: Lake Ciecz, also known as Trześniowskie (58.8 m), Lake Powidzkie (46.0 m), and Lake Popielewskie (45.8 m).

The cartographic materials from the 1920s and 1980s prove that the areas of the lakes in the Wielkopolsko-Kujawskie Lakeland declined by 15.21 %, whereas by 9.6 in the Pomeranian Lakeland and

10.0% in the Masurian Lake District. Out of 539 lakes whose bathymetric plans had been studied, the areas of as many as 419 lakes declined. Furthermore, the areas of 110 lakes increased, and 10 lakes remained unchanged. Irrigation and drainage works carried out in the 19th century and regulations of river channels are regarded to have been the primary causes of these changes. That also had certain influence upon the levels of the lake water tables, lake depths and the extents of plant growth.

According to the Inland Fisheries Institute, the total area covered by emerged plants in 256 lakes of the analysed lakeland amounted to 2 661.5 ha, and 2 943.6 ha on the grounds of the orthophotomap, with the mean plant overgrowth indicator in the analysed lakes of 10.6 % and 12.3 % respectively. The measurements based on aerial photographs showed that the highest values were obtained for 6 lakes, and they were higher than 40 %, In the case of 36 lakes they were above 20%. They characterised most frequently small lakes of the area from 30 to 80 ha located in the southern and western part of the studied region (the Sławskie Lakeland, the Krzywińskie Lakeland and the Poznańskie Lakeland) (Tab. 1). On the other hand, the lowest values were recorded for the lakes of different areas and mean depth, rarely exceeding 3.5 m. For 27 lakes these values were below 5 % (Tab. 2). These lakes are mainly located in the northern part of the Laakeland (the Chodzieńskie Lakeland). The lakes of up to 500 ha are recorded to have their indicator of plant overgrowth most frequently higher than 10.0 %, though there is no relation to the depth of the lakes (Tab. 3).

The analysis of the degree of the plant overgrowth of the lakes and the lake's mean depth provided interesting data (Tab. 4). In the case of the shallowest lakes (with the meam depth to 2.5 m) the plant overgrowth indicator is 18.4 % on average, and it declines alongside the increase in depth. Whereas, in the deepest lakes (with the mean depth of over 10 m) this indicator reaches the values below 6.3 % on average.

In the process of plant overgrowth of the lakes, whose indicators decline alongside the increasing distance from the shore, the indicator of shoreline plant overgrowth seems to be important. The values show which water bodies are mostly influences by this process. Among those 256 analysed lakes the highest values are recorded for small lakes of various shapes and small mean depths (lakes: Żółwin, Trzebidzkie, Wonieść) and they amount to over 9.0. The lakes of varied areas and mean depth show values below 0.4 (Tab. 5).

Table 1

The highest indicators of plant overgrowth of the lakes (emerged plants) according to an orthophotomap and the Inland Fisheries Institute

Lake (numbers accordingto the Catalogue of Lake of Poland after Choiński 2006)	After orthophotomap		After Inland Fisheries Institute	
	ha	%	ha	%
Żółwin (III-29-45)	4.28	81.5	4.5	10.5
Trzebidzkie (III-50-2)	54.9	69.3	2.5	9.3
Brzeźno (III-20-35)	12.5	61.4	6.3	25.9
Małe (III-50-2)	18	56.8	5	28.5
Obrzańskie (III-49-7)	40.3	43.5	12.6	14.5
Świerczyńskie (III-56-10)	26.6	43.5	10.5	20.5
Wielkie (III-50-1)	24.6	39	5.6	10.8
Zapowiednik (III-55-34)	9.3	36.7	3.5	14.5
Wyszanowskie (III-29-37)	12.4	35.8	6.4	22.1
Wonieść (III-50-3)	99.9	35.5	12.5	10.3

Table 2

The lowest indicators of plant overgrowth of the lakes (emerged plants) according to an orthophotomap and the Inland Fisheries Institute

Lake (numbers accordingto the Catalogue of Lake of Poland after Choiński 2006)	After orthophotomap		After Inland Fisheries Institute	
	ha	%	ha	%
Psarskie (III-18-122)	0.1	0.6	4	10.3
without name (III-10-9)	0.2	0.9	0.6	18
Gosławskie (III-45-1)	5.9	1.2	20.2	5.3
Kubek (III-8-13)	1.5	2.2	5.4	7.8
Czarne (III-10-3)	0.8	3.1	3.2	11.6
Chojno (III-8-19)	1.4	3.2	5.8	10.3
Skrzynka (III-11-37)	0.9	3.3	0.9	3.2
Ciecz (III-28-38)	5.9	3.4	11	6
Długie (III-29-10)	3.2	3.5	14.9	15.6
Radziszewskie (III-8-21)	1.6	3.6	2	4.4

Table 3

Emerged plants in the area intervals of the analysed lakes on the grounds of various data

Surface (ha)	After orthophotomap		After Inland Fisheries Institute	
	ha	%	ha	%
0-25	90.6	13.8	125.0	13.8
25-50	311.9	13.3	317.3	10.4
50-100	567.8	19.7	402.7	16.0
100-250	746.8	10.3	680.4	9.4
250-500	566.7	10.1	438.8	8.1
500-1000	268.9	7.1	277.9	7.5
> 1000	225.0	7.0	413.5	10.4

Table 4

Changes in plant overgrowth (emerged plants) in the mean depth intervals of the analysed lakes on the grounds of various data

Mean depth, m	After Inland Fisheries Institute		Dane według ortofotomapy	
	ha	%	ha	%
0-2,5	608.4	14.3	816.3	18.4
2,5-5,0	1007.0	10.2	854.2	11.4
5,0-7,5	496.8	8.3	605.4	8.7
7,5-10,0	401.0	9.2	321.8	8.4
10,0-12,5	130.2	5.4	177.3	6.3
> 12,5	17.3	5.6	11.6	4.2

Table 5

Maximum and minimum indicators of the shoreline overgrowth ($ha \cdot km^{-1}$) in the Wielkopolsko-Kujawskie Lakeland

The highest values		The lowest values	
Lake (numbers according to the Catalogue of Lake of Poland after Choiński 2006)	Value	Lake (numbers according to the Catalogue of Lake of Poland after Choiński 2006)	Value
Żółwin (III-29-45)	39.96	Psarskie (III-18-122)	0.04
Trzebidzkie (III-50-3)	15.25	Łęgowskie (III-10-13)	0.14
Wonieść (III-50-4)	9.34	without name (III-10-9)	0.19
Małe (III-50-2)	7.20	Kubek (III-8-13)	0.21
Wielkie (III-50-1)	6.83	Czarne (III-10-3)	0.34
Brzeźno (III-20-35)	5.70	Bragant (III-18-80)	0.35
Świerczyńskie (III-56-10)	5.66	Zbyszewickie (III-3-18)	0.35
Obrzańskie (III-49-7)	5.04	Stołuń (III-17-22)	0.36
Dolskie Wielkie (III-51-19)	4.82	Pożarowskie (III-8-29)	0.37
Czeszewskie (III-4-2)	4.56	Skrzynka (III-11-37)	0.37

For over 50–60 years of the 20th century the total area of the lakes declined by 15.21 % in the Wielkopolsko-Kujawskie Lakeland. The disappearance of the lakes is rightfully associated with the declining level of the water table, growing sediment deposition within the lake basin and progressing eutrophication. These processes result in the progression of plants in the lakes, which is proven by the indicator of shoreline plant overgrowth ($ha \cdot km^{-1}$). The mean value of the indicator from the mid-20th century for the 256 analysed lakes amounts to 1.4 $ha \cdot km^{-1}$, whereas it reaches as much as 1.7 $ha \cdot km^{-1}$ at the turn of first and second decade of the 21st century (60 years of difference). This is clear evidence to the increasing plant overgrowth of the lakes regardless of the lake morphometry or types of plants.

Conclusions

The degree of plant overgrowth of the 256 lakes located in the Wielkopolsko-Kujawskie Lakeland (i.e. 9 % of their total number) amounted to 12.3% of their area and covered 3 145.6 ha.

These lakes constitute a representative group for the determination of the changes. The calculations and comparison of the most important parameters referring both to the lake basin and the degree of plant overgrowth made it possible to draw several conclusions:

- The analysed region constitutes the morphologically oldest area of the Weichselian glaciation, thus the lake basins are most developed (plant overgrowth and sediment deposition in the basins). Moreover, the entire area, which is mainly agricultural, has been influenced by anthropopressure (irrigation and drainage works and regulations of river channels).
- The changes in the progression of plants mainly involve the shoreline of the lake basin And is represented by the lake's plant overgrowth indicator and the shoreline overgrowth indicator.
- The mean indicator of plant overgrowth defined for 256 lakes on the grounds of the orthophotomap equals 12.3% and is higher by 1.7% with respect to the data obtained from the bathymetric plans. The minimum values below 4 % are characteristic of 13 lakes, whereas the maximum values are higher than 20% for 36 lakes.
- The mean indicator of plant overgrowth of the shoreline equals 1.7 $ha \cdot km^{1}$ for the analysed lakes, while the extreme values stayed with-

in the limits 0.04–40.0 ha·km^{-1}. This indicator showed increase from 1.4 to 1.7 ha·km^{-1} in the years 1960–2010.

- Alongside the progression of plants in the littoral zone plant islands or land islands are formed in the different parts of the lakes. Altogether, out of 256 analysed lakes 57 land lakes of the area of 129.4 ha and 72 islands of emerged plants of the total area of 211.3 ha were established.
- The analysis of the materials proved that the disappearance of the lakes located in the Wielkopolsko-Kujawskie Lakeland went at a varied pace This process mainly depends upon morphometric and climatic conditions and the management of the basins in particular lakes.

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Pawłowski B.

THE IMPACT OF THE WŁOCŁAWEK DAM AND RESERVOIR ON THE DURATION OF THE ICE PHENOMENA ON THE VISTULA RIVER IN TORUŃ

Key words: Vistula River, human impact, ice phenomena.

Reservoirs built on rivers have different functions: energy production, water supply for large cities, industry and agriculture, reduction of flood waves (and mitigation of the impacts of water scarcity), tourism and recreation as well as navigation. Construction of large reservoirs has important effects on the adjacent areas, their water conditions, flora and fauna, geomorphological processes, as well as climatic conditions. In terms of the reservoirs located in the temperate latitudes, there are also changes in the ice regime. Upstream of a barrages the duration of the ice cover increases, while downstream the shortening of the ice phenomena period is observed. The latter changes may be the result of flow variations as a result of the peak-load rhythm of the hydroelectric plant, interrupted continuity of the sediment transportation as well as changes in the thermal conditions of the waters below the barrage.

Toruń is located on the Lower Vistula, on the 734th kilometre of the river. According to Mikulski (1965), Toruń has the oldest existing water level records, dating back to the years 1760–1772. In 1898 the river gauge was mounted in the place where it sits today (Fig. 1). It has always been within the proper centre of the city (Pawłowski, 2009). The most important studies providing characteristics of the conditions and space-time diversity of the course of ice seasons on the Vistula River include works by Lambor (1959), Gołek (1964), Majewski (1987) and Grześ (1991). On the Lower Vistula River the ice cover is formed by the frontal progression of mobile forms of ice – so-called frazil pancakes (visible in Fig. 1). In the progression phase of the ice cover, there is also border ice, and in shallow parts of the riverbed, ice bars. The natural breakdown of the ice cover initiates the spring snow-melt high water, and may be accompanied by ice jams.

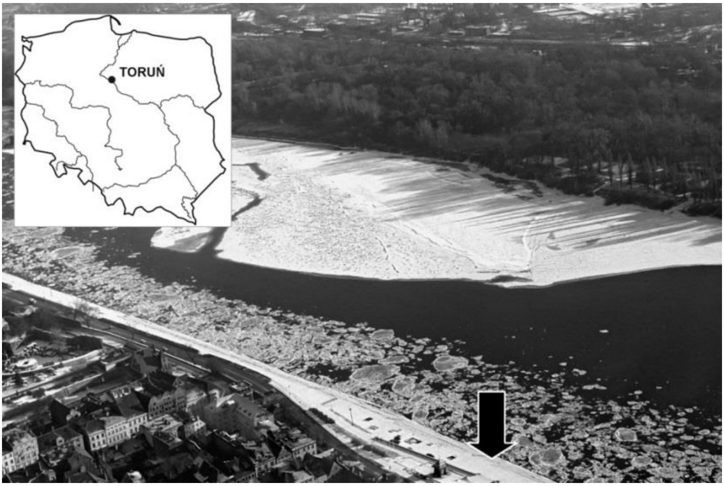

Fig. 1. The Vistula River in Toruń on 19th December 1996, with the location of the gauging station and the location of Toruń within Poland (insert). Photo by B. Pawłowski

From the nineteenth century there have been spectacular changes in the duration of ice phenomena and ice cover in Toruń [13]. The variability of the parameters' trends in the ice cycle of the Vistula River, as observed in Toruń, are typical of the rivers and lakes of the northern hemisphere [18, 6]). According to Magnuson et al. (2000), over the last 150 years the start date of the ice cover build-up for rivers (e.g. the Mackenzie and Angara) and lakes (e.g. Lake Suva) has been postponed by 5.8 days/100 years, on average, whereas the date of disappearance of ice phenomena has fallen 6.5 days/100 years earlier than previously. The main reason for this is the increase of the annual mean air temperature, estimated at 1.2 °C/100 years, on average, which is particularly apparent in the cold half-year. Changes in the start and dissapearance day of the ice cover in Toruń (13 and 9 days/100 years), however, are much greater than the above [13]. The ice regime of the Vistula River in Toruń has changed as a result of both natural processes (such as climate change) and anthropogenic processes. – one of the major was the construction of the Włocławek Dam and Reservoir. The first instance of human influence on the stretch of the Vistula River in Toruń that is significant in the history of ice phenomena was an attempt to control the river in the territory annexed by Prussia. The first works were begun in

1880, according to a design from 1879, and completed around 1892. A number of supplementary structures were also constructed, which were finished in 1907.

Construction of the Włocławek Dam and Reservoir

Since the 1970s, the Vistula River has been largely influenced by the Włocławek Dam and Reservoir. Of all the artificial reservoirs in Poland, Włocławek's has the largest area (7,040 ha) and the second largest capacity (387.2 million m^3). It is 59 km long and hass an average width of 1.2 km. As the largest hydroelectric power station in the country (with a capacity of 160.2 MW), it also provides power generation as well as retention and tourism functions. It does not play a significant role as a retention reservoir against flooding, and is the only existing part of the planned Lower Vistula River Cascade. The bed scour that has developed downstream of the dam presently reaches Toruń. Peak demand from the power plant triggers short-term variations in the water discharge; hourly fluctuations reach 160 km down the river [1]. Variations in the water level hinder the formation of ice cover and may lead to breakup of the ice cover and ice run (e.g. from border ice), resulting in downstream ice jams. Additionally, the areas adjacent to the upstream section of the reservoir are exposed to flooding due to ice jams (Grześ 1991). Both the reservoir and the dam hold most of the debris and suspended matter, as well as the ice flowing down the river. According to Lambor (1959), the suspended matter is a factor in the build-up of frazil ice, as it supplies nuclei for the crystallisation of ice formed in the river's currents, in the progression phase of the ice cover development. In Toruń it surely influences the flowing frazil ice that can be observed more rarely. On the stretches of the river below dams, the changes of the duration of ice phenomena are also a result of changes temperature of the water. For example, in the Ropa River in the Polish Carpathians, changes in the physicochemical properties of the water, were caused by the Klimkowka Reservoir. At a distance of 16 km below the dam, the average annual temperature of thewater in the river has decreased by 0.6 °C. In November and December the average temperature of water increased by 1.3 °C. The changes in the temperature of the water result in the reduction of most ice phenomena occurrence on the river and the time of their formation during the winter. On average, after the reservoir had started operations, the number of days when ice phenomena can be observed on the river below the reservoir decreased by 21 days [16].

Research materials and methods

The following definitions of the parameters were assumed in this work:

- Duration of ice cover (D_{IC}) – total number of days with the river covered by ice during a winter season;
- Duration of ice phenomena (D_{IP}) – total number of days with any form of ice on the river (border ice, frazil pancakes, ice cover, ice floe);
- Temperature of the winter season (T_{WS}) – average December-March air temperature.

This study uses data series for D_{IP} and D_{IC} for the Vistula River in Toruń, obtained mainly from the Institute of Meteorology and Water Management (*IMiGW*), for the period 1908 (after river's control work) – 2012. In the study period, the duration of ice phenomena decreased from the maximum of 136 days in 1909 to just 2 days in 2007, while ice cover decreased from 100 days (1964) to seasons without any ice cover.

Monthly air temperature data for Toruń, covering the period 1908-2005 [12], is also used. Data for 2006–2012 was supplemented with data from the Internet database available at <www.tutiempo.net>. In the present analysis, the mean temperature of the winter season (T_{WS}) was based on the four-month mean (December, January, February and March[1)]). Similarly, the duration of the ice cover of lakes was analysed by Marszelewski and Skowron (2006).

The aim of the study was to identify the contribution of the Włocławek Dam and Reservoir in changes to the ice regime of the Vistula River as it flows through Toruń, and determine their impact on the duration of D_{IP} and D_{IC}; at different T_{WS} values was also determined. The correlation between the ice cover duration (D_{IP} and D_{IC}) and T_{WS} was established.

The study was made for two periods of hydrodynamic conditions in the Vistula River: 1908-1969 (Period 1) and 1970–2012 (Period 2). It was assumed that for the same T_{WS} the course of ice phenomena should be similar. Differences in the ice phenomena and ice cover duration for the respective periods, with the same values of the T_{WS}, should be the result of influence of the Włocławek Dam and Reservoir.

Results

In each of the two periods, a different correlation between the duration of the ice phenomena with the T_{WS} was determined. These correlations are shown in Figure 2.

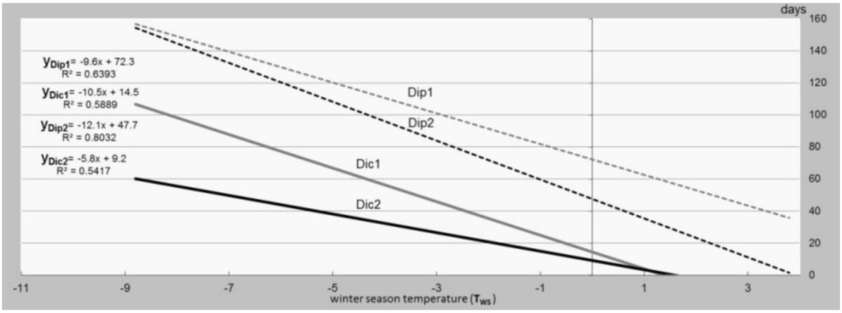

Fig. 2. Correlation between the winter season air temperature (T_{WS}) and the analysed parameters: D_{IP1}, D_{IC1} – 1908–1969, 1908–1969, D_{IP2}, , D_{IC2} - 1970–2012

In the following analysis, the duration of ice phenomena and ice cover calculated from the formulas given in Figure 3 were used. These were calculated for the value of the temperature T_{WS} = -2°C (cold winter seasons) and T_{WS} = 0°C (average current winter seasons) and summarised in Table 1.

Table 1

Duration of ice phenomena (D_{IP}) and ice cover (D_{IC}) on the Vistula River in Toruń

	Period 1 $_{1908\text{-}1969}$		Period 2 $_{1970\text{-}2012}$	
T_{WS}	-2°C	0°C	-2°C	0°C
D_{IP}	92	72	71	47
D_{IC}	36	15	21	9

The first analysed period (1908–1969) includes the controlled river, but before the construction of the Włocławek Dam. The mean TWS1 for this period was –0.9 °C. The DIP for the TWS = –2 °C was 92 days, and DIC – 36 days. The DIP for the TWS = 0 °C was 72 days, D_{IC} = 15 days (Fig. 2). Within 62 years, 23 winter seasons without ice cover were recorded in Toruń.

The second analysed period (1970-2012) covers the time from the construction of the Włocławek Reservoir (Dam) to the present (Fig. 2). The mean T_{WS2} in this period was close to 0.0°C. The D_{IP} of the T_{WS} = = –2 °C was 71 days, and D_{IC} = 21 days. The D_{IP} for the T_{WS} = 0°C was 47 days, D_{IC} = 9 days. Within 43 years, 33 winter seasons without ice cover were recorded in Toruń. The construction of the Włocławek Dam and Reservoir significantly reduced the number of days with frazil ice run. As already mentioned, this has to do with the retention in the reservoir of a large part of the suspension carried by the river. This type of influence of the reservoir on the ice cover is also visible in the river reach below Toruń. Similar changes of the D_{IP} after 1970 were also recorded by Gorączko (2013) in Fordon, over 40 km downstream of Toruń.

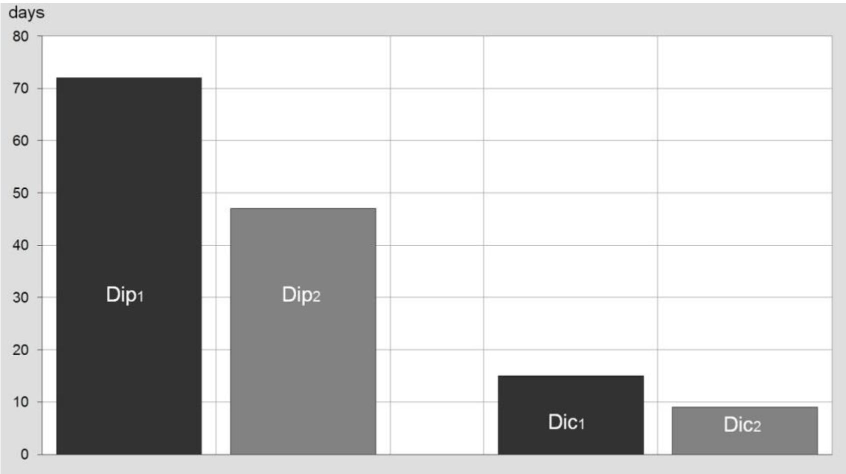

Fig. 3. Shortened duration of ice phenomena (D_{IP}) and ice cover (D_{IC}) in Toruń after the construction of the Włocławek Dam and Reservoir. The calculations were performed for the temperature value T_{WS} = 0.0 °C

The construction of the Włocławek Reservoir in 1970 resulted in further shortening of the duration of ice phenomena. D_{IP} in the cold winter seasons was shortened by 23 %, and in the winter seasons with average temperature conditions, by up to 35% compared to the baseline values at the end of the nineteenth century. After 1970, there was also a big change in D_{IC} – by 42% and 40% for cold and average T_{WS} conditions respectively.

Discussion

Icebreaking activity has been carried out on the Vistula River since the end of the nineteenth century. It begins at the river mouth, so that the ice floe can easily float to the sea [17]. As a result of icebreaking, the natural ice cover duration is reduced. Icebreaking operations were conducted on the Vistula River in Toruń on several occasions during the analysed period (for example, in March, 1996). The data on D_{IC} for these seasons were omitted when determining the correlation with T_{WS}.

The ice cover duration on the Vistula River in Toruń also depends on other factors not analysed here. Among these, the most important role belongs to the volatility of the contamination levels of the Vistula River's water, which increased during the analysed period. In terms of meteorological factors, the volume of the ice produced on the river is not only affected by air temperature, but also cloudiness. As shown by studies carried out in winter 2013, a smaller thickness and durability of ice cover are affected by snowfall occurring during theice cover progression phase [14]. The course of ice phenomena also depends on the intensity (velocity) of the river flow. Since the completion of the river control work, sandy shoals move along the riverbed at an average speed of several hundred meters per year. They cause frequent changes in the transverse shape of the river and greatly hinder water transport [1]. Shallow places in the riverbed (leading to ice bridges) can also initiate the progression of frontal ice cover. All of these un-analysed conditions have certainly influenced the reduction in the correlation coefficient values shown in Figure 2.

Much larger ice regime changes below the barrage than those observed in Toruń have been recorded on the Warta in Uniejów. Constructed in 1986, the Jeziorsko Reservoir (capacity 162 million m^3, surface area 39 km^2) and the barrage damming the Warta are located about 18 km upstream of Uniejów. After bringing the reservoir into the operation almost three-fold reduction in the duration of ice phenomena and two-fold reduction in the ice cover was recorded in Uniejów. Precise identification of the scope of the impact of the damming on the changes of the ice regime of the Warta in Uniejów would also require cosidering the temperature course of the winter season in the period before and after the damming. After the construction of the Rożnów-Czchów reservoir complex on the Dunajec, a significant shortening of the ice cover period was recorded downstream. In the region of Żabno (the distance from the reservoirs is similar to this between Włocławek and Toruń) the ice phenomena duration was shortened by 37 %, while the ice cover duration by 64 %. After the construction of the reservoirs, the number of cases of winters with the ice cover has decreased by almost a third. From October to February there is an increase of water temperature on the stretch of the river downstream of the reservoirs; the differences reach 2–3 °C. The length of the river stretch necessary to compensate for the water temperature change is over 80 km [2].

Conclusions

Changes in the structure, range and duration of ice cover have a significant economic impact, e.g. for the operation of hydraulic engineering infrastructure and navigation. In the event of changes in the ice regime of rivers and lakes, we usually have to deal with a significant proportion of the anthropogenic factor. Synergistic effects of natural factors and anthropopressure result in changes where it is difficult to identify the role of different elements in the transformation of the ice regime. The method used here allows the identification of changes resulting from the construction of the barrage and the reservoir upstream of Toruń.

The currently observed ice phenomena duration in Toruń is more a result of anthropogenic factors (changes due to river control and caused by the construction of the Włocławek Dam and Reservoir) than climate change. The following percentage shares in reducing the ice phenomena and ice cover duration in Toruń caused by the construction of the Włocławek Dam and Reservoir was recorded: shortened by 35 % for D_{IP} and 40 % for D_{IC}. The calculations were performed for the temperature value T_{WS} = 0,0 °C. Changes also included the frequency of occurrence of ice cover. Currently, ice cover in Toruń is formed if the average winter temperature is lower than –2 °C and its appearance is treated as an extraordinary phenomenon, especially by younger people in the Toruń Region.

For the currently observed correlations of ice phenomena (ice cover) duration and temperature to be stable, it is necessary to maintain the river's hydro-engineering structures in good condition. This is also a significant factor in the effectiveness of the city's icebreakers (at river depth). Currently, many are in need of renovation or complete reconstruction. In Toruń, in the years 2012–2013, such works were conducted in the area of the road bridge of Gen. Elżbieta Zawacka, and on several groins below the city centre. These works are also important for the maintenance of adequate parameters of the navigation route and protection against flooding (with the ability to conduct icebreaking action). Further changes in the course of the Vistula River's ice regime in Toruń will certainly be influenced by the possible construction of another dam of the Lower Vistula River Cascade. This investment is being planned for the section of the Vistula River between Włocławek and Toruń.

Notes

Initially, the analysis was performed using temperatures from only three months. Such winter season is defined as (from the names of the months) DJF (Kundzewicz and Huang 2010). However, for the ice phenomena in Toruń the DJF index resulted in lower values of correlation coefficients.

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TRANSFORMATIONS OF THE ELEMENTS OF THE WATER BALANCE DURING THE FIRST YEAR AFTER LOGGING IN THE TAIGA ZONE OF NORTHERN EUROPEAN RUSSIA

Methods for estimating the change in elements of the water balance in the first year after logging were suggested. The effect of the stand productivity and age on the amount of evaporation from the forest after logging was determined. It is demonstrated that the amount of evaporation depends on the age, growth conditions and productivity of the stand.

Key words: clear-cutting, evaporation, runoff.

The average forest cover in Northern European Russia (NER), which comprises the Archangelsk, Vologda and Murmansk Regions, Republic of Karelia and Komi Republic, is around 47%. Most of NER falls within the northern and middle taiga subzones. The prevalent type of vegetation is coniferous forests, with pine forests dominating in Karelia and the Murmansk Region, and spruce forests having the greatest share in the rest of the territory. Among the deciduous species of the region one can name birch and aspen. Given the high percent cover of forests a major economic activity in the territory in timber harvesting. The plant cover in logged sites undergoes fundamental transformations, which bring about substantial changes in radiation, thermophysical and hydrological processes. The clear-cutting technology in flatland forests of European Russia implies that the tree stand is removed completely from an area of up to 50 ha in one effort within a short time period [6]. Such logging substantially transforms the coenosis in the site, and modifies the conditions for the formation of elements of the water balance.

The lowest total evaporation and the highest runoff from the site are usually observed in the first year after logging, and because of the scope of the consequences it is so important to estimate changes in the annual values of these elements of the water balance. Furthermore, these estimates are the starting points for the dynamics of water balance elements over long-term transformations of the geocomplex.

The hydrological role of forests depends on the site conditions, stand productivity and plant species diversity. The main controls of annual evaporation and runoff in the forest are the vitality and species diversity of the ground cover, the species composition of the tree stand, its age, growth (site) conditions, and productivity.

The qualitative characteristic of the forest growth conditions (site conditions) responsible for the stand productivity and standing stock is the quality class. There are five major quality classes (I, II, III, IV, V), two additional classes (Ia, Va), and on some occasions classes Ic, Ib, Vb, Vc can also be distinguished. Quality classes Ic, Ib, Ia, I, II denote forest biogeocoenoses of the highest productivity, and classes V, Va, Vb, Vc – of the lowest productivity. The quality classes are determined using the summary tables of relationship between stand height and age.

In this paper we suggest a method for estimating the change in annual evaporation and runoff immediately after logging. The effect of forest characteristics on post-impact changes in elements of the water balance is demonstrated.

The change of evaporation over the year is estimated as the difference between evaporation from the felled site (E_{cl}) and evaporation from the forest prior to the impact (E_f):

$$dE = E_{cl} - E_f. \tag{1}$$

Evaporation from forest is determined using conventional formula as the sum of three components [4, 8]:

$$E_f = E_t + E_i + E_s, \tag{2}$$

where E_t is transpiration by the stand, mm; E_i – intercept evaporation, mm; E_s – evaporation from the ground cover, mm.

We suggest that evaporation from the felled site itself is determined using the equation:

$$E_{cl} = k_s E_s, \tag{3}$$

where k_s is the coefficient of transition from evaporation under forest canopy to evaporation from the felled site.

After substituting (2) & (3) into (1) and performing some simple conversions we get the equation for estimating the post-impact change in evaporation in the following form:

$$dE = E_s (k_s - 1) - (E_t + E_i). \tag{4}$$

The equation for estimating the change in annual runoff was obtained as the difference between the water balance equations applied to runoff after and before the impact, with the meteorological conditions averaged over a long-term period. After the necessary conversions it will take the following form:

$$dY = Y_{cl} - Y_f = (P_{cl} - P_f) - [E_s (k_s - 1) - (E_t + E_i)] + dY_{clf}, \tag{5}$$

where Y_{cl} and Y_f are runoff from the felled site and from the same site prior to the impact, respectively, mm; P_{cl} and P_f – precipitation in the forest site after and before the impact, respectively, mm; dY_{clf} – change in runoff due to disturbance of the soil hydrophysical properties by logging machines.

Equation (5) provides for determination of the post-felling change in runoff over a specific year for which data of observations over precipitation and moisture stores in the soil in the forest site are available for the period before and after the impact.

When computing multi-annual average change in runoff one can ignore the effect of logging and fires on precipitation in limited localities and set the increment in moisture stores at zero. In this case equation (5) will take the form

$$dY = - [E_s (k_s - 1) - (E_t + E_i)] / \tag{6}$$

Annual transpiration by the stand is determined by the equation [4]:

$$E_t = k_{tr}\, m, \tag{7}$$

where m is the foliage raw weight, t/ha; k_{tr} – transpiration coefficient, which is 19, 8.5 and 35 mm/t for pine, spruce and birch, respectively [2].

The foliage weight is computed from the formula [5] in formalized form [2]:

$$m = M\, K\, c\, \exp(-f\, h), \tag{8}$$

where M is the stemwood stock, m^3/ha; h –mean height of the tree stand, m; K – index describing the share of foliage in the total tree green stock (small branches, twigs and foliage), which was 0.78 for pine, 0.60 for spruce, 0.56 for birch; c, f – regression coefficients, which were 0.29, 0.10 for pine; 0.81, 0.099 for spruce, and 0.30, 0.083 for birch.

Evaporation from the ground cover under forest canopy was calculated by the empirical formula [3]:

$$E_s = 0{,}8\ E_0 \exp(-0{,}3\ LAI), \tag{9}$$

where E_0 is evaporability estimated according to Budyko-Zubenok [7], mm; LAI – leaf area index, ha/ha.

Where measurements are missing, the leaf area index is determined from the ratio [3]:

$$LAI = k_l\ m, \tag{10}$$

where k_l is the coefficient of transition, which is 0.35 ha/t for pine, 0.28 for spruce, and 0.62 for birch [1].

Annual evaporation from the canopy is calculated as:

$$E_i = E_{il} + E_{iws} + E_{ia}, \tag{11}$$

where E_{il} is evaporation of rainfall intercepted by the crowns in the warm season, mm; E_{iws} – evaporation of snow from the canopy, mm; E_{ia} – evaporation from the canopy during the transitional period, when liquid and solid precipitation is equiprobable, mm.

Total rainfall evaporation from crowns during the warm season is estimated using formula the [3]:

$$E_{il} = k_{Ei}\ P_{il} \ln(m + 1), \tag{12}$$

where P_{il} is the amount of rainfall over the calculation period, mm; k_{Ei} – coefficient equaling 0.105, 0.100 and 0.108 for pine, spruce and birch stand, respectively.

When crowns are covered in snow, i.e. for most of the winter season in the boreal zone, evaporation from the coniferous forest canopy is estimated by the formula [3]:

$$E_{iws} = 0{,}065\ d\ LAI\ n, \tag{13}$$

where d is air humidity deficit, gPa/day; n – duration of the calculation period, days.

Evaporation from coniferous and deciduous forest during the transitional period is estimated by the formula suggested by Krestovsky [4]:

$$E_{ia} = a\ m\ P_{ia}, \tag{14}$$

where a is the index equaling 0.01; P_{ia} – precipitation over the transitional period, mm;

The coefficient of transition from evaporation under forest canopy to evaporation from the felled site (k_s) is determined using observed data on evaporation under forest canopy and in open sites. The coefficient depends on the leaf area index, as illustrated by the graph in Fig. 1.

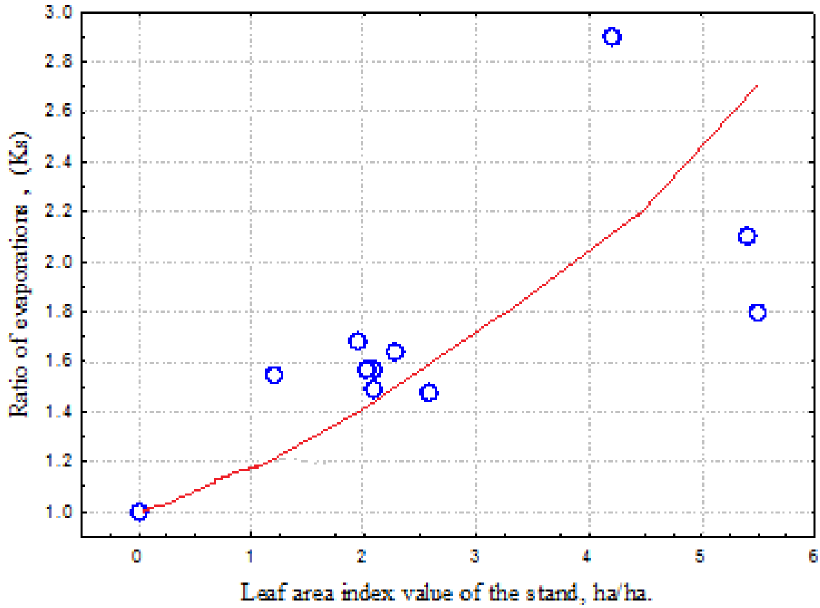

Fig. 1. Dependence of the relationship between evaporation from an open site and under forest canopy on the leaf area index value of the stand

The graph shows how coefficient k_s increased along with growing leaf area index. The scattering of points in Fig. 1 is largely indicative of the accuracy of determinations of the leaf area index and the ratio of evaporations.

The foliage (needles), which is removed through logging, is responsible for transpiration and intercept evaporation from the forest canopy, which in most cases account for 65–85 % of total evaporation. The same components of total evaporation from forest constitute a substantial part of measured evaporation – hence the correlation between total evaporation from forest and its change after removal of the tree stand (Fig. 2).

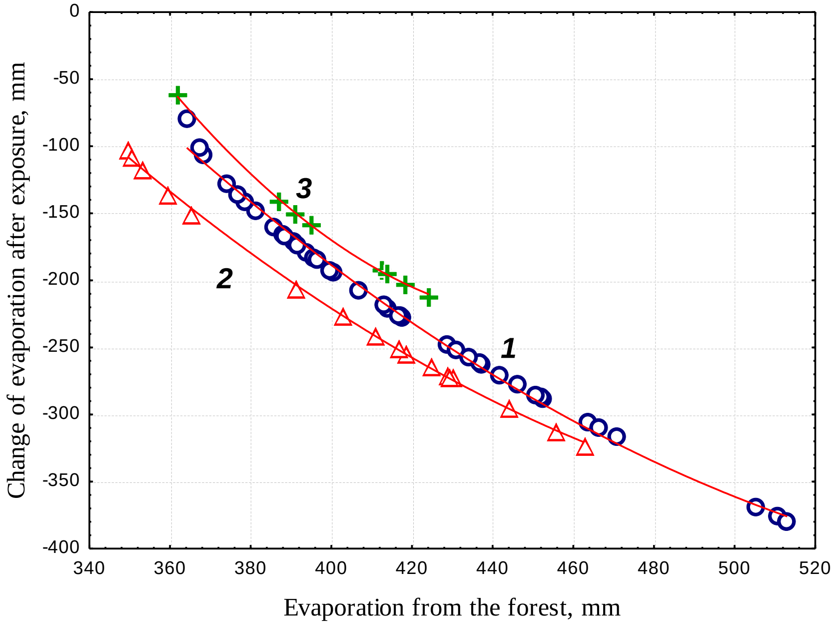

Fig. 2. Relationship between change in evaporation and evaporation from the forest before the impact (*1* – pine forest, *2* – spruce forest, *3* – birch forest)

The relationships shown in Fig. 2 were plotted for single-species tree stands, that is why the correlations are so close.

The presence of such a relationship suggests that the forest productivity has influence on changes in evaporation after stand removal.

Usually, logging removes mature stock, but since there exist other ways of clearing a forest site of trees (forest fires, pests), we also considered the effect of the forest age on changes in evaporation.

The effects of the stand productivity and age are shown in Fig. 3.

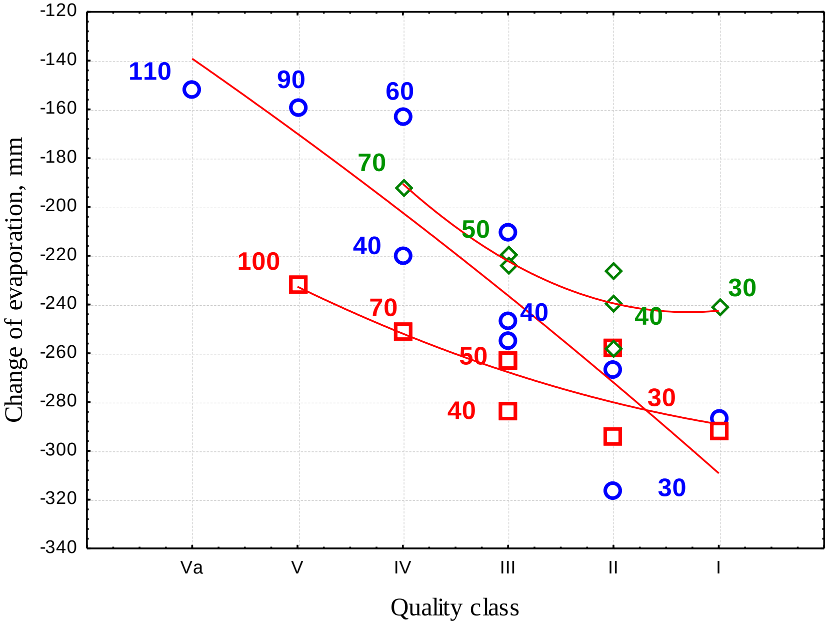

Fig. 3. Maximum post-impact changes in evaporation in forests differing in productivity and site conditions (numbers are the age of the stand)

This graph further confirms that the maximum change in evaporation in different forests after the impact is greater in sites with better conditions for tree growth. Furthermore, the age at which changes in evaporation are the greatest decreases as the stand productivity increases (Fig. 3). This happens because the age at which total evaporation is maximal is lower in higher productivity stands [3]. Forest growing in better conditions will reach peak biomass and its increment earlier, since its moisture consumption is maximal at an age of 30-50 years. Poorer site conditions slow down growth, wherefore evaporation from low-productivity forests will keep growing until 100 – 120 years. Another factor for a high evaporation from young mixed coniferous stands is a significant contribution of birch and aspen, which grow faster than pine and spruce.

The data in Fig. 3 can be regarded as potential dimensions of post-logging change in evaporation for the age series of single-species stands of the same quality class.

Post-impact changes in evaporation much depend on the forest age. Fig. 4 shows the age-related variation of change in evaporation after stand removal in Karelian forests of average productivity. The valuation characteristics for the calculations were taken from the growth tables produced by the Forest Research Institute of the Karelian Research Centre for the forest types common in Karelia.

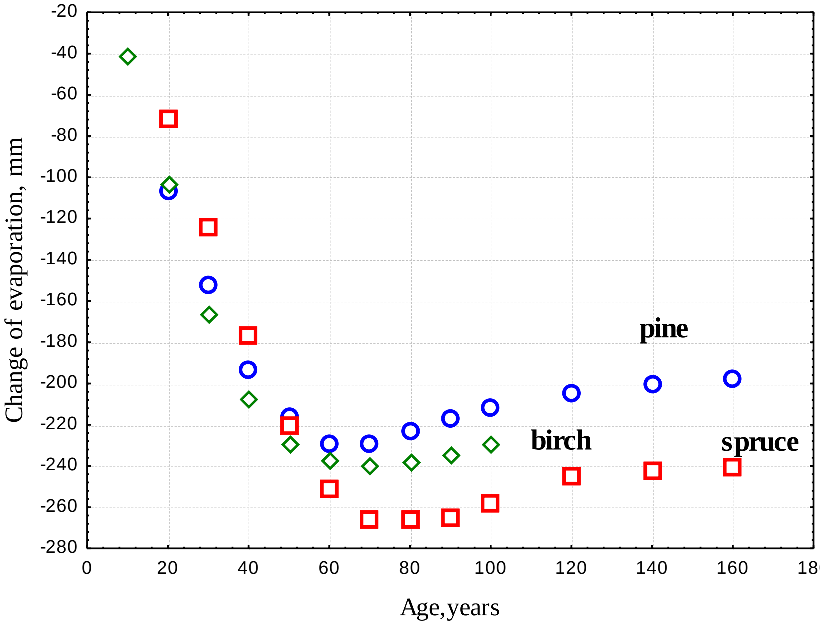

Fig. 4. Post-impact changes in evaporation in pine, spruce and birch stands of different age

Evaporation changes least significantly in young stands. The scope of change in evaporation in stands of quality classes III.5 – IV.5 keeps growing until an age of 70-80 years. In more productive forests the parameter does not grow since an age of 30 – 50 years, whereas in low-productivity forests it would keep growing until 100 years or more.

Thus, application of the method for estimating the change in elements of the water balance in the first year after tree stand removal revealed the effect of the stand productivity and age on the scope of change in evaporation from forest after clear-cutting.

The main factor for increased runoff from a felled site in the first year after the impact is reduced evaporation.

The scope of decrease in evaporation was found to depend on the age, site conditions, and stand productivity. Evaporation from young low-productivity forests in the boreal zone of Northern European Russia in the first year after stand removal decreased by 30 - 50 mm. In older and more productive forests the reduction in evaporation from a forest site after the impact may reach 300 mm.

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Doganovsky A.M., Davydenko E.V.

ESTIMATION OF THE STATISTICAL PARAMETERS OF UNEXPLORED LAKES IN NORTHWEST RUSSIAN FEDERETION

Lakes are worldwide distributed water bodies with slow water exchange. They are commonly used in economic purposes. Lake systems (including the lake itself as well as its catchment) can have quite different size, water capacity, shape of the lake bed and effluent streams, ratio of areas of the lake surface and its basin, etc.

All the mentioned parameters determine the lake water exchange structure and its level regime.

Coefficient of external water exchange K_w can be determined in volume units (km^3) from the equation of water balance:

$$V_{infl} + V_{atm} - V_{evap} - V_{runoff} = \pm \Delta V_{acc}\,, \qquad (1)$$

where V_{infl} is inflow of water from drainage areas; V_{atm} are atmospheric precipitations to the lake water surface; V_{evap} is evaporation from the lake surface; V_{runoff} is runoff of lake water, and V_{acc} is retention of water in the lake.

When $\Delta V_{acc} = 0$, the balance becomes equilibrated. Coefficient K_w is determined as ratio of the total precipitation or evaporation components to the volume of water in the lake (V_0). However usually, for internal water body processes the water exchange coefficients are calculated as yearly inflow or runoff quantities divided by volume of water V_0 in the lake.

$$K'_w = V_{inflow} / V_0 \text{ and } K''_w = V_{runoff} / V_0\,. \qquad (2)$$

There are more than 100 thousand lakes on the investigated area, however 98 % of them have the area less than 5 square kilometers.

A lot of lakes were not investigated. There are neither hydrometric data not determinations of volumes of their water masses. therefore, we receive data on volumes of water by using relationship $V_0 = f\ (A_0)$, where A_0 is the lake surface area. Parameters V_{inflow} and V_{runoff} are calculated by methods well-known in hydrology.

In our case it is supposed that basins of the same origin and similar periods of evolution should have comparatine dimensions. For example, basins with the same A_0, but tectonic origin are deeper than glacial ones [2]. In total, on the considered territory was studied more than 70 explored objects with areas more than 5 km^2 and the dependences were plotted (fig. 1)

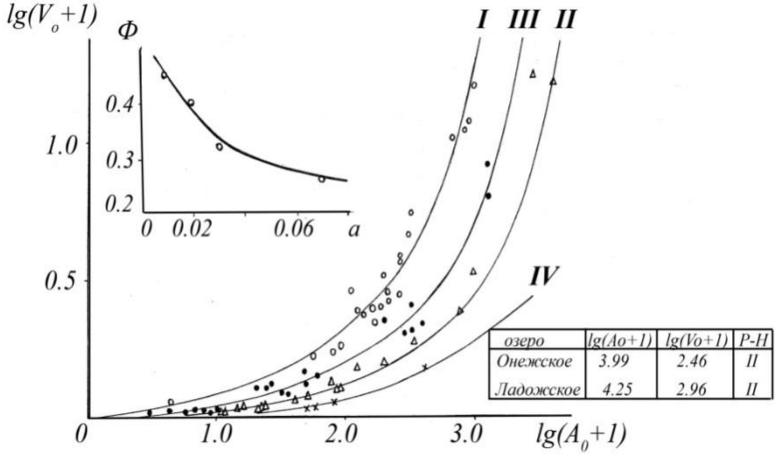

Fig. 1: The dependences of volume of water in the lake from its area

Analysis of all received data permitted us to determine four regions. Each of them characterized with their own close dependence $V_0 = f(A_0)$, presented by equation

$$Y = ax^m e^{x-1}, \qquad (3)$$

where $y = \lg (V_0 + 1)$, $x = \lg (A_0 + 1)$, a and m are empirical parameters depending on the geomorphologic and geologic peculiarities of the regions.

The lakes from the west Karelia and from greater part of Kola Peninsula with location on the height 100 m and more are referred to the first region (I).

The second region (II) stretches by narrow stripe along the main moraine belt being zone of maximum glacial retention.

The lakes from the east Karelia, Kola Peninsula with heights of location less than 100 m are referred to the third region (III).

The fourth region (IV) is situated to South-East and is limited by boundary line of Moscow glaciation, i.e. before Smolensk-Moscow upland.

These regions are characterized by their own shapes of river channel that were typified according to dependence of their average yearly water discharge in riverheads (*Q*) on the levels of lakes (*H*). Data from 20 sites were analyzed for this task.

In this work we are developing computational schemes for determine the parameters of the distribution curves of lake levels for unexplored reservoirs on morphometric characteristics of lakes.

To solve this problem we choose 30 different types of lakes from different regions with the longest series of observations (Table 1). All these lakes have been treated, tested for homogeneity and calculate their statistical parameters.

These reservoirs differ series structure and statistical parameters. The main reason for these changes is the intensity of external water exchange ($К_В$), which is expressed as:

$$К_{в} = \left(V_{пр} + V_{ос}\right)/V_{о} \qquad (4)$$

where $V_{пр}$ is inflows into the lake; $V_{ос}$ is volume of precipitation in the lake; $V_{о}$ is volume of the lake.

$К_В$ values vary widely and depend on the geographic location of the system, i.e. the degree of hydration territory on the value of specific sizes and catchment basin [1].

The essence of water exchange (how often changes in lake water) is a very important parameter for the determination of many regime characteristics , such as the nature of fluctuations in the level (r(1)) , the nutritional status of the pond elevation standing level.

Lake systems for different climatic zones and in a changing climate "contribution" of each of the components is different and is associated with the process autocorrelation [*r*(1)], and autocorrelation, in turn, is determined largely by the value of control:

$$r(1) = 1 - \frac{К_{в}}{\varphi}, \qquad (5)$$

where φ is a parameter depending on the structural features of the basin (F) and channel flowing river (the ratio of the average depth to the maximum).

Equation (5) shows us that the autocorrelation coefficient depends on the water exchange rate.

Water exchange coefficient characterizes the climatic factors that affect the autocorrelation coefficient and the parameter φ characterizes the factors of underlying surface. First, we wanted to determine which parameters depend φ. In a first approximation, we wanted to see how dependent on φ of the relative depth of the pond. Index of the relative depth of the pond allows any attribute to a class, the depth that gives an idea about the nature of his regime.

To do this, first the coefficients have been calculated and then the water exchange rate, equation (5) was solved for the autocorrelation parameter φ to determine the factors of the underlying surface value of influencing r (1). And we got the schedule of dependence the parameter φ from the form factor of the basin (Fig. 2).

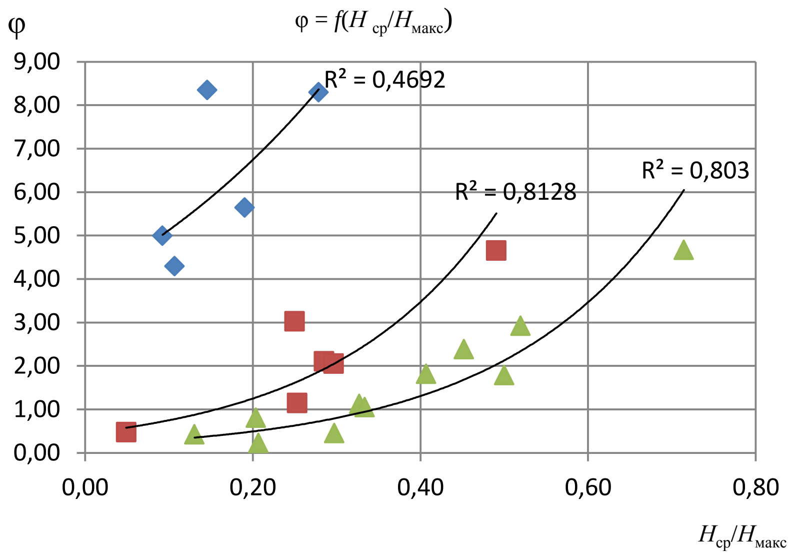

Fig. 2: The schedule of dependence the parameter φ from the form factor of the basin

On the basis of these relationships, we can conclude, that having information about the depth of the lake and water exchange ratio, we can calculate the first autocorrelation coefficient.

Conclusion

The development of new more reliable methods for the calculation of regime characteristics with Kw' as the argument is a problem of the first order. Also it is necessary to have more perfect procedures for the calculation of this parameter for unexplored objects and estimation of its behaviour over time.

Table 1

List of lakes from different regions with the longest series of observations

Names of lakes	Water surface area, km^2	Vol-ume, km^3	Catch-ment area, km^2	Overflow stream, km^3	H max	H av	H av/H max	Kex
Gimolskoe	80,5	0,2576	2665	0,862572	30	3,20	0,11	3,35
Vodlozero	322	0,9982	5280	1,745601	16,3	3,10	0,19	1,75
Kubenskoe	648	1,296	14700	4,334213	13	1,20	0,09	3,34
Tulmozero	12,22	0,083096	830	0,316848	24,4	6,80	0,28	3,81
Suoyarvi	58,5	0,203	2120	0,769	24	3,5	0,15	3,76
Verchnee Kuyto	198	1,7226	7390	2,610685	33	9,40	0,28	1,52
Syabero	14,2	0,03124	39,7	0,012643	45	2,20	0,05	0,40
Chereme-neckoe	15	0,12	496	0,127835	27	8,00	0,30	1,07
Sumozero	73,9	0,370	1630	0,514	20	5	0,25	1,39
Pyalozero	17,46	0,045	328	0,103	5,3	2,6	0,49	2,28
Leksozero	163,9	1,410	3504	1,293	34	8,6	0,25	0,92
Sandal	152	1,824	993	0,313	58	12	0,21	0,17
Pertozero	12,84	0,141	165	0,052	37	11	0,30	0,37
Kroshnozero	8,9	0,05073	193	0,075351	17,2	7,00	0,41	1,49
Kupeckoe	11,3	0,060	444	0,140	10,2	5,30	0,52	2,34
Vedlozero	59,6	0,447	619	0,247659	15	7,50	0,50	0,55
Yanisyarvi	200	2,4	3660	1,316639	57	11,60	0,20	0,55
Umbozero	313	4,695	2380	1,548064	115	15,00	0,13	0,33
Kavgo-lovskoe	5	0,0125	20,7	0,007578	3,5	2,50	0,71	0,61
Glubokoe	37,9	0,18082	213	0,076836	37,9	12,40	0,33	0,42
Krasnoe	9,13	0,060	168	0,053	14,6	6,6	0,45	0,88
Lismozero	84,8	0,339	620	0,196	12	4	0,33	0,58

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Ugreninov G.N., Kostyuk A.N.

THE DESIGN OF THE DISCHARGE IN THE TIME OF ICE PERIOD

An account of the design procedure of the discharge in the time of ice period with use of K.V. Grishanin´s invariant.

Key words: water level, discharge, ice, invariant, function, trend, error.

One of the objectives of the Federal Target Program "Development of water sector of the Russian Federation in 2012–2020" - development of the Hydromet provide prognostic information about the daily discharge of water is not less than 80 % of the core network of hydrological stations observations. Thus the information about the daily expenses must come from the posts online.

In principle, the daily discharge of water can be determined in real time using sonar flowmeters and other modern technology, such as inductive current meter. But due to weak domestic equipment hydrological stations such equipment and the lack of qualified observers, there is a need to develop methods of operative definition of daily water discharge for standard information on water levels and ice diving depth, involving information on the costs of water, measured over the last winter and this winter season.

Mathematical models of streamflow gauging records at freeze and ice phenomena offered I.F. Karasev [3], but their operational use at Roshydromet network requires additional information, in particular on the slopes of the water surface, whereas such data in most cases are not available.

One possible way of calculating the daily operational discharges of water is to use known invariants in hydrology, such as T.V. Vekshina [1] taking into account the runoff period overgrowing channels used invariant M.A. Velykanova.

The proposed methodology is based on an approximate invariance of the parameter M- dimensionless hydraulic radius K.V. Grishanina [2]:

$$\mathrm{M} = \frac{R \cdot (g\chi)^{0.25}}{(Q)^{0.5}}, \tag{1}$$

where R is hydraulic radius, m; is the length of the wetted perimeter, m; Q is a water discharge, m^3 / s; g is the acceleration of gravity, m/s^2.

Invariance of the parameter M was set by K.V. Grishanin theoretically and tested in practice in relation to rivers with sustainable riverbed and fine-grained sediments. These conditions are generally observed under the ice on the plains of rivers. In developing the methodology of operational definition of daily winter water discharge without requiring measurement of flow rates under the ice, were closed the following winter conditions:

– Ice is full and single-layer;

– No ice dams during freezing conditions;

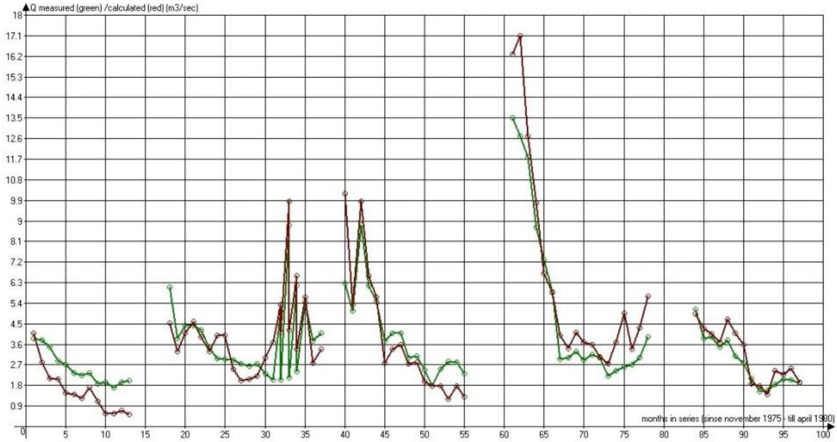
– No ice bridge (across the width of the river ice is immersed in water);

– The water does not flow over the ice.

Accepted conditions to some extent idealized winter condition of the river, especially in the initial period of freezing.

Analysis of winter water discharge measured in rivers Leningrad, Arkhangelsk and Murmansk regions and the Republic of Komi, indicates the presence of a trend parameter M during the winter season as changes in ice thickness and roughness of the bottom surface. This trend is described by the function $M = f(T)$, where T is the duration of the period from the start date of freeze-up (t_o) to the estimated date of determination of the winter flow (t). Dependence $M = f(T)$ is set according to the measured flow rates over the past winter, preferably at least three winter seasons. It is possible that the measured discharges in this winter season will point to the need for clarification of the $M = f(T)$, by supplementing the initial information with new information. Depending on $M = f(T)$ the value of parameter M is determined on rated date t (M_t).

In the case when taken the methodology conditions of the ice regime of lowland rivers, the variation of M during the winter season low. If the information on the costs of water are essential, and any regular measurements are not possible, then in the first season of winter observations on the river, mindful of the quasi-invariance of magnitude M, is allowed only during the winter restrict flow measurement and observations of the standard level and ice thickness. According to a measured flow of water is determined value of M_t where t – the date of the flow measurement. Trend $M = f(T)$ can be estimated by calendar interpolation, assuming that the rate of M during the winter reduced on average by $\Delta M \approx 0{,}1\overline{M}$



Picture 1. Curves of measured water discharges during the winter period (green) are well correlated with calculated (red) winter water discharges for the same period

The ratio error of the proposed method, the results calculated by checking calculations about 1000, is δ = 0,07–0,12 (Picture 1). The lowest ratio errors obtained when determining the costs of the rivers during the winter with average water discharge order $Q_{\text{winter}} \geq 50$ m³/sec. The worst results were obtained applying the proposed methodology in determining the water flow of the small rivers with complex conditions and the presence of frost retaining all sorts of phenomena.

The resulting estimate of the Ratio error indicates acceptable in most cases the informational content of the proposed methodology. However, when preparing the annual data from the State Water Cadastre daily expenses, calculated by the proposed method, are subject to change by using the results of all measurements winter expenses per calendar year.

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Kolosova L.

MODELING OF POLLUTANT SPREADING IN WATERCOURSES

One of the areas of application of mathematical models is solving hydroecological tasks. In evaluation of pollutant concentrations most widely used transport models based on the Saint-Venant equations and the equation of turbulent diffusion.In this work the solution of the plane and the spacialtasks of pollutant spreading with the A. V. Karaushev method by using the program MATLAB was reviewed.

Key words: Pollutant spreading, equation of turbulent diffusion, hydroecological tasks, mathematical models.

Mathematical models are widely used in hydrology for various tasks. One of the areas of mathematical models application is solving tasks at the intersection of the two disciplines – hydrology and ecology. Hydroecological tasks can be divided into three classes: evaluation of the current condition, prediction and management of process.

The first task is to determine the spatial and temporal changes in the concentration of pollutants in water bodies. It is possible to rate this either by direct measurement of the concentration or by model calculations.

The second task is to give a forecast of possible values for some future time according to the availability of information on current concentrations.

Finally, the third task solution allows you to control pollution process, for example, by adjusting the amounts of pollutants.

Results of modeling find their application in regulation of emissions, wastewater dilution calculations. The aim of the work is to consider the various mathematical models that can be used in hydroecology to solve prognostic problems.

Currently, there are four main types of mathematical models: *transport*, *geomigratory*, *thermodynamic* and *kinetic*. In practice, in evaluation of pollutant concentrations most widely used transport models based on the Saint-Venant equations and the equation of turbulent diffusion (equation 1).

$$\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} + v_y \frac{\partial C}{\partial y} + v_z \frac{\partial C}{\partial z} =$$
$$= D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial z^2} + \frac{\partial^2 C}{\partial z^2}\right) - f(C), \quad (1)$$

where C is a concentration of pollutant, g/m^3; t is time, s; v_x, v_y, v_z are velocity components (*m/s*) in the coordinates *x*, *y*, *z* (*m*); D is a turbulent diffusion coefficient, m^2/s.

Depending on the nature and characteristics of the flow equation (1) can be written with different simplifications [1].

Total estimated algorithm includes the following:

- Denote the place of wastewater emission and accordingly locate the hydrometric section; downstream flow divides into the estimated units.
- Wastewater velocity is taken equal to the average velocity of the flow.
- Calculate the cross-section area of inflow.
- Select step of the grid and calculate the area between units.
- Calculate the turbulent diffusion coefficient.
- Calculate the distance between the estimated sections.
- Calculate the concentration of the pollutant by finite difference scheme.

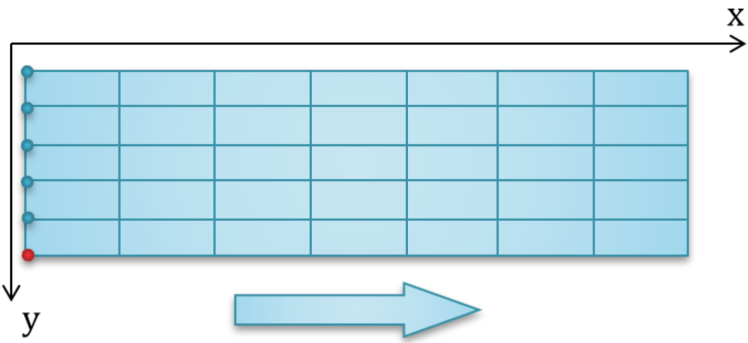
This algorithm is similar for 2-D and 3-dimensional tasks, except the calculation of the area for plane task, because in this case the flow changes only in two coordinates.

Modeling of pollutant spreading was implemented in program MATLAB. The input parameters: width B, height H, length L, velocity V, discharge Qe, discharge of pollutants Qst, concentration of the pollutants Ce, Cst, Chezy coefficient C, location of emissions.

2-D and task

We considered stationary in time process with no transverse flows.The estimated area of the flow is the plot, where river Tosna flows into the Neva river. Tosna represents the pollutant inflow, and concentration of the river Tosna pollutant is much more than the concentration in Neva river.

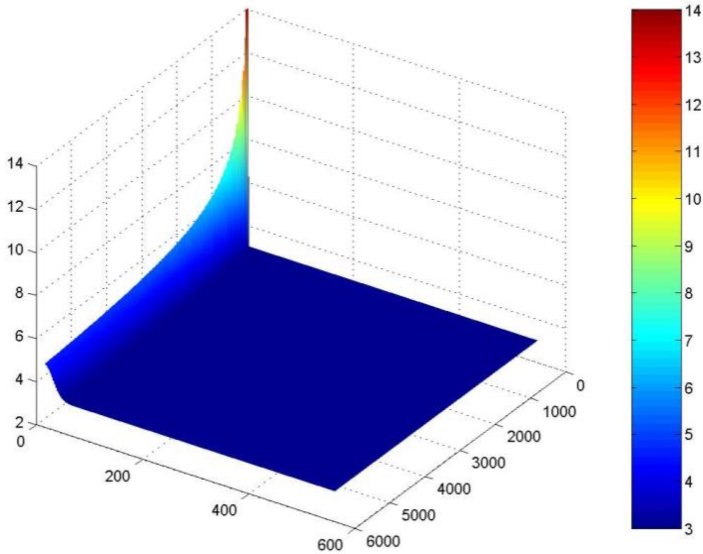
This area presented as the rectangle divided into estimated units (picture 1).



Picture 1. Estimated area of the flow (for the plane task)

We set the initial and the boundary conditions, and using the equation 2 [2, p. 36] can see the pollutant spreading in the Neva river, changing on the surface layer of the flow (picture 2).

$$C_{x+1,y} = \frac{1}{2}\left(C_{x,y-1} + C_{x,y+1}\right). \tag{2}$$



Picture 2. Results of solving of the plane task on the Neva river
(color shows the rate of the concentration)

3-dimensional task

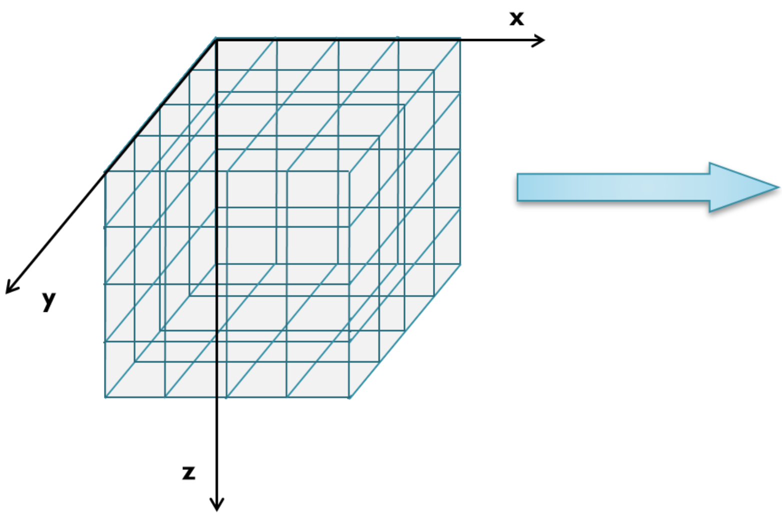
We considered a spatial task with small transverse flow velocities and stationary time process. In this case, the diffusion equation is a second order differential equation in partial derivatives (equation 3).

$$\frac{\partial C}{\partial x} = \frac{D}{v}\left(\frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right). \tag{3}$$

The initial conditions are defined by the concentration of pollutants in width and depth of the initial cross-section. The boundary conditions are given by the concentration on the faces of restricting flow (surface, bottom, side faces). Solution of the equation was performed by finite difference method (equation 4) [2, p. 35].

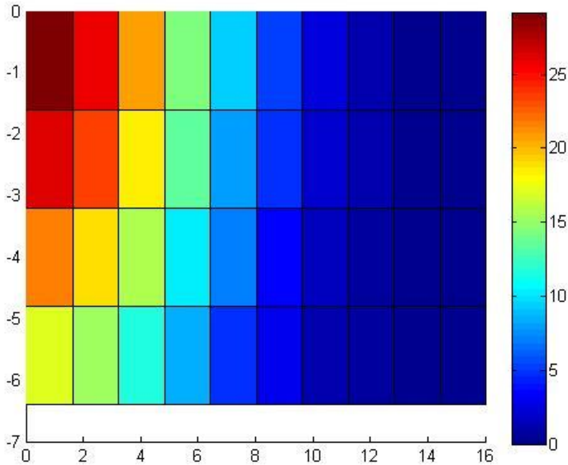
$$C_{x+1,y,z} = \frac{1}{4}\left(C_{x,y+1,z} + C_{x,y-1,z} + C_{x,y,z+1} + C_{x,y,z-1}\right). \tag{4}$$

Estimated area of the flow presented as the parallelepiped divided into estimated units (picture 3).



Picture 3. Estimated area of the flow (for the spatial task)

As the results of modeling we can see the pollutant spreading in the flow, changing by cross-sections (picture 4).



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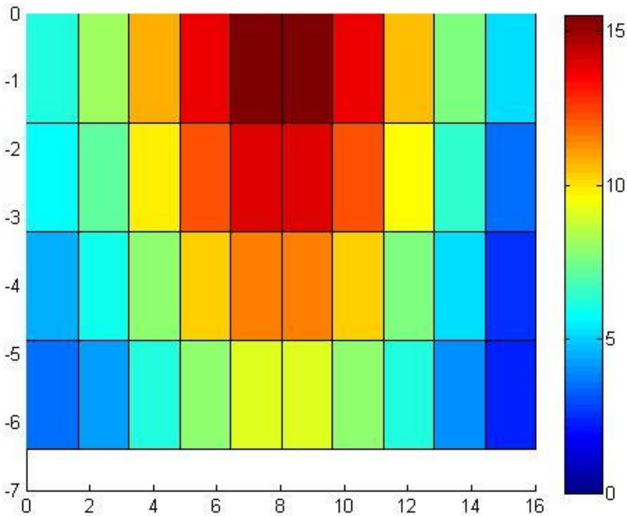

b

Picture 4. Visualization of the results of spatial task, the last estimated cross-section
a) a source of pollution at the right side of the flow,
b) a source of pollution at the center of the flow

The question of the application of the resultsis very actual and therefore the calculation program could be improved in several ways. First of all is to set the parameters of the real streams and to proceed to unsteady regime. The final result in perspective is program enables to predict pollutant concentrations at any point of the watercourse.

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НАУЧНО-ПОПУЛЯРНОЕ ИЗДАНИЕ

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