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Seeking a compromise between pharmaceutical pollution and phosphorus load: Management strategies for Lake Tegel, Berlin

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ABSTRACT

Lake Tegel (Berlin, Germany) is controlled by two main inflows: inflow #1 (River Havel) is heavily phosphorus-laden, whereas inflow #2 is an artificial confluence that includes discharge from a municipal wastewater treatment plant distinguished by high levels of phosphorus and pharmaceuticals. To reduce the phosphorus load on the lake, a phosphorus elimination plant (PEP) is situated at inflow #2. Moreover, the two inflows are short-circuited by a pipeline that transfers part of the inflow #1 water to the PEP and finally releases it into inflow #2. The pipeline and the PEP have contributed to a continuous reduction in the total phosphorus concentration of Lake Tegel in the past 25 years. We investigate the question of whether the existing lake pipeline can also be used to reduce the amount of pharmaceuticals in Lake Tegel originating from inflow #2 by dilution with water from River Havel, by diverting part of inflow #2 around the lake, or by a combination of both strategies. The circulation pattern of Lake Tegel is complicated by complex bathymetry and numerous islands and is therefore highly sensitive to winds. We tested seven different management scenarios by hydrodynamic modeling for a period of 16 years with the two-dimensional version of the Princeton Ocean Model (POM). None of the scenarios provided a strategy optimal for both pharmaceuticals and phosphorus. Nonetheless, compound regimes, such as alternating the pipe flow direction or adding another pipeline, allowed the most abundant pharmaceutical (carbamazepine) to be reduced while maintaining the current phosphorus level. This study demonstrates the ability of immediate lake regulation measures to maintain water quality. In the case of Lake Tegel, the pipeline can be fully effective with regard to pharmaceuticals only in combination with additional efforts such as advanced pharmaceutical treatment of wastewater and/or phosphorus reduction in the River Havel catchment.

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1. Introduction

The contamination of freshwater systems by industrial and domestic compounds is increasing worldwide. Among the major anthropogenic pollutants in large urban agglomerations are phosphorus and pharmaceutically active compounds from treated wastewater (Nützmann et al., 2011). In the case of phosphorus, its sources, fate and relevant environmental processes are well understood, whereas existing knowledge on pollution by pharmaceuticals is insufficient for effective risk management (Kummerer, 2009). A framework was set by the European Medicines Agency, who published an environmental risk assessment guideline for human pharmaceuticals (EMEA, 2006) based on the relation of the predicted environmental concentration (PEC) to the predicted no-effect-concentration (PNEC).

The reduction of pharmaceuticals in the environment is motivated by environmental hygiene rather than human toxicological risks, which seem to be negligible (Kummerer, 2009). Hence, any measure must be assessed according to its net environmental benefit before being implemented. Wenzel et al. (2008) investigated the environmental impacts of three different advanced wastewater treatments (sand filtration, ozonation and membrane bioreactors) and compared them to the benefit of avoiding emissions for nine selected micropollutants within a life cycle assessment (LCA). The authors found the impacts and benefits to be of the same order of magnitude. This example demonstrates the need for further research on alternatives to advanced wastewater treatment for reducing the concentration of pharmaceuticals in open waters.

A large amount of recent studies is dedicated to the fate of pharmaceuticals in the aquatic environments and their potential effects on the ecosystems (Corcoran et al., 2010; Jones et al., 2001). Transport modeling is used for assessment of pharmaceuticals propagation and development of appropriate reduction strategies on the regional scales (Ort et al., 2009). The phosphorus-related management strategies have longer history for both for wastewater (Tchobanoglous et al., 2003) and natural open waters (Marsden, 1989). Regulation measures with regard to both pollutants are especially critical for enclosed water bodies—lakes and reservoirs—located in large megalopolises and used simultaneously as drinking water sources, recreational sites and receiving waters for treated wastewater. Their complex hydrodynamics represents an additional difficulty for development of adequate regulation measures.

Using Lake Tegel located in the German capitol Berlin as a natural example, we applied a deterministic circulation model to assess efficiency of water regime regulation scenarios for reduction of pharmaceuticals load from the wastewater plant and phosphorus load from the inflow of the River Havel. The hydrodynamics of Lake Tegel have been previously investigated by Schimmelpfennig et al. (2012) by applying a two-dimensional hydrodynamic circulation model including conservative tracer transport. In the present study, we use the same two-dimensional approach to evaluate different operation strategies for the regulation system including a pipeline connecting the river inflow with the outlet of the wastewater plant and a phosphorus elimination plant.

2. Methods

2.1. Study site

Lake Tegel is a small, shallow lake (length 4 km, maximum depth 16 m, mean depth 6 m, residence time of main basin 50–100 days) located in northwestern Berlin (52°34′N, 13°15′E) (Fig. 1) affected by two inflows. The inflow #1, River Havel, has a mean annual flow (MAF) of 13 $m^3\ s^{-1}$. The mean monthly flow ranges from 3 to 40 $m^3\ s^{-1}$. The smaller inflow #2 (MAF 2.4 $m^3\ s^{-1}$) is a confluence of a lake pipeline, the stream Tegeler Fliess, and the Nordgraben canal. Approximately 70–90% of the water in the Nordgraben canal is treated wastewater from a municipal wastewater treatment plant. The water from the pipeline, stream and canal is treated together in a phosphorus elimination plant (PEP) by coagulation/flocculation, sedimentation and dual-media filtration (Heinzmann et al., 1991). The PEP and lake pipeline went into operation in 1985. The lake pipeline pumps water from a point near the outflow of Lake Tegel to the PEP to increase the discharge of inflow #2 and decrease the phosphorus load to Lake Tegel, mainly during the summer. During the winter, the lake pipeline occasionally pumps water in the opposite direction if the total discharge of the stream and the canal exceeds the capacity of the PEP or if the PEP is out of service because of maintenance.

Lake Tegel has one main outflow (located 1 km from inflow #1) with a downstream lock that regulates the discharge of the River Havel and consequently the water level of the lake. An additional outflow is the almost stagnant Berlin-Spandau ship canal (MAF 0.07 $m^3\ s^{-1}$).

More than one hundred drinking water wells are installed along the east and west shores and on two islands. These wells extract water from the lake via bank filtration (Fig. 1). Additionally, some water is taken directly from the lake and used for artificial groundwater recharge. The mean annual water extraction rate from Lake Tegel by these waterworks is 1.16 $m^3\ s^{-1}$, as calculated with a bank-filtration-to-groundwater ratio of 7:3 for all shore-parallel well galleries (Wiese and Nützmann, 2009).

2.2. Sampling and chemical analysis

Water samples for pharmaceutical analysis were taken from April 2009 until April 2010. The inflows and outflow were sampled monthly. Inflow #2 was sampled at the effluent of the PEP by a 24 h mixing probe. Inflow #1 and the outflow were sampled by equally mixing the water from four different subsamples taken at points 2 m deep distributed equally over the cross section of River Havel. Surface water samples were taken on two days (June 2009 and April 2010) at a depth of 0.5 m (see Fig. 1 for locations). At the deepest point of the lake, vertical profiles were estimated by sampling water from eight different depths (every 2 m) during the stratified period (May, July and September) and