Simulation of river pollution by heavy metals under different scenarios of anthropogenic load on watershed and climate changes

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Abstract

The aim of research is modelling *copper* and *zinc* contents in watercourses of the Nizhnekamskoe Reservoir (NKR) watershed under various scenarios of economic activity. This watershed is characterized by high background concentrations of heavy metals due to wide occurrence of ore deposits and considerable concentration of ore-parent elements in rocks. The semi-distributed physically based ECOMAG-HM model was developed to simulate cycling of heavy metals in river basin: on the surface, in soil, groundwater and river water. The contributions of natural and anthropogenic (wastewater) factors to river water pollution by metals and under various scenarios of changes in anthropogenic load were evaluated based on the ECOMAG-HM model. Numerical experiments shown that self-purification of the watershed by copper content with a decrease from natural and anthropogenic sources of pollutants decreases by about 7-8% for every 400 years. Thus, to reduce the copper content in river waters to the maximum allowed concentration for waters used for fisheries (1 μg/L), it will take more than about 3500-4000 years.

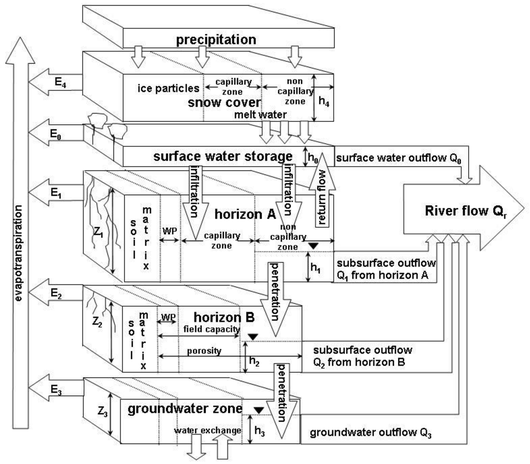
Study area

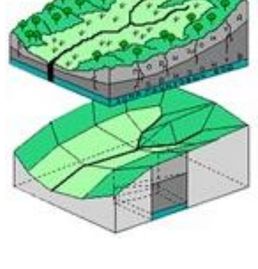
The Nizhnekamskoe Reservoir watershed is located in the South Ural region of Russia and has an area of 186000 km². About two-thirds of the watershed area, its western and central parts, is flat, whereas its eastern part belongs to the Ural Mountain Area. Forests account for about 50% of the territory, and the lake area is very small. The soils in the area (chernozem, sod-podzol and grey forest soil) have a high humus content and heavy texture. Well-drained mountain soils are widespread in the eastern part of the watershed. One can see a variety of climate conditions here: from semiarid steppe regions, with annual precipitation of 300–400 mm and mean annual air temperature of about 3°C, to wetter regions with annual precipitation exceeding 600 mm and mean annual air temperature lower than 1°C. The intra-annual distribution of river runoff in the region characterizes the water regime as a typical snow-dominated one. The spring flood accounts for more than 60% of the annual runoff.

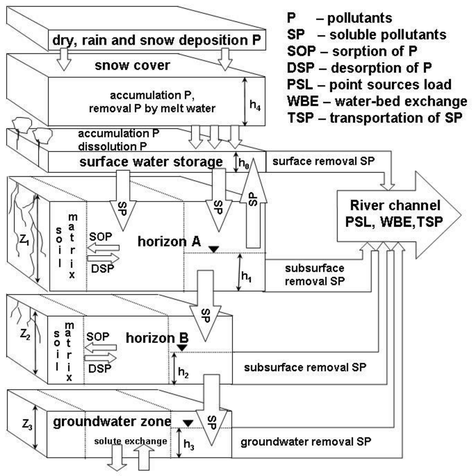
Human activity in the watershed

The industrial development of the region, which started more than 300 years ago, consisted mostly in exploitation of mineral deposits, and was carried out without any ecological limitations. At present a considerable amount of heavy metals enter water bodies with wastewaters from large populated localities, containing plants of various industrial sectors. The leading industries in the region are mining, metallurgy, oil production, petroleum processing, chemistry, power industry.

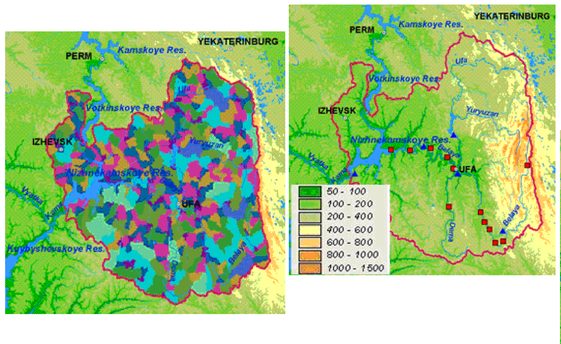
ECOMAG-HM structure



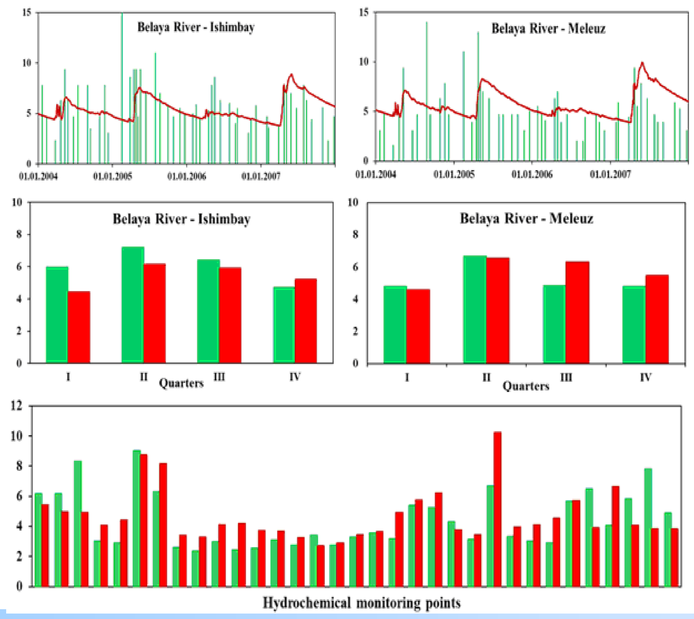




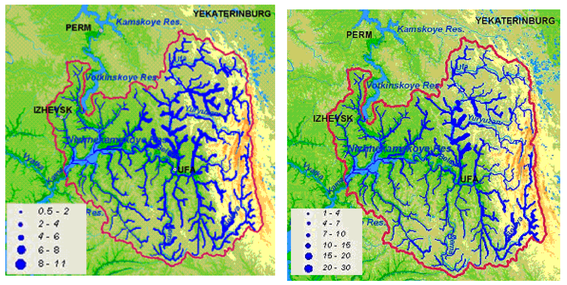
Model set-up for the NKR watershed



Observed (green) and simulated (red) zinc concentrations (μg/L) in river water



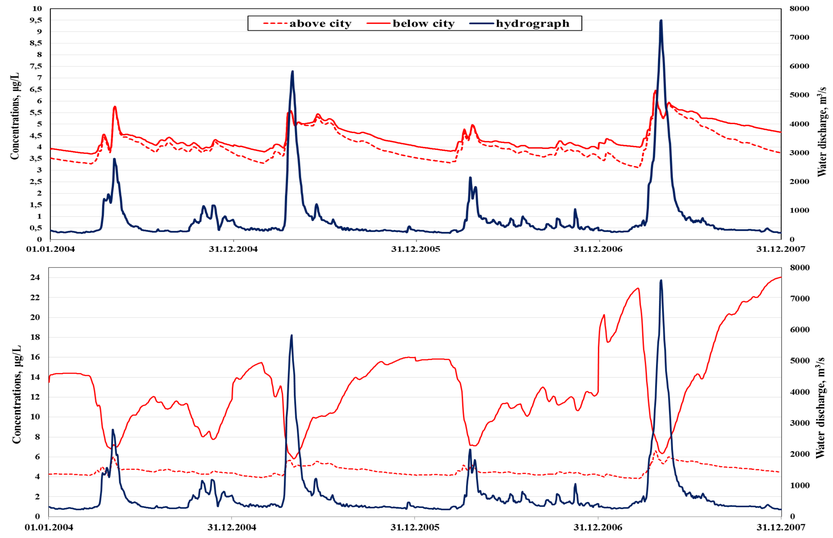
Simulated mean annual copper (left) and zinc (right) concentrations in the river water (μg/L)



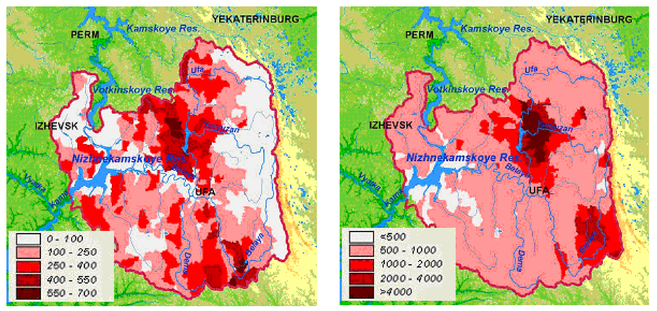
Simulated components of metals load (t/year) from NKR watershed

Year	Metal load		Actual load of metal by wastewater	Metal settling onto riverbed	Total metal load into NKR	
	With surface water flow	With subsurface water flow			Simulated	Actual
Copper						
2004	25	130	2,3	82	75	127
2005	50	192	2,4	106	138	166
2006	18	123	2,3	78	65	54
2007	68	252	2,1	130	192	129
Mean annual	40,3	174,3	2,3	99	118	119
Zinc						
2004	22	165	7,2	125	69	97
2005	46	207	7,9	152	109	109
2006	14	153	7,9	114	61	97
2007	61	265	12,7	186	153	155
Mean annual	35,8	197,5	8,9	144,3	98	114,5

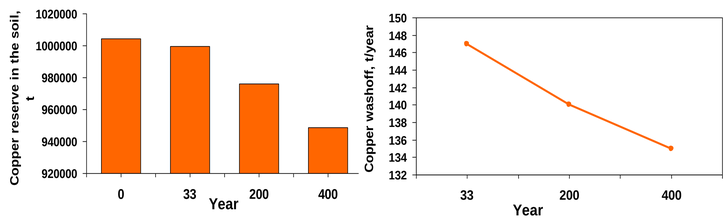
Simulated zinc concentrations in the Belaya River – Ufa city station under different wastewater discharge scenarios: actual wastewater discharges (top), 20 times increase in discharges (bottom)



Simulated mean annual specific zinc washoff in the NKR basin: surface and sub-surface, g/(year km²)



Changes in the copper content in the NKR basin: copper reserve in the soil and copper washoff into the river network



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