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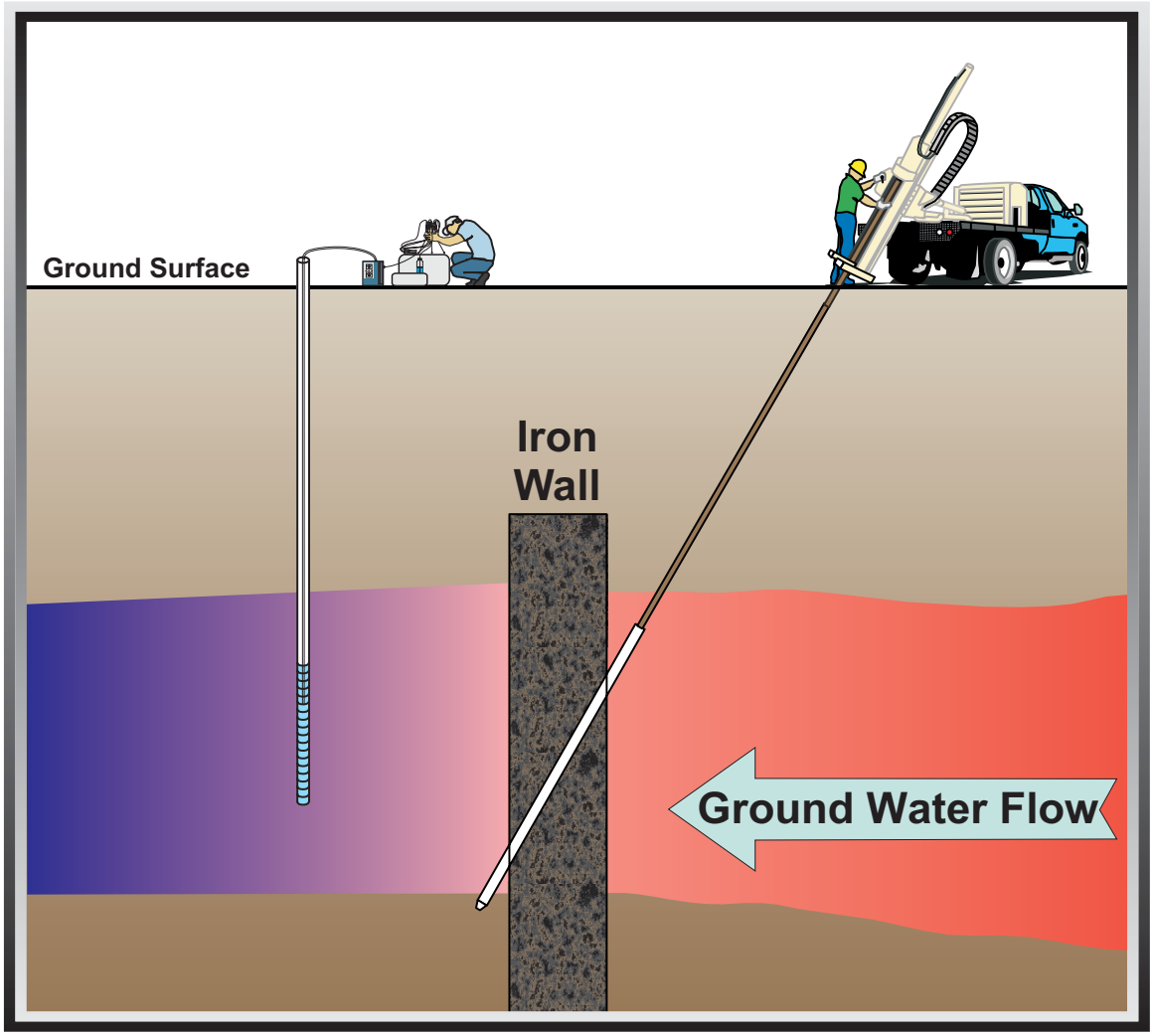
Capstone Report on the Application, Monitoring, and Performance of Permeable Reactive Barriers for Ground-Water Remediation:

Volume 1

Performance Evaluations at Two Sites



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Capstone Report on the Application, Monitoring, and Performance of Permeable Reactive Barriers for Ground-Water Remediation:

Volume 1 – Performance Evaluations at Two Sites

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Notice

The U.S. Environmental Protection Agency through its Office of Research and Development funded the research described here. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

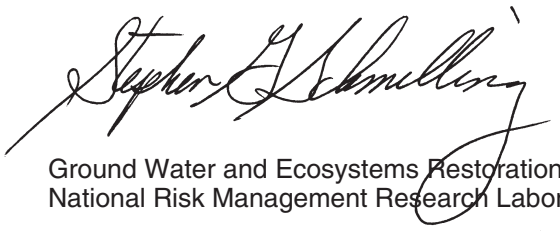
All research projects making conclusions or recommendations based on environmentally related measurements and funded by the Environmental Protection Agency are required to participate in the Agency Quality Assurance Program. This project was conducted under an approved Quality Assurance Project Plan. The procedures specified in this plan were used without exception. Information on the plan and documentation of the quality assurance activities and results are available from the Principal Investigator.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development (ORD) to assist the user community and to link researchers with their clients. The purpose of this document is to provide detailed performance monitoring data on full-scale Permeable Reactive Barriers (PRBs) installed to treat contaminated ground water at two different sites. This report will fill a need for a readily available source of information for site managers and others who are faced with the need to remediate ground water contaminated by chlorinated solvents, chromium, arsenic, nitrates, and other organic and inorganic compounds and are considering the use of this cost-effective technology. The PRBs discussed in this report are among the oldest full-scale systems available for study and provide an opportunity to analyze the performance of systems with more than five years of field history. In addition, the PRBs examined here have contrasting design and hydrogeochemical characteristics that are useful in the context of gaining insight about the factors that govern PRB longevity and long-term performance. The information provided in this document will be of use to stakeholders such as state and federal regulators, Native American tribes, consultants, contractors, and other interested parties.



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Abstract

Research results discussed in this report explore the geochemical and microbiological processes within zero-valent iron Permeable Reactive Barriers (PRBs) that may contribute to changes through time in iron reactivity and decreases in reaction zone permeability. Two full-scale PRBs were evaluated in this study: the U.S. Coast Guard Support Center PRB located near Elizabeth City, North Carolina, and the Denver Federal Center PRB in Lakewood, Colorado. Detailed water sampling and analysis, core sampling, and solid-phase characterization studies were carried out to: i) evaluate spatial and temporal trends in contaminant concentrations and key geochemical parameters; ii) characterize the type and nature of surface precipitates forming over time in the reactive barriers; and iii), identify the type and extent of microbiological activity within and around the reactive barriers.

Trends in geochemical parameters (e.g., pH and oxidation-reduction potential) may signal changes in system performance, but no clear correlations between these parameters and decreased system performance have been observed to date at the sites studied. Long-term trends in geochemical parameters are consistent with contaminant removal trends observed at both sites. Spatial and temporal variations in the concentration distribution of terminal electron accepting species (e.g., sulfate), specific conductance, and Eh suggest that both anaerobic iron corrosion and microbial activity play important roles in controlling the oxidation-reduction potential in iron barriers. Low Eh values ($\leq$100 mV relative to the standard hydrogen electrode) and decreases in the specific conductance of ground water between upgradient contaminant plumes and sampling points within reactive iron media are consistently observed in normally operating PRB systems.

The rate of mineral and biomass buildup was evaluated at both sites. The principal factors that determine the amount of mineral precipitation in zero-valent iron PRBs are flow rate, ground-water chemistry, and microbial activity. After five years of operation, the Elizabeth City and Denver Federal Center reactive barriers have developed consistent patterns of spatially variable mineral precipitation and microbial activity. The development of precipitation and biomass fronts result from abrupt geochemical changes that occur at upgradient interface regions coupled with ground water solute transport. Upgradient regions at both sites investigated in this study have witnessed the greatest accumulation of mineral mass and biomass. However, neither of the sites of this study show complete filling of available pore space after five years, suggesting that flow characteristics should not be affected by the accumulation of authigenic components. For zero-valent iron systems, the reactive media is a long-term sink for C, S, Ca, Si, Mg, and N. Porosity loss in the iron media due to precipitation of inorganic carbon and sulfur minerals can be estimated by integrating the concentrations of inorganic carbon and sulfur as a function of distance in the iron and estimating the volume loss by using the molar volumes of zero-valent iron, calcium carbonate, iron carbonate, and iron sulfide. Porosity loss estimates have ranged from about 1% to 4% per year in this study. Based on these estimates, the average porosity of the PRB at Elizabeth City, for example, would not be expected to approach that of the surrounding aquifer for 15 to 30 years. As corrosion minerals form on the surface of the iron media, reactive surfaces are coated, presumably decreasing the effective reactive surface area. However, corrosion products formed include some minerals which themselves are highly reactive and capable of transforming inorganic and organic contaminants into immobile or non-toxic forms. This phenomenon must also be factored into lifetime projections.

While long-term performance observations of the Elizabeth City and Denver Federal Center site are now past five years, there has still not been sufficient time to adequately predict the lifetime of these PRBs or most other PRBs. It is clear that lifetimes exceeding 10 years are reasonable to expect under some conditions and that PRBs may function adequately for much longer. Continued studies are needed to better predict longevity based on ground-water composition, flow rate and contaminant flux.

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