Journal of Environmental Management 91 (2009) 87–101

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Tool for assessment of process importance at the groundwater/surface water interface

Ravi C. Palakodeti, Eugene J. LeBoeuf*, James H. Clarke

Department of Civil & Environmental Engineering, VU Station B 351831, 2301 Vanderbilt Place, Nashville, TN 37235-1831, United States

ARTICLE INFO

Article history:
Received 1 January 2009
Received in revised form
26 June 2009
Accepted 15 July 2009
Available online 26 August 2009

Keywords:
Groundwater/surface water interface
Spreadsheet modeling
Ratio of process importance
Screening tool
Kinetic process

ABSTRACT

The groundwater/surface water interface (GWSWI) represents an important transition zone between groundwater and surface water environments that potentially changes the nature and flux of contaminants exchanged between the two systems. Identifying dominant and rate-limiting contaminant transformation processes is critically important for estimating contaminant fluxes and compositional changes across the GWSWI. A new, user-friendly, spreadsheet- and Visual Basic-based analytical screening tool that assists in evaluating the dominance of controlling kinetic processes across the GWSWI is presented. Based on contaminant properties, first-order processes that may play a significant role in solute transport/transformation are evaluated in terms of a ratio of process importance (P_i) that relates the process rate to the rate of fluid transfer. Besides possessing several useful compilations of contaminant and process data, the screening tool also includes 1-D analytical models that assist users in evaluating contaminant transport across the GWSWI. The tool currently applies to 29 organics and 10 inorganics of interest within the context of the GWSWI. Application of the new screening tool is demonstrated through an evaluation of natural attenuation at a site with trichloroethylene and 1,1,2,2-tetrachloroethane contaminated groundwater discharging into wetlands.

1. Introduction

Approximately 75% of Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) sites are located within one half mile of a surface water body and nearly 50% of all Superfund sites have impacted surface water (Conant, 2000; Tomassoni, 2000; Conant et al., 2004). The regulatory framework for addressing this problem is not completely developed; however, limited guidance exists through RCRA Corrective Action (CA 750) in the form of Environmental Indicators (EI). Part of the EI documentation for controlling migrating groundwater requires site managers to evaluate if there is a "significant" discharge, i.e., if the maximum concentration of each contaminant discharging is less than ten times the appropriate groundwater concentration and that the existing environmental conditions do not increase the potential for adversely impacting surface waters. While contaminant concentrations may be measured in vicinity of the discharge points for the purpose of this evaluation, delineating environmental conditions or transforming processes that may affect the composition or nature of the discharging plume at all suspected discharge locations is often difficult and expensive. In order to evaluate if exiting contaminants impact receiving surface water bodies, it is necessary to understand the conditions that exist close to the discharge areas and the processes that affect contaminant transport.

Contaminated groundwater discharging into surface water bodies traverses through the groundwater/surface water interface (GWSWI). GWSWI represents a hydraulically and biogeochemically complex aquifer zone near a surface water body that may be potentially important for evaluating contaminant transport and assessing overall ecological risk (USEPA, 2000; Medina et al., 2002; Ford, 2005; Smith, 2005). Many studies have shown that an emergent contaminant plume may be subject to dramatic changes in contaminant distribution, flux, and nature as it traverses GWSWI (Lendvay et al., 1998; Conant et al., 2004; Chapman et al., 2007). Additionally, several biogeochemical processes such as nitrification/denitrification (Capone and Bautista, 1985; Doussan et al., 1997; Grischek et al., 1998; Holloway and Dahlgren, 2001; Grimaldi et al., 2004), mineral weathering coupled to microbial degradation of organic carbon (Jacobs et al., 1988; Vongunten et al., 1991; Bourg and Bertin, 1993), and biological degradation or natural attenuation of organic compounds (Schwarzenbach et al., 1983; Vieux, 1991; Ahel et al., 1996; Lendvay et al., 1998; Lorah and Olsen, 1999b; Happell et al., 2003; Conant et al., 2004) have been documented in the literature that may potentially affect contaminant fate and

* Corresponding author. Tel.: +1 615 343 7070; fax: +1 615 322 3365.
E-mail address: eugene.j.leboeuf@vanderbilt.edu (E.J. LeBoeuf).

0301-4797/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2009.07.011

transport across the GWSWI (see Fig. 1 for additional processes that may occur at GWSWI). In the context of sites with emergent contaminant discharge issues, GWSWI may therefore represent a potential remedial zone and/or a transformation zone that could result in more toxic discharge to surface waters. Evaluation of dominant processes affecting transport through GWSWI thus represents a potentially important step in the evaluation and management of contaminated sites in close proximity to surface water bodies.

The transformation processes affecting a discharging contaminant depend on the properties of the specific contaminant (physical and chemical), and the environmental conditions characterizing the space through which the contaminants move (Westbrook et al., 2005). While the general properties of a known contaminant can be compiled from literature databases, existing conditions and dominant processes that affect fate and transport are site specific. Conditions at sites may be unique and it may be economically infeasible to perform comprehensive sampling or measure specific reaction products from potential transformation processes at all suspected locations. Therefore, a scientifically defensible and economically efficient identification of potentially dominating transformation processes is important for sites with GWSWI issues. A screening tool that not only evaluates the significance of transforming processes but also provides useful contaminant property information for various organics and inorganics will find best utility for this purpose.

Following the identification of dominant processes, site managers may also find utility in evaluating various case scenarios for contaminant transport through the use of simple screening-level analytical models. Analytical models represent the simplest of the contaminant mass transport models with exact solutions to the advection–dispersion–reaction equation with constant parameter values and simplified boundary conditions. These models, however, are restricted to modeling the transport of relatively few dissolved constituents in simplified systems. Despite these restrictions, analytical solutions are featured in popular spreadsheet tools such as the extensively used bioremediation tool, BIOSCREEN-AT (Karanovic et al., 2007) or the natural attenuation decision support system BIOCHLOR (Aziz et al., 2000; Clement et al., 2002). The ease of use and simplicity in modeling allow spreadsheet implementation of analytical models to serve as screening-level tools enabling decision makers to rapidly assess site conditions or investigate the need for higher model sophistication.

With the aim of catering to the abovementioned needs, the Tool for Assessment of Process Importance (TAPI) at the groundwater/surface water interface was designed to utilize user data input to evaluate the dominance of potential transformation processes and manage useful data pertaining to dissolved contaminants within the GWSWI environment. TAPI allows users to (i) evaluate dominance of kinetic processes through a proposed dimensionless ratio; (ii) access peer-reviewed data on contaminant properties and display environmental fate summaries for 29 organic contaminants and 10 metals of interest; (iii) access useful information for evaluating equilibrium processes such as sorption (soil/sediment organic carbon partition coefficients for organics (K_{oc}) and linear sorption coefficients for organics and inorganics (K_d)); (iv) evaluate redox conditions at sites (through Pourbaix diagrams for inorganics); and (v) perform screening-level evaluations of contaminant transport scenarios and assist in the decision to require additional sampling or develop complex site models in a scientifically defensible fashion.

In the first part of this article, we provide the basis for the proposed ratio for evaluating the importance of kinetic processes within GWSWI. The second portion presents the spreadsheet implementation of the proposed ratio along with other features of the tool. The third part employs the tool to demonstrate its utility for a site with volatile organic compound contamination. The final part provides discussion of observations from the demonstration and limitations of TAPI.

2. Ratio of process importance

TAPI is a screening tool that helps users evaluate the dominance of a kinetic transformation process within GWSWI. A transforming

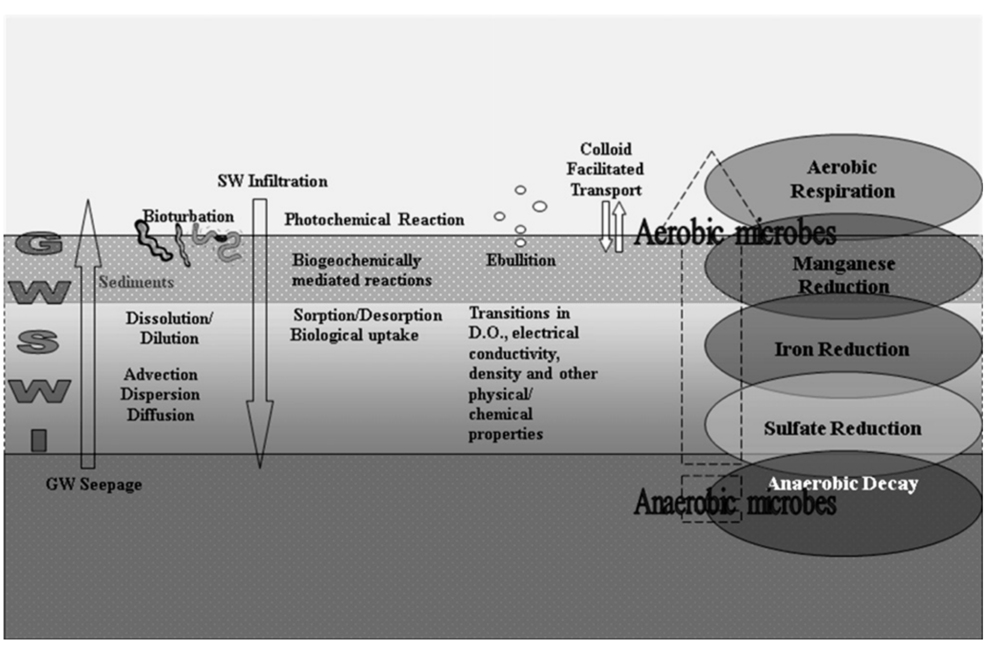

Fig. 1. Processes and conditions affecting contaminant transport across the GWSWI. GWSWI is characterized by physical processes such as advection and dispersion along with photochemical reactions and biologically mediated reactions which affect contaminant fate and transport. Further, the properties of the system such as transitions in redox potentials, dissolved oxygen, and contaminant properties such as density, and other physicochemical properties affect the applicable processes.