Available online at www.sciencedirect.com
ScienceDirect
Journal of Contaminant Hydrology 89 (2007) 71–106
JOURNAL OF Contaminant Hydrology
www.elsevier.com/locate/jconhyd

Transport of *Escherichia coli* bacteria through laboratory columns of glacial-outwash sediments: Estimating model parameter values based on sediment characteristics

J. Levy [a,*], K. Sun [a,1], R.H. Findlay [b,2], F.T. Farruggia [c,3], J. Porter [b,4], K.L. Mumy [b,5], J. Tomaras [b,6], A. Tomaras [b,7]

[a] *Department of Geology, Miami University, Oxford, OH 45056, USA*
[b] *Department of Microbiology, Miami University, Oxford, OH 45056, USA*
[c] *Department of Botany, Miami University, Oxford, OH 45056, USA*

Received 7 March 2005; received in revised form 4 July 2006; accepted 13 August 2006
Available online 13 November 2006

Abstract

Bacterial transport through cores of intact, glacial-outwash aquifer sediment was investigated with the overall goal of better understanding bacterial transport and developing a predictive capability based on the sediment characteristics. Variability was great among the cores. Normalized maximum bacterial-effluent concentrations ranged from 5.4×10^{-7} to 0.36 and effluent recovery ranged from 2.9×10^{-4} to 59%. Bacterial breakthrough was generally rapid with a sharp peak occurring nearly twice as early as the bromide peak. Bacterial breakthrough exhibited a long tail of relatively constant concentration averaging three orders of magnitude less than the peak concentration for up to 32 pore volumes. The tails were consistent with non-equilibrium detachment, corroborated by the results of flow interruption experiments. Bacterial breakthrough

* Corresponding author. Tel.: +1 513 529 1947; fax: +1 513 529 1542.
E-mail address: levyj@muohio.edu (J. Levy).
[1] Current address: CH2M HILL Inc., 3 Hutton Centre Drive, Suite 200, Santa Ana, CA 92707, USA.
[2] Current address: Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0344, USA.
[3] Current address: School of Life Sciences, Arizona State University, Mail Code 4601, Tempe, AZ 85287, USA.
[4] Current address: Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA 18015, USA.
[5] Current address: Department of Microbiology and Molecular Genetics, Harvard Medical School, Boston, MA 02115, USA.
[6] Current address: Environmental Science and Engineering, Colorado School of Mines, Golden, CO 80401, USA.
[7] Current address: Department of Microbiology, University of Colorado Health Sciences Center, Aurora, Colorado 80011, USA.

doi:10.1016/j.jconhyd.2006.08.006

was accurately simulated with a transport model incorporating advection, dispersion and first-order non-equilibrium attachment/detachment. Relationships among bacterial transport and sediment characteristics were explored with multiple regression analyses. These analyses indicated that for these cores and experimental conditions, easily-measurable sediment characteristics – median grain size, degree of sorting, organic-matter content and hydraulic conductivity – accounted for 66%, 61% and 89% of the core-to-core variability in the bacterial effective porosity, dispersivity and attachment-rate coefficient, respectively. In addition, the bacterial effective porosity, median grain size and organic-matter content accounted for 76% of the inter-core variability in the detachment-rate coefficient. The resulting regression equations allow prediction of bacterial transport based on sediment characteristics and are a possible alternative to using colloid–filtration theory. Colloid–filtration theory, used without the benefit of running bacterial transport experiments, did not as accurately replicate the observed variability in the attachment-rate coefficient.

Keywords: Bacterial transport; Sediment characteristics; Column experiments; Transport modeling; *Escherichia coli*

1. Introduction

Fecal contamination of groundwater causes numerous disease outbreaks in the US (Craun and Calderon, 1997; Macler and Merkle, 2000). World-wide, there is a substantial risk of well-water contamination when pit latrines are located within 200 m of wells (Foppen et al., 2005). *Escherichia coli* (*E. coli*), a species of coliform bacteria, are commonly used as indicators of fecal contamination due to the ease of their detection and quantification. Therefore, predicting the transport and fate of *E. coli* in a variety of geologic settings is important to assessing the likelihood of fecal contamination reaching a well.

The likelihood of allochthonous bacteria such as *E. coli* contaminating a well via transport in groundwater depends on many factors (Gerba et al., 1991; Harvey, 1991; Bitton and Harvey, 1992). The majority of previous studies used column experiments to examine the effects of individual factors on bacterial transport. These experiments focused on the effects of the bacteria themselves (Huyysman and Verstraete, 1993; McCaulou et al., 1994; Harvey et al., 1995; McCaulou et al., 1995; Weiss et al., 1995; Harvey et al., 1997), the physical and chemical properties of aquifer sediments (Fontes et al., 1991; Harvey et al., 1993; Morley et al., 1998; Fuller et al., 2000; Bolster et al., 2001; Dong et al., 2002), the presence of sediment surface coatings (Scholl and Harvey, 1992; Knapp et al., 1998; Bolster et al., 2001) and sediment organic content (Johnson and Logan, 1996). The influence of groundwater chemistry (mainly the ionic strength and pH) (Fontes et al., 1991; Scholl and Harvey, 1992; Gross and Logan, 1995; Jewett et al., 1995; Bolster et al., 2001) and hydraulic conditions (Morley et al., 1998; Hendry et al., 1999) have also been considered.

Most of these studies are not well suited for developing a practical predictive capability for two main reasons. First, most previous studies focused on the effects of individual factors on bacterial transport, and did not allow assessment of the combined effects on bacterial transport due to changes in more than one factor simultaneously. Second, most of the previous studies used columns packed with artificial aquifer material (such as commercial sand) or repacked with sieved and washed natural aquifer materials. Because artificial structures may be created during the repacking of columns (Harvey, 1997), or natural preferential pathways may be destroyed, bacteria may exhibit different transport behavior through intact natural sediment cores as compared to repacked artificial columns. Natural physical and chemical heterogeneities may also affect transport of bacteria (Fontes et al., 1991; Harvey et al., 1993; Mills et al., 1994; Morley et al.,