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The risk of river pollution due to washout from contaminated floodplain water bodies during periods of high magnitude floods

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SUMMARY

The risk of river pollution due to washout (removal of pollutants) from contaminated floodplain water bodies (floodplain lakes and quarries whose origin is related to the large-scale mining of nonmetallic building materials in the floodplain zone) during high magnitude flood periods is analyzed using a combination of one-, two- and three-dimensional hydrodynamic modeling and in situ measurements. The modeling performed for the floodplain water bodies contaminated by *N* compounds shows that during large magnitude floods washout occurs. The washout process consists of two stages: an initial rapid stage lasting about two hours during which the upper (3–4 m thick) layer is washed out, followed by a second stage when the concentration of NH4-N in the floodplain water body remains nearly constant. The maximum contaminant concentration in the river in the vicinity of a water intake for drinking water located 21 km downstream is attained about 9 h from the beginning of the flood; concentration of NH_4-N can reach values several times larger than acceptable concentration guidelines. The initial primary peak in contaminant concentration at the water intake is followed by a slight decrease in contaminant concentration; a second peak related to the contaminant transport through the inundated floodplain subsequently occurs, after which the concentration slowly decreases, reaching acceptable values after 30–40 h. Contaminated floodplain water bodies located near drinking water supply systems are not significant sources of contamination during small and moderate floods, but during high magnitude floods, they can become sources of water pollution. Operational measures that can decrease potential health risks are discussed.

1. Introduction

The potential impact of high magnitude floods is currently a key concern for many populations living near flood zones or relying on water from flood-affected areas. Studies of the impact of floods generally focus on characterizing flow regimes and estimating the possible area inundated by a flood of a given magnitude (see, for example, Bates and De Roo, 2000; Giannoni et al., 2003; Goppert et al., 1998; Horritt, 2000; Knight and Shiono, 1996; Mignot et al., 2006; Nicholas and Walling, 1997). However, in some cases the critical characteristics of flooding are hydrochemical parameters related to changes in the chemical composition of water rather than just hydraulic parameters related to the rise in water levels. The concentration of pollutants have been shown to increase, remain the same, or decreasing with increasing discharge, depending on the source of the contaminants (see, Miller and Orbock Miller, 2007 for a review). Generally, the higher the discharge, the more intensive is the process of dilution, i.e. the lower is the concentration of contaminants in water. However, this is not true in the case when flooding activates new sources of water pollution, such as contaminated floodplain water bodies. While being reliable and safe at small and moderate water discharges, during high magnitude floods such floodplain sources can be inundated and limit water consumption by downstream consumers.

The problem of the contamination of water bodies is attracting the attention of many researchers. In most of papers (see, for example, Miller and Orbock Miller, 2007; Middelkoop, 2000; Carreira et al., 2008; Zachmann et al., 2013; Grygar et al., 2014) the influence of floods on the pollution of floodplain soils by heavy metals and the recovery of biochemical functionality in polluted floodplain soils are studied. The mechanisms of interaction in the system water – bottom sediments are also intensively investigated (e.g. Walling et al., 2003).

The present paper utilizes a multi-step modeling approach and in situ observations to (a) assess the washout (removal) of *N*

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compounds from contaminated floodplain water bodies (floodplain lakes and quarries whose origin is related to the large-scale mining of nonmetallic building materials in the floodplain zone) during flood events of various frequencies and magnitudes, (b) determine the rate of dispersal of the contaminant plume along the river, and (c) assess the magnitude of contamination that reaches the intake for the domestic water supply.

2. Brief description of the examined water body

In the present paper we analyze the risk of river pollution due to washout from contaminated floodplain water bodies during large magnitude floods by using a section of the Vyatka River near the city of Kirov (Fig. 1) as a study site. The Vyatka River exhibits a hydrologic regime typical of East-European rivers. It is characterized by a clearly defined high flow spring period and low flows during summer that are occasionally interrupted by short, but intense rainfall events, winter is typically characterized by limited precipitation.

On average, about 60% and, in some years, about 80%, of the annual flow occurs during spring flooding, primarily as a result of snowmelt. Spring flooding usually begins at the start of April, reaches a maximum discharge in early May and then ends around the middle of June. The average flood duration is thus slightly longer than two months, with flood duration ranging from a maximum of 96 days to a minimum of 34 days. The average maximum daily discharge for the entire observation period from 1887 to 2013 is 2916 m^3/sec. The coefficient of variation of the selected time series is 0.25, with a very weak asymmetry. Accordingly, the maximum river discharge with a return period in four years is 3350 m^3/sec; for a return period of ten years it is 3780 m^3/sec.

To address the problem of chemical waste storage (ammonia production), large-scale construction of liquid waste accumulation ponds has been carried out in the study area. Additionally, a number of floodplain quarries were created during the mining of nonmetallic building materials. These quarries have a total area of about $1.9 \cdot 10^5$ m^2 and a characteristic depth of 7–9 m. Infiltration within the liquid waste accumulation ponds resulted in contamination of groundwater in the considered floodplain area. As a result of the filtration of contaminated groundwater into floodplain lakes and quarries they became potential sources of pollution along the Vyatka River. Contaminated groundwater may influence pollution of the Vyatka River directly; however, the intensity of this process is sufficiently smaller than the pollution due to washout of contaminated floodplain water bodies during periods of flood. The depth of Vyatka River is 4–5 m and typical depths of contaminated floodplain water bodies under consideration is 8–10 m. Thus, filtration of contaminated groundwater primarily occurs to these water bodies. Pollution of the Vyatka River due to washout from inundated contaminated floodplain water bodies is a short-term event. In situ measurements show that, except for this short period of time, the concentration of NH4-N in the Vyatka River does not exceed 0.2 mg/l, suggesting that contribution of pollution of the Vyatka River by groundwater is small.

The main limiting pollutant in the floodplain water bodies under consideration is ammonia (NH_4). Its key constituent, which is controlled and regulated, is ammonium nitrogen (NH_4-N). The concentration of NH_4-N in surface layers of the considered water bodies (contaminated lakes and quarries) is about 600 mg/l and increases with depth to about 850 mg/l. The average concentration throughout a cross-section in the Vyatka River is about 0.1–0.3 mg/l (it is usually uniform downstream). According to the current Russian Federation standards for drinking water quality, the

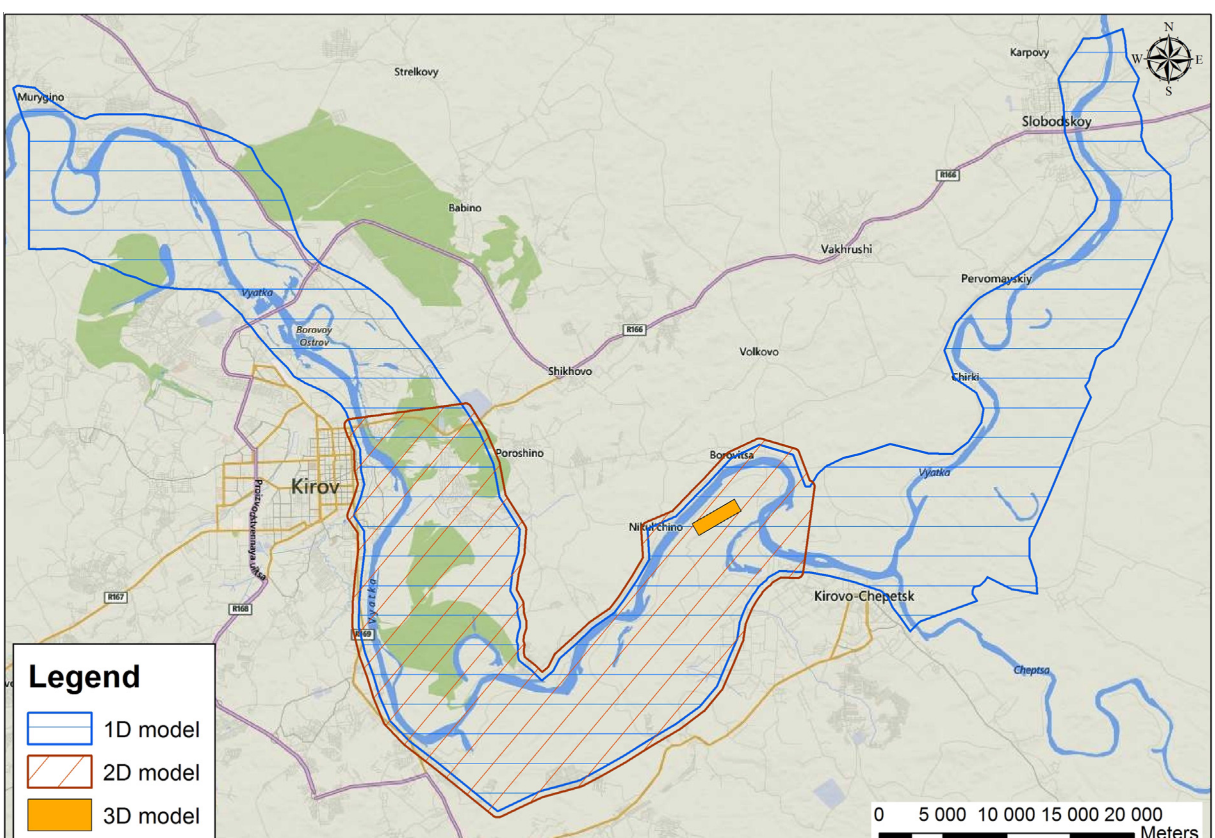

Fig. 1. The study site. Domains covered in the 1D, 2D and 3D models.