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Editorial

Groundwater Contamination, Subsurface Processes, and Remediation Methods: Overview of the Special Issue of Water on Groundwater Contamination and Remediation

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Abstract: This special issue of *Water* brings together ten studies on groundwater contamination and remediation. Common themes include practical techniques for plume identification and delineation, the central role of subsurface processes, the pervasiveness of non-Fickian transport, and the importance of bacterial communities in the broader context of biogeochemistry.

Introduction

Groundwater accounts for 99% of the global stock of liquid fresh water [1], and consequently provides a major source for agricultural, industrial, and domestic water consumption. For example, groundwater provides the drinking water supply for an estimated 44% of the population of the United States [2]. In many cases, groundwater quality can be superior to surface water quality, because its movement through the soils, granular minerals, and fractured rock that constitute aquifers provides natural filtration, which in turn reduces the concentration of suspended solids, organic materials, and microbial pathogens.

However, groundwater can also be vulnerable to contamination from natural and anthropogenic sources, the latter of which can be introduced into aquifers through accidental spills, surface leaching, waste ponds, septic systems, road salting, road runoff to recharge basins, landfill leachate, and saltwater intrusion due to overpumping. Once contaminated, groundwater remediation is notoriously challenging, for a number of reasons. First, flow through porous media is slow, which not only limits the rate at which contaminants can be removed, but also imposes a fundamental limitation on the mixing of treatment amendments with contaminated groundwater: Groundwater flow is almost universally laminar, so turbulent mixing is not an option, in stark contrast to most applications of engineered fluid mixing. Second, in many cases, contaminants sorb onto aquifer materials, so remediation is challenging for the same reason that treating a biofilm infection on human tissue is challenging—it is difficult to treat contaminants fixed on surfaces [3]. And third, there is never complete information about the subsurface, so uncertainty is intrinsic, and judgment is required. With such an important resource presenting such challenges, it comes as no surprise that groundwater remediation is a major branch of environmental science and engineering, with active research spanning more than five decades, and with annual spending in the billions of dollars (e.g., [4]).

This special issue of *Water* brings together ten original studies, focused on groundwater contamination and remediation, that were solicited from December 2017 and submitted through August 2018. This overview is organized under the broad headings of groundwater contamination, subsurface processes, and remediation methods, where the central heading of subsurface processes provides the essential link between the problem of contamination and the solution of remediation.

Groundwater Contamination

The studies in this special issue address a broad spectrum of groundwater contaminants, which can be classified into natural sources (e.g., arsenic or salinity), anthropogenic sources (e.g., industrial chemicals, pesticides, or sewage effluent), and emerging contaminants (e.g., nanoparticles or hydraulic fracturing fluids). Under the heading of natural sources, Vera et al. [5] focus on arsenate, and Haluska et al. [6] address sulfate—whose source can be natural or anthropogenic. Most of the studies considered anthropogenic sources, with Beretta et al. [7] and Haluska et al. [6] addressing the industrial additive and known carcinogen hexavalent chromium, Plymale et al. [8] focusing on the toxic salt ferrocyanide, Haluska et al. [6] measuring the organic contaminants 1,4-dioxane and hexahydro-1,3,5-trinitro-s-triazine (RDX), Prieto-Amparán et al. [9] studying sewage effluent, and Wells et al. [10] tracking the fertilizer-derived anion nitrate. As a particular subset of anthropogenic contaminants, two studies discuss emerging contaminants, particularly related to hydrocarbon resources, as Hu et al. [11] study oil shale development, while Ning et al. [12] focus on petroleum contamination.

Subsurface Processes

Most of the studies in this special issue have placed their emphasis on subsurface processes, the essential link between contamination and remediation. To facilitate the discussion, these studies will be discussed under two headings: Critical processes controlling contaminant sources, transport, and fate; and methods to identify the concentration and extent of contaminant plumes.

Regarding critical processes, Lu et al. [13] bring us up-to-date with a comparison of models for non-Fickian transport, reflecting the consensus that the traditional model of Fickian dispersion of solutes, including contaminants, has serious limitations. In parallel, Hu et al. [11] discuss the potential impacts from emerging contaminants related to oil shale development. Three studies explore the central role of biology in groundwater remediation, reflecting our new understanding of subsurface processes through the interdisciplinary lens of biogeochemistry: Ning et al. [12] study the spatial pattern of bacterial communities at a petroleum-contaminated site; Plymale et al. [8] study bacterial communities at a nuclear waste-contaminated site; and Moradi et al. [14] contribute a model describing thermally-enhanced bioremediation. Taken together, these studies demonstrate that our ability to remediate groundwater depends on knowing the contaminants, understanding the fluid mechanics, and interpreting processes in the context of hydrology, geochemistry, and microbiology.

Regarding methods to identify the concentration and extent of contaminant plumes, two studies present methods applicable to individual wells, specifically Haluska et al. [6] who consider passive flux meters for measuring a variety of organic and inorganic contaminants, and Vera et al. [5] who discuss polymer inclusion membranes for measuring arsenate. Two other studies present methods for regional groundwater analysis, including Wells et al. [10] who highlight the application of groundwater isotopes, age-dating, and monitoring to identify nitrate plumes in an agricultural region and Prieto-Amparán et al. [9] who present a multivariate and spatial analysis to map sewage contamination. Taken together, these four studies minimize uncertainty, and therefore address a fundamental challenge in groundwater remediation.

Remediation Methods

The call for papers for this special issue invited papers addressing passive methods, such as monitored natural attenuation, and ex-situ methods, such as pump-and-treat, but the response focused entirely on in-situ methods, such as bioremediation or chemical oxidation. In particular, two studies present novel approaches to predict and enhance the performance of remediation techniques: Beretta et al. [7] present a support tool for identifying remediation options for hexavalent chromium, while Moradi et al. [14] offer an original cross-pollination between bioremediation and energy storage, both of which depend on subsurface temperature. These papers show, once again, the value of creativity in science.

Conclusions

To draw out a few common themes, the studies in this special issue offer practical techniques for plume identification and delineation, emphasize the central role of subsurface processes, acknowledge the pervasiveness of non-Fickian transport, and embrace the importance of bacterial communities in the broader context of biogeochemistry. Reflecting on this special issue as a whole, and on the much larger contemporary literature on groundwater contamination and remediation, one recalls Schwartz and Ibaraki's rhetorical question on hydrogeological research: Is this the beginning of the end, or the end of the beginning [15]? The breadth and depth of research reflected here suggests that 2001 was the end of the beginning. This conclusion is not surprising, of course, when one recognizes that Schwartz and Ibaraki's rhetorical question [15] predated much of our current understanding of non-Fickian transport, bacterial communities, and biogeochemistry. We invite you to study this special issue, to find for yourself some of the technical methods and broader perspectives required for effective groundwater remediation.

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