

Modeling the transformation of biogenic substances in a deep-water ecosystem (using Lake Teletskoye as a case study)

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The aim of the study

is assessment of the permissible biogenic load on Lake Teletskoye (TO) to preserve the stable state of the aquatic ecosystem based on modeling the cycle of nitrogen and phosphorus compounds, including taking into account the spatial and temporal factor

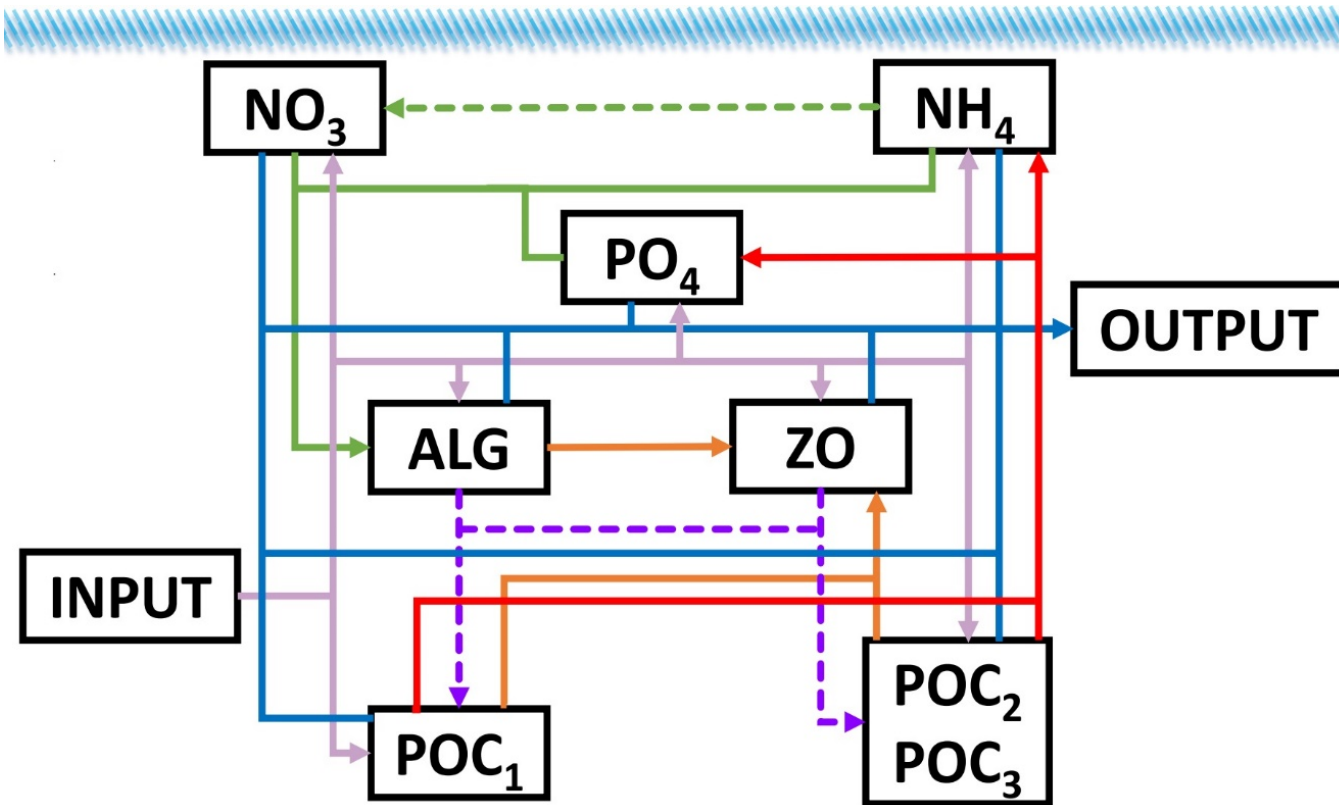
Methodological tools:

1. a phenomenological approach to simulating the biogeochemical cycles of limiting elements;
2. use of the Delft3D software suite for modeling.



Location	Altai Republic
Coordinates	 51°31'45"N 87°42'53"E
Primary inflows	Chulyshman 70 other smaller rivers and 150 temporary streams
Primary outflows	Biya
Basin countries	Russia
Max. length	78 km (48 mi)
Max. width	5 km (3.1 mi)
Surface area	233 km ² (90 sq mi)
Average depth	174 m (571 ft)
Max. depth	325 m (1,066 ft)
Water volume	40.54 km ³ (9.73 cu mi)
Surface elevation	434 m (1,424 ft)





ZO - zooplankton, gC/m^3 ;
 ALG - phytoplankton, gC/m^3 ;
 NH_4 - ammonium nitrogen, gN/m^3 ;
 NO_3 - nitrate nitrogen, gN/m^3 ;
 PO_4 - phosphate phosphorus, gP/m^3 ;

POC_1 - organic matter with fast decomposition, gC/m^3 ;
 POC_2 - organic matter with middle decomposition, gC/m^3 ;
 POC_3 - organic matter with slow decomposition, gC/m^3 .

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} + w \frac{\partial C}{\partial z} = D \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} \right) + R + S \quad (1)$$

where

C – concentration of modeled substances;

D – diffusion coefficient;

R – the rates of physical, chemical, and biological processes;

S – the rates of input from sources external to the ecosystem.

$$M_i^{t+\Delta t} = M_i^t + \Delta t \times \left(\frac{\Delta M}{\Delta t} \right)_{Tr} + \Delta t \times \left(\frac{\Delta M}{\Delta t} \right)_R + \Delta \quad (2)$$

where

Δt – time step;

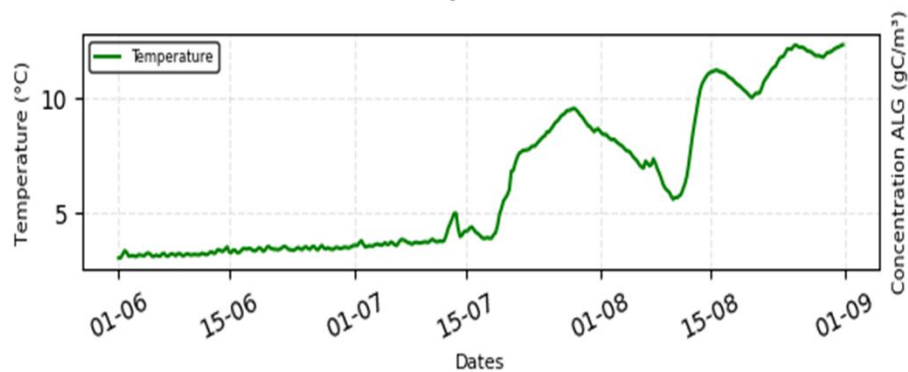
M_i^t and $M_i^{t+\Delta t}$ – is the mass of the modeling ingredient i at t

mass change rates as a result:

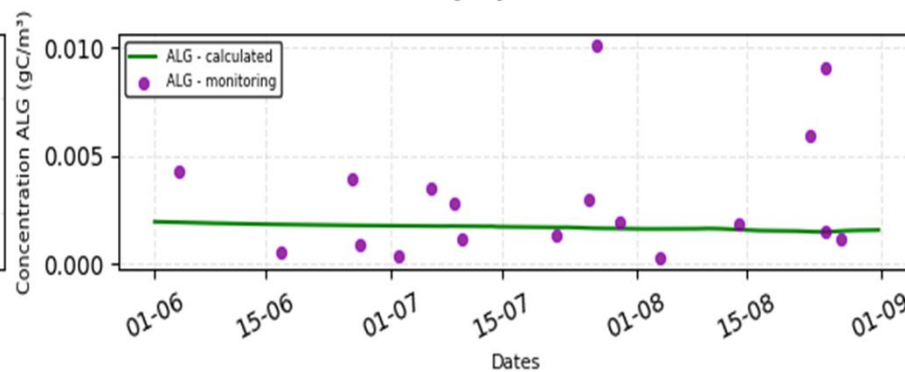
$\left(\frac{\Delta M}{\Delta t} \right)_{Tr}$ – transfer between neighboring cells;

$\left(\frac{\Delta M}{\Delta t} \right)_R$ – physical, chemical and biological processes;

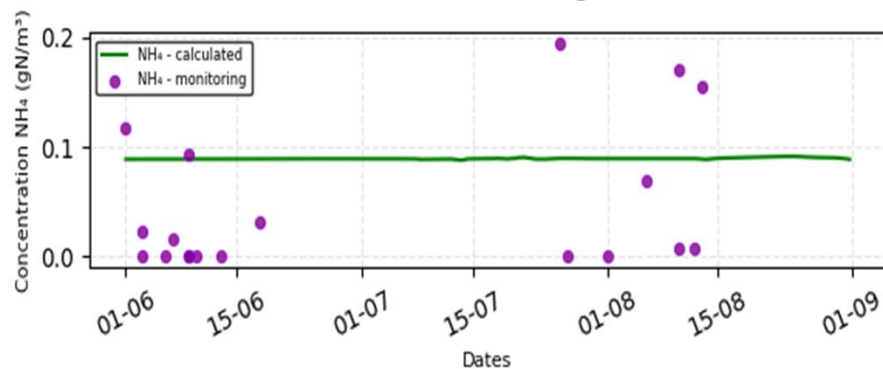
Temperature



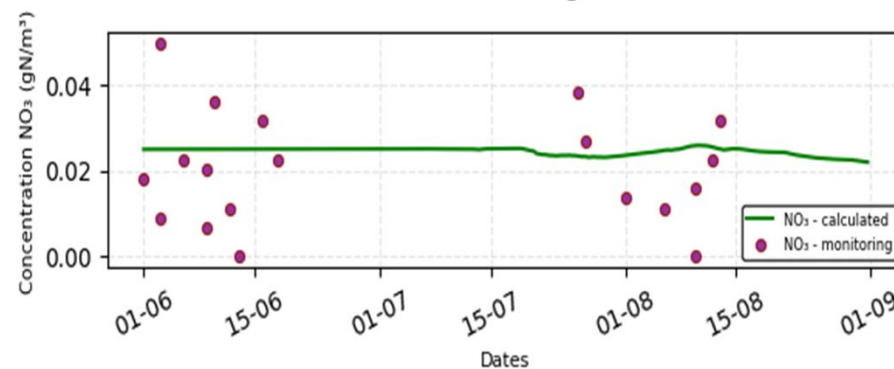
Phytoplankton



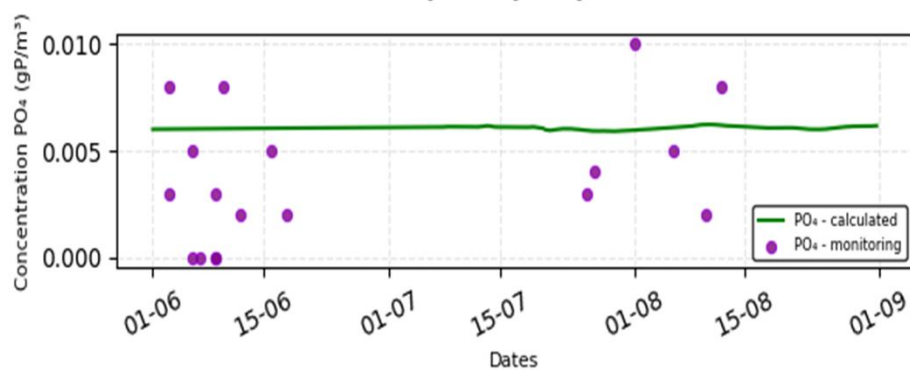
Ammonium nitrogen



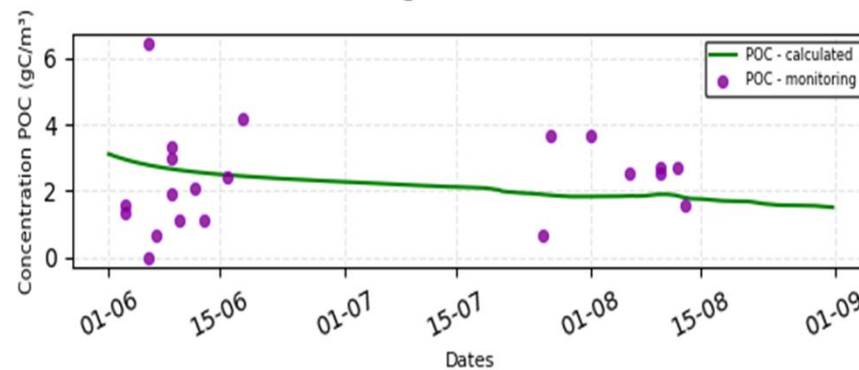
Nitrate nitrogen



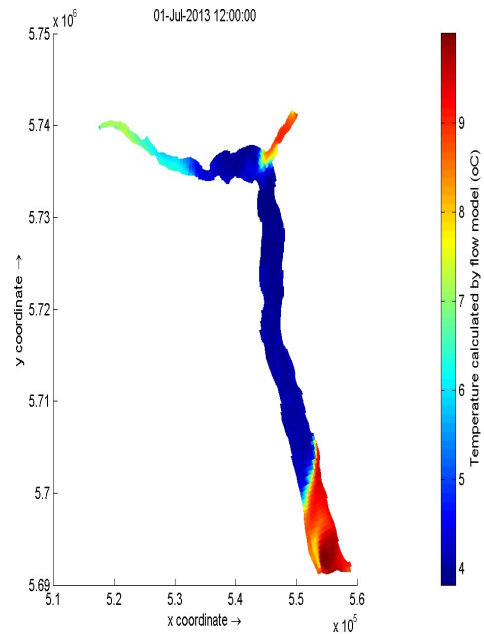
Phosphate phosphorus



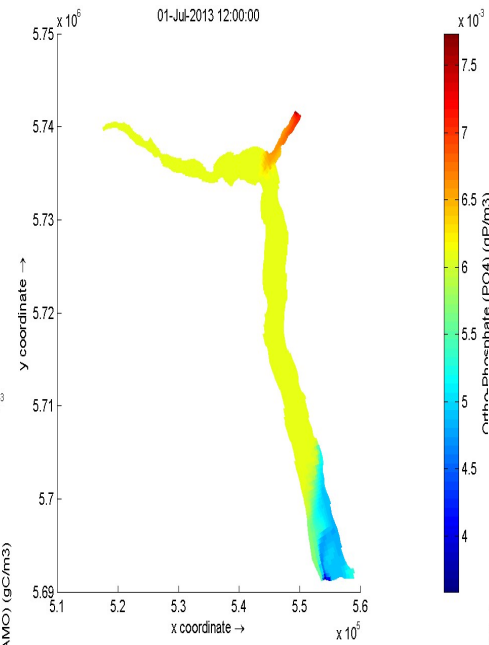
Organic matter



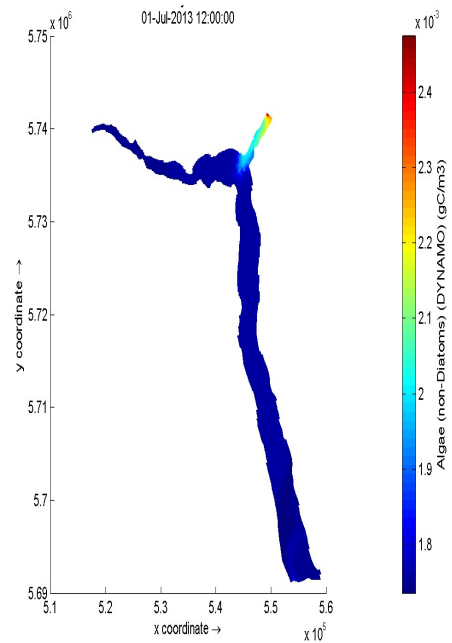
Temperature



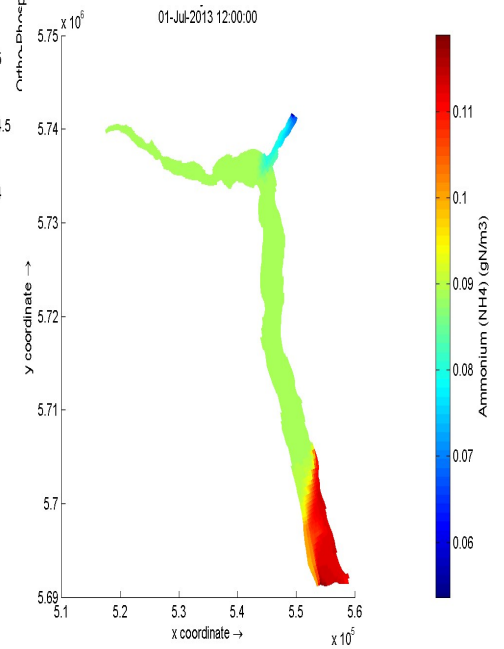
Phosphate phosphorus



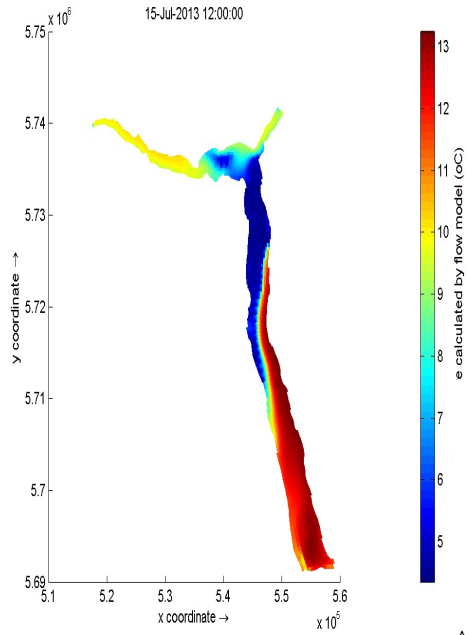
Phytoplankton



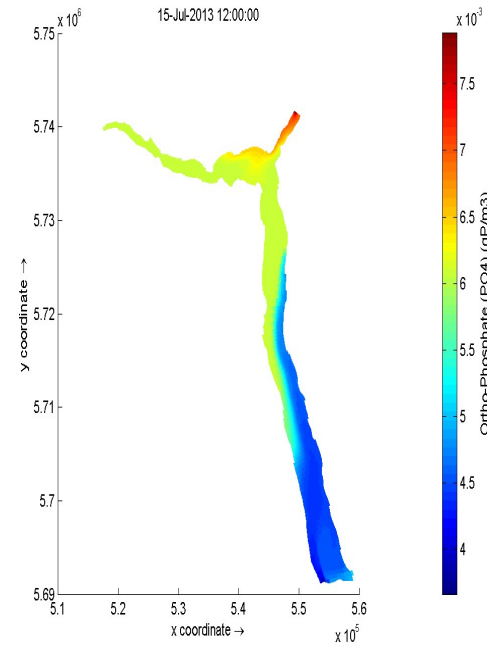
Ammonium nitrogen



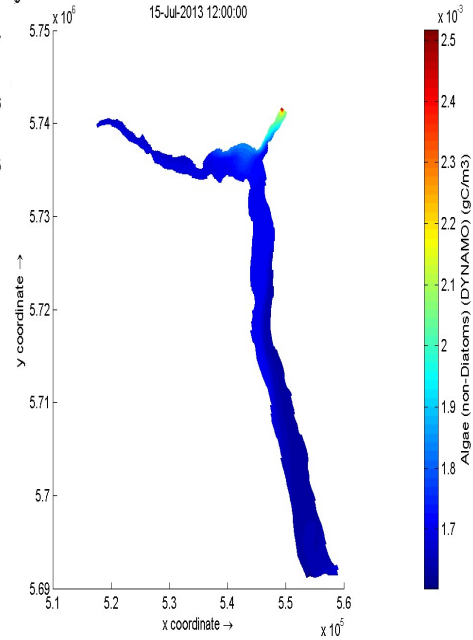
Temperature



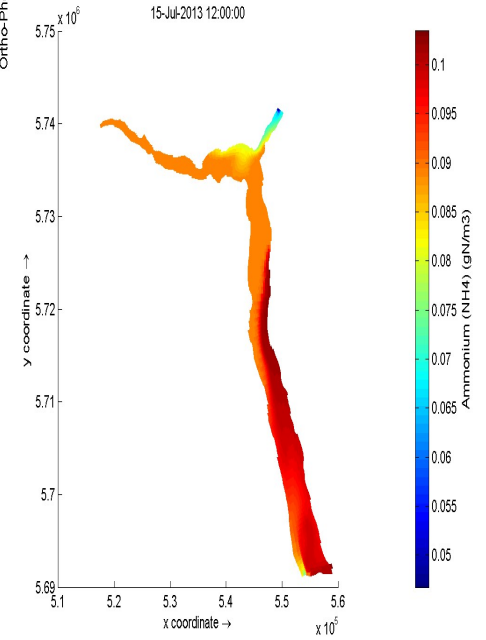
Phosphate phosphorus



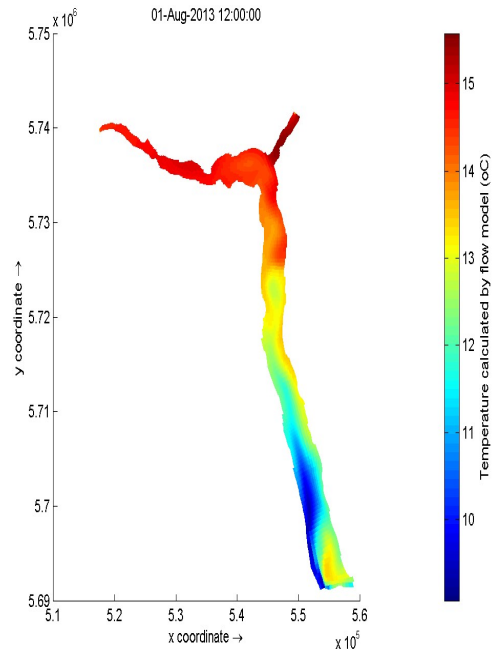
Phytoplankton



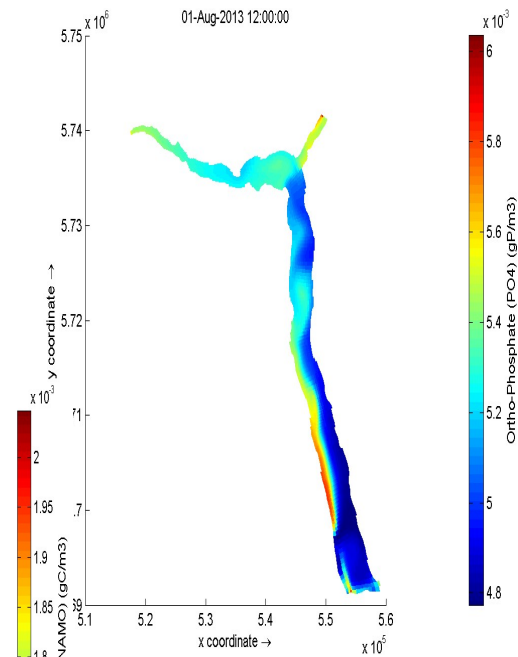
Ammonium nitrogen



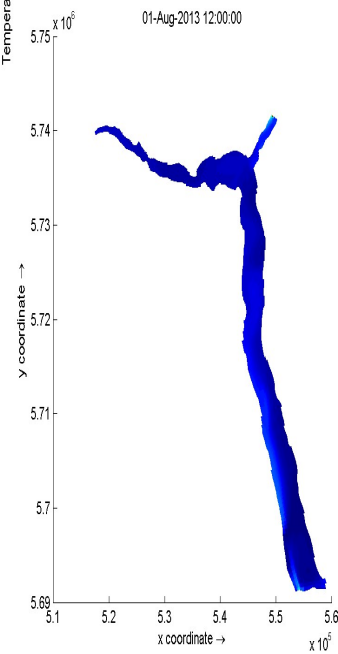
Temperature



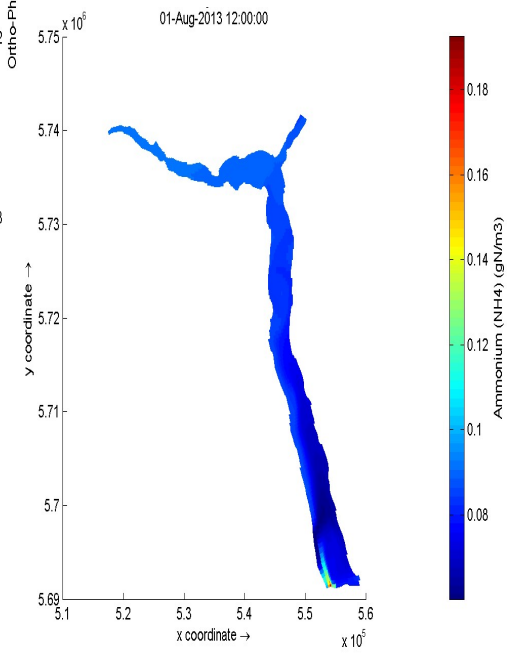
Phosphate phosphorus



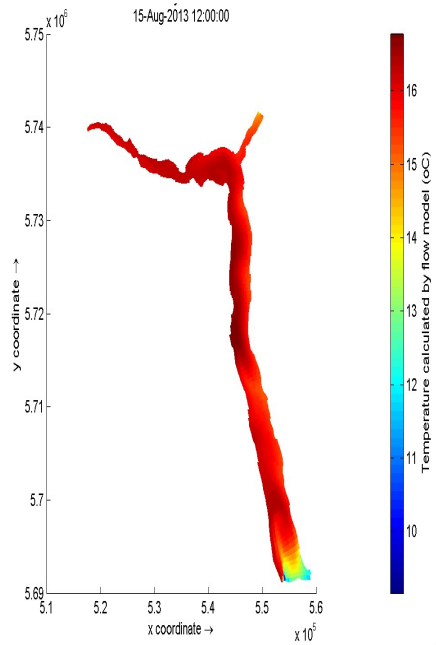
Phytoplankton



Ammonium nitrogen

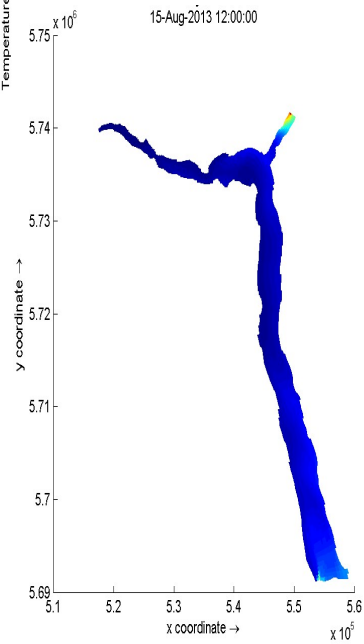


Temperature



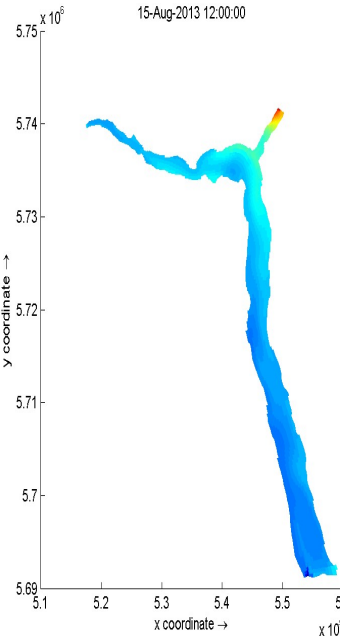
Temperature calculated by flow model (°C)

Phytoplankton



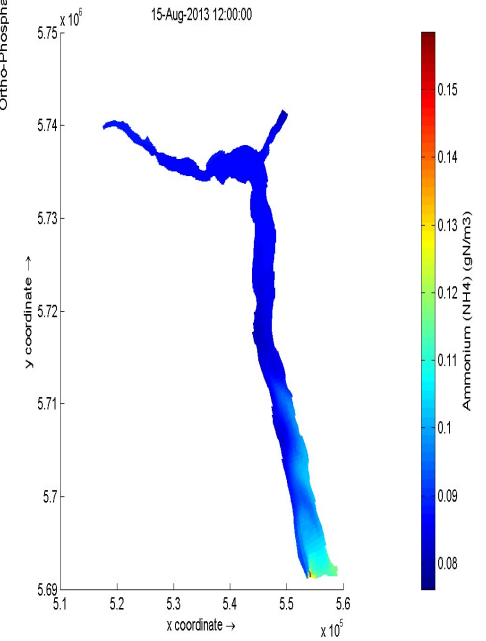
Algae (non-Diatoms) (gC/m³)

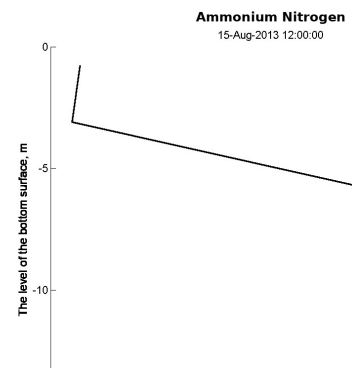
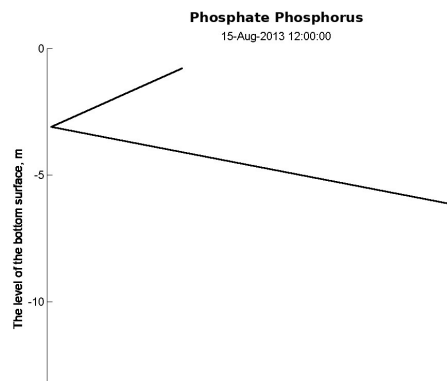
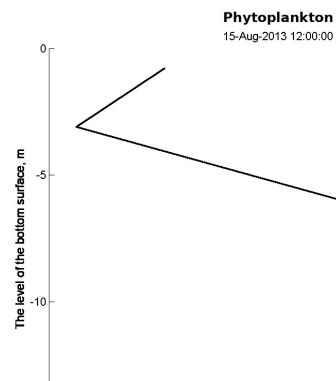
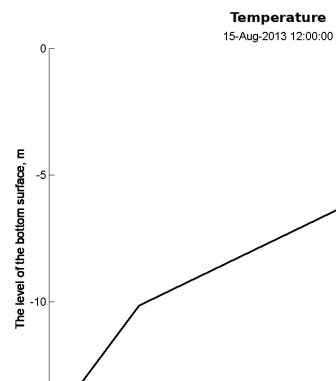
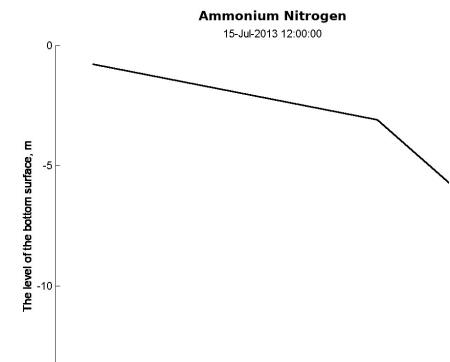
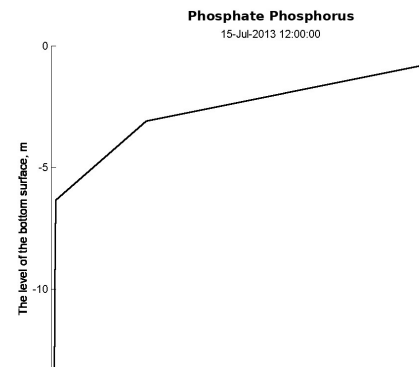
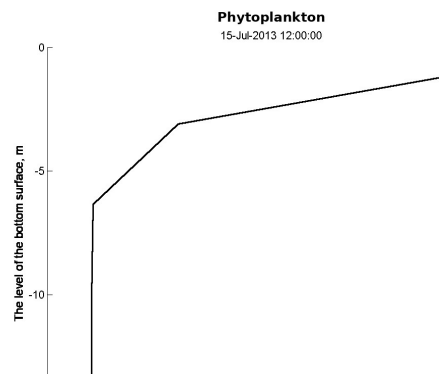
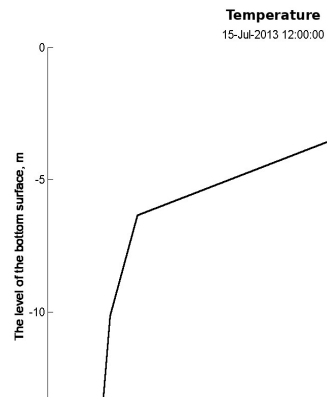
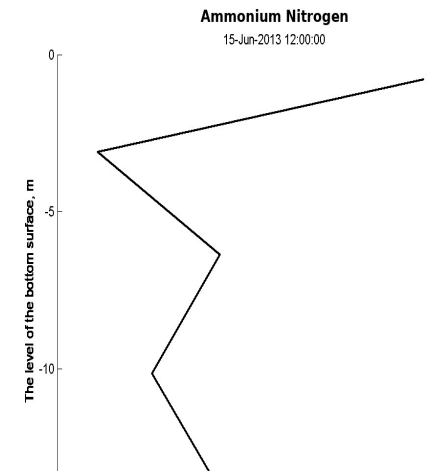
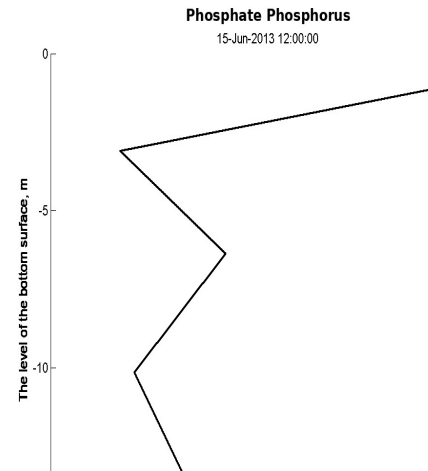
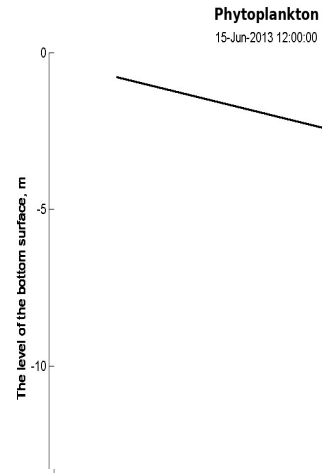
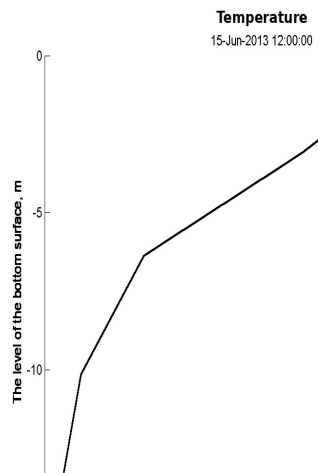
Phosphate phosphorus



Ortho-Phosphate (PO₄) (gP/m³)

Ammonium nitrogen





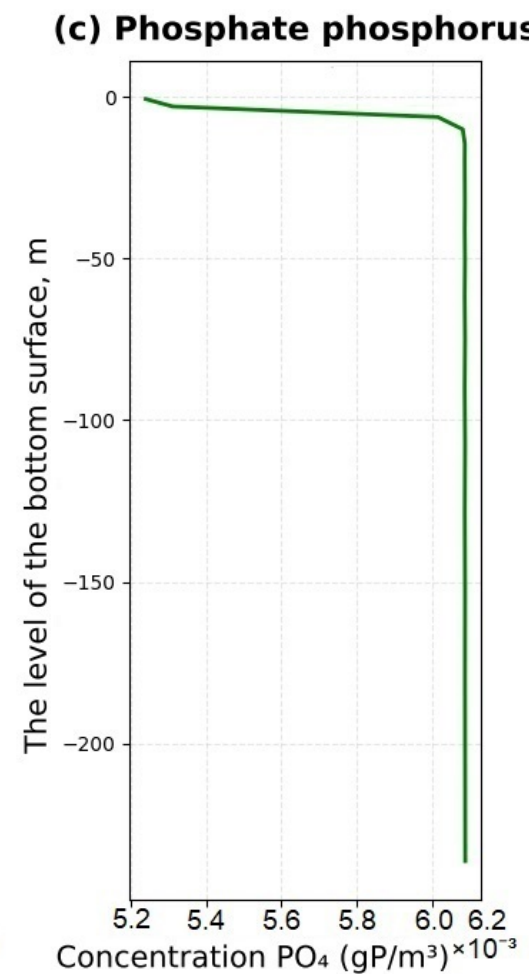
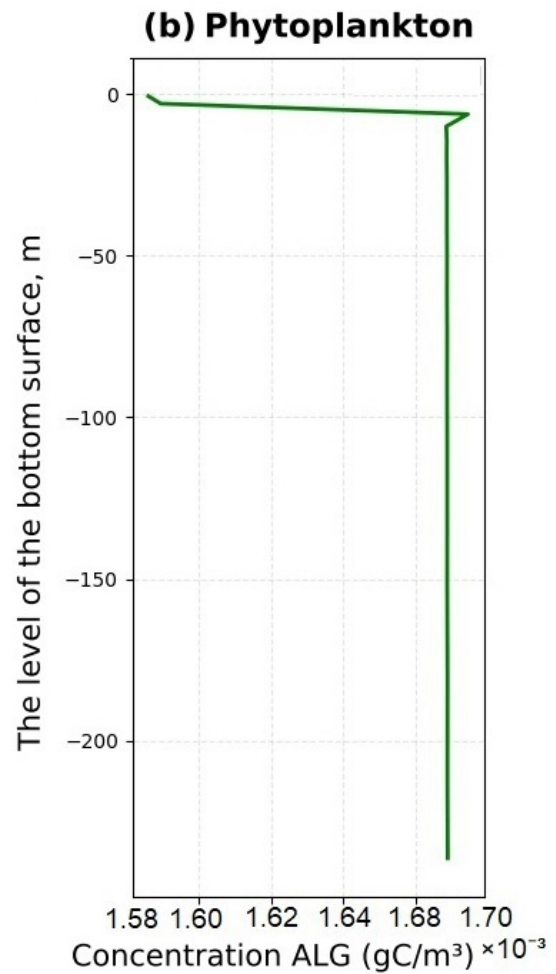
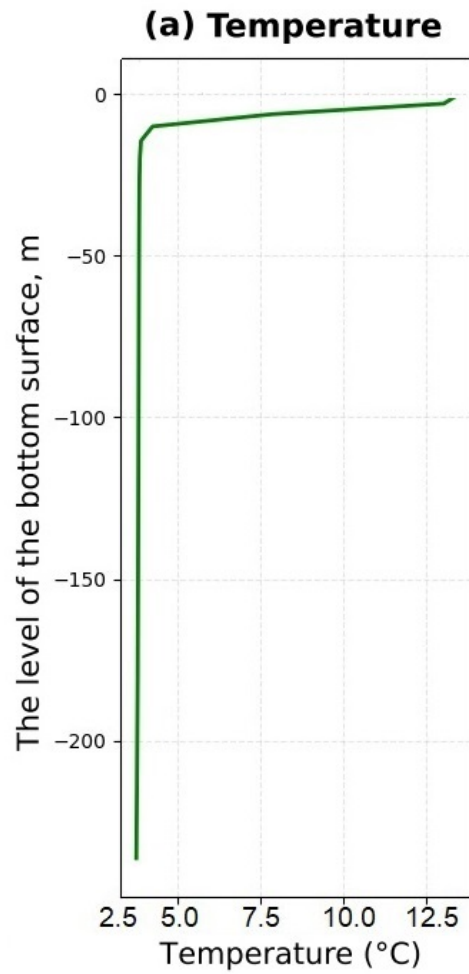


Table.1 Model assessment of the main components of nitrogen and phosphorus inputs and losses in Lake Teletskoye

(in tons of N)

	Entrance N	Year
	Receipt of N forms with a surface runoff	8081.531
	Entering the water from the bottom	17.520
1	By summing	8099.051
	Output N	Year
	With the river Biya	-7768.699
	Sedimentation	-11.790
2	In total	-7780.489
3	Residual (sum of clauses 1 and 2) in tons of nitrogen	318.562
4	Residual by N, in percentage terms	-4%

(in tons of P)

	Entrance P	Year
	Receipt of P forms with a surface runoff	125.153
	Entering the water from the bottom	0.740
5	By summing	125.894
	Output P	Year
	With the river Biya	-123.763
	Sedimentation	-0.213
6	In total	-123.976
7	Residual (sum of clauses 5 and 6) in tons of phosphorus	1.917
8	Residual by P, in percentage terms	-2%

Table 2. The assimilative characteristics of lakes (dash means no data available)

№	Lakes	Water exchange period, years	P_{total}			N_{total} (N_{org} - in cases*)		
			Holding capacity of lakes	Coefficients of transformation rate of substance, year ⁻¹	Total assimilation, tP/year	Holding capacity of lakes	Coefficients of transformation rate of substance, year ⁻¹	Total assimilation, tN/year
1	Onega	15.6	0.72	0.14	624	0.7*	0.13*	6122*
2	Ladoga	11.7	0.63	0.13	1284	0.69*	0.16*	-
3	Pskov-Chudskoe	1.16	0.52	0.354	112	0.53	0.64	1136
4	Kroshnoo zero	0.88	0.47	0.63	2.1	0.38*	0.49*	-
5	Teletskoe	4.35	0.02	0.005	3.5	0.06	0.014	585



Conclusion

1. A simulation model of the nitrogen and phosphorus cycle in a deep reservoir is proposed using Lake Teletskoye as an example.
2. Biogeochemical processes in Lake Teletskoye are numerically reproduced in the hydrological conditions of the summer period of 2013. The results obtained were compared with the monitoring data 1985 -2003.
3. Dynamic modeling of spatially heterogeneous processes in the ecosystem of Lake Teletskoye has been performed. Based on the proposed model of trophic interactions, the features of the formation of water quality in a deep reservoir are explained.
4. The assimilation potential of the lake in relation to phosphorus compounds is insignificant, practically absent. A relatively small increase in anthropogenic pollution can lead to a violation of the stability of the lake ecosystem.
5. It is necessary to bring the research on Lake Teletskoye up to modern level:
 - both in terms of the number of observation points of the monitoring network in the characteristic zones, the increase in the list of monitored indicators and the frequency of monitoring;
 - as well as improving the quality of the instrumental and methodological base.



Thank you for attention!

