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STUDY OF WATER QUALITY IMPROVEMENTS DURING RIVERBANK FILTRATION AT THREE MIDWESTERN UNITED STATES DRINKING WATER UTILITIES

W. J. Weiss (1), E. J. Bouwer (1), W. P. Ball (1), C. R. O'Melia (1), M. W. LeChevallier (2), H. Arora (2,3), R. Aboytes (2), T. F. Speth (4)

(1) Dept. of Geography & Environmental Engineering, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218, (2) American Water Works Company, Inc., 1025 Laurel Oak Road, Voorhees, NJ 08043, (3) Currently at: O'Brien and Gere Engineers, Inc, 8201 Corporate Dr., Suite 1000, Landover, MD 20785, (4) U.S. Environmental Protection Agency, Water Supply & Water Resources Division, 26 W. Martin Luther King Dr., Cincinnati, OH 45268 (Email: jweiss@jhu.edu)

Riverbank filtration (RBF) is a process during which surface water is subjected to subsurface flow prior to extraction from wells. During infiltration and soil passage, surface water is subjected to a combination of physical, chemical, and biological processes such as filtration, dilution, sorption, and biodegradation that can significantly improve the raw water quality (Tufenkji et al, 2002; Kuehn and Mueller, 2000; Kivimaki et al, 1998; Stuyfzand, 1998). Transport through alluvial aquifers is associated with a number of water quality benefits, including removal of microbes, pesticides, total and dissolved organic carbon (TOC and DOC), nitrate, and other contaminants (Hiscock and Grischek, 2002; Tufenkji et al., 2002; Ray et al, 2002; Kuehn and Mueller, 2000; Doussan et al, 1997; Cosovic et al, 1996; Juttner, 1995; Miettinen et al, 1994). In comparison to most groundwater sources, alluvial aquifers that are hydraulically connected to rivers are typically easier to exploit (shallow) and more highly productive for drinking water supplies (Doussan et al, 1997). Increased applications of RBF are anticipated as drinking water utilities strive to meet increasingly stringent drinking water regulations, especially with regard to the provision of multiple barriers for protection against microbial pathogens, and with regard to tighter regulations for disinfection by-products (DBPs), such as trihalomethanes (THMs) and haloacetic acids (HAAs).

In the above context, research was conducted to document the water quality benefits during RBF at three major river sources in the mid-western United States, specifically with regard to DBP precursor organic matter and microbial pathogens. Specific objectives were to:

1. Evaluate the merits of RBF for removing/controlling DBP precursors and certain other drinking water contaminants (e.g. microorganisms).

2. Evaluate whether RBF can improve finished drinking water quality by removing and/or altering natural organic matter (NOM) in a manner that is not otherwise accomplished through conventional processes of drinking water treatment (e.g. coagulation, flocculation, sedimentation).

3. Evaluate changes in the character of NOM upon ground passage from the river to the wells.

The experimental approach entailed monitoring the performance of three different RBF systems along the Ohio, Wabash, and Missouri Rivers in the Midwestern United States and involved a cooperative effort between the American Water Works Company, Inc. and Johns Hopkins University. Samples of the river source waters and the bank-filtered well waters were analyzed for a range of water quality parameters including TOC, DOC, UV-absorbance at 254-nm (UV-254), biodegradable dissolved organic carbon (BDOC), biologically assimilable organic carbon (AOC), inorganic species, DBP formation potential, and microorganisms. In the second year of the project, river waters were subjected to a bench-scale conventional treatment train consisting of coagulation, flocculation, sedimentation, glass-fiber filtration, and ozonation. The treated river waters were compared with the bank-filtered waters in terms of TOC, DOC, UV-254, and DBP formation potential. In the third and fourth years of the project, NOM from the river and well waters was characterized using the XAD-8 resin adsorption fractionation method (Leenheer, 1981; Thurman & Malcolm, 1981). XAD-8 adsorbing (hydrophobic) and non-adsorbing (hydrophilic) fractions of the river and well waters were compared with respect to DOC, UV-254, and DBP formation potential to determine whether RBF alters the character of the source water NOM upon ground passage and if so, which fractions are preferentially removed.

The results demonstrate the effectiveness of RBF at removing the organic precursors to potentially carcinogenic DBPs. When compared to a bench-scale conventional treatment train optimized for turbidity removal, RBF performed as well as the treatment at one of the sites and significantly better than the treatment at the other two sites in terms of removal of organic carbon and DBP precursor material. Removals of TOC and DOC upon RBF at the three sites generally ranged from 30 to 70% compared to 20 to 50% removals upon bench-scale treatment of the river waters. Reductions in precursor material for a variety of DBP precursors for trihalomethanes, haloacetic acids, haloacetonitriles, haloketones, chloral hydrate, and chloropicrin upon RBF ranged from 50 to 100% using both the formation potential (FP) and the uniform formation conditions (UFC) tests (Standard Methods, 1998; Summers et al., 1996), while reductions upon bench-scale treatment were generally in the range of 40 to 80%. The significantly higher reductions of the DBP precursors relative to those of TOC and DOC indicate a preferential reduction upon ground passage in the NOM that reacts with chlorine to form DBPs.

Upon both bench-scale conventional treatment and RBF, a shift was observed in DBP formation from the chlorinated to the more brominated species due to the removal of DOC relative to bromide upon treatment or RBF. As DOC is removed, the bromide:DOC ratio increases, leading to the formation of more brominated DBPs. The shift was more pronounced upon RBF due to the generally higher reductions in DOC. UFC testing with a constant chlorine:DOC:bromide ratio ruled out the possibility of any significant preferential removal of the NOM precursor material for the more chlorinated DBPs. These results highlight the importance of the bromide ion in the formation of DBPs in drinking water, especially in light of the higher theoretical cancer risk associated with the brominated DBPs. Risk calculations demonstrated the ability of RBF to reduce the theoretical excess cancer risk due to THMs formed upon chlorination, in all cases, and with substantially better performance than the bench-scale treatment train.

The characterization studies were carried out to evaluate whether the observed removals of DBP precursor material upon RBF reflected a preferential removal of NOM of particular character. The results of this study indicate that RBF appears to be equally capable of removing material of different character. The different removal mechanisms in the subsurface (e.g. sorption, biodegradation, filtration) combine to provide similar removal of the operationally defined hydrophilic and hydrophobic fractions of organic material upon ground passage. Thus, the reductions in DBP formation upon RBF observed during the first two phases of this research are largely the result of a decrease in the NOM concentration rather than a major shift in the NOM character.

Preliminary monitoring of a number of microorganisms indicates that RBF may also serve as a significant barrier for the removal of microbial contaminants, including human pathogens. The monitoring data demonstrated $>$3 log removal of $Clostridium$ spores and $>$2 log removal of bacteriophage. Assuming that these indicator organisms can be used as surrogates for $Giardia$ cysts and human enteric viruses, RBF at the three study sites surpassed the performance requirements in the United States for conventional coagulation, sedimentation, and filtration (e.g., 2.5 log removal for $Giardia$ cysts and 2.0 log removal of viruses).

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