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7 IN SITU REACTIVE WALLS

7.1 INTRODUCTION

In situ reactive walls are an emerging technology that have been evaluated, developed, and implemented only within the last few years. This technology is gaining widespread attention due to the increasing recognition of the limitations of pump and treat systems, and the ability to implement various treatment processes that have historically only been used in above-ground systems in an in situ environment. This technology is also known in the remediation industry as “funnel and gate systems” or “treatment walls” and will be referred to as in situ reactive walls in this chapter.

The concept of in situ reactive walls involves the installation of impermeable barriers downgradient of the contaminated groundwater plume and hydraulic manipulation of impacted groundwater to be directed through porous reactive gates installed within the impermeable barrier. Treatment processes designed specifically to treat the target contaminants can be implemented in these reactive or treatment gates. Treated groundwater follows its natural course after exiting the treatment gates. The flow through the treatment gates is driven by natural groundwater gradients, and hence these systems are often referred to as passive treatment walls. If a groundwater plume is relatively narrow, a permeable reactive trench can be installed across the full width of the plume, and thus preclude the necessity for installation of impermeable barriers.

In situ reactive walls eliminate or at least minimize the need for mechanical systems, thereby reducing the long-term operation and maintenance costs that so often drive up the life cycle costs of many remediation projects. In addition, groundwater monitoring and system compliance issues can be streamlined for even greater cost savings.

Most of the developmental work on in situ reactive walls was performed at the Waterloo Center for Groundwater Research, University of Waterloo, Ontario, Canada. Since this is an innovative and emerging technology, as of yet there are not many reported case studies in the literature.

7.2 DESCRIPTION OF THE PROCESS

Application of in situ reactive walls should be considered as an alternative to pump and treat systems. Reactive walls can be installed at the downgradient edge of the plume as a containment system and/or immediately downgradient of the source area to prevent further migration of elevated levels of contaminant mass. Physical, chemical, or microbial processes can be implemented at the porous reactive gates.
Several configurations of *in situ* reactive walls systems are feasible, and the applicability of this technology will depend on the geologic and hydrogeologic conditions, as well as contaminant distribution in the vertical and horizontal dimensions at a given site.

### 7.2.1 Permeable Reactive Trench

The simplest configuration is a permeable reactive trench that extends across the entire width of the plume (Figure 7.1). This system can be installed by digging a trench and filling it with permeable material to create an artificially permeable environment. The permeable material selected will depend upon the required porosity and permeability in the trench. As the contaminant plume moves through the wall, contaminants can be removed by various mass transfer processes such as air stripping, biodegradation, adsorption, and metal-enhanced dechlorination. Suitability of this configuration for a specific site will depend upon the contaminant type and distribution, preferred mass removal process, geologic and hydrogeologic conditions, and ease of implementation of the selected process in a cost-effective manner.

Permeable reactive trenches can be considered as a system that incorporates an *in situ* reactor to achieve the same mass transfer reactions that are utilized in an above-ground treatment system during a pump and treat operation. It should be noted that the *in situ* system has a distinct advantage over above-ground systems due to the significantly higher residence times available within the *in situ* reactor. Typical groundwater flow velocities will provide residence times of days, if not weeks, within the *in situ* reactor in comparison to minutes or hours available in above-ground reactors. As a result, mass removal efficiencies could be expected to reach close to 100% in a properly designed system. However, other more cost-effective configurations may be available to achieve the same mass transfer process depending on the site geologic conditions. For example, if the geology is homogeneous and permeable and the contamination is deep, conventional air sparging (with air injection wells) may be more cost-effective in comparison to permeable reactive walls with air injection points. If
the geology is less permeable and contamination is shallow, permeable reactive walls may be the preferred treatment technique.

Table 7.1 describes the potential mass transfer reactions suitable for implementation within the reaction trench for various contaminants.

### 7.2.2 Funnel and Gate Systems

Funnel and gate systems can be implemented using various configurations, depending upon the plume width and depth and the type of mass transfer reaction required. Options for the funnel (cut-off walls) include sheet pile walls or slurry walls and options for the gate include permeable nonreactive materials such as pea gravel (for air sparging) or oyster shells (for biodegradation) and reactive materials such as activated carbon or zero-valence iron.

#### 7.2.2.1 Single Gate System

The simplest configuration is a single gate with cut-off walls extending on both sides of the gate (Figure 7.2). This configuration is more suitable for a narrow, elongated plume. Funnel and gate systems can be constructed through the entire thickness of an aquifer, if the contamination extends across the full depth of an aquifer, as seen in situations where DNAPLs are present. When the contaminant plume is shallow, as may be the case under LNAPL conditions, penetration of the system may be required only to the depth of contamination.

The above two configurations are known as a *fully penetrating gate system* and a *hanging gate system*, respectively (Figure 7.3).

The main advantage of a funnel and gate system over a permeable reactive trench, across the full plume width, is that a smaller-scale reactor, at the gate, is used for treating a given plume at a lower cost. If a reactor requires periodic media replacement (such as a carbon or ion exchange bed) or flushing out the precipitated metals it will be easier to accomplish the change out using a “small” gate.

<table>
<thead>
<tr>
<th>Contaminant(s)</th>
<th>Air stripping</th>
<th>Aerobic biodegradation</th>
<th>Absorption; (carbon, ion exchange)</th>
<th>Abiotic dechlorination</th>
<th>Anaerobic biodegradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCE, PCE, DCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene, toluene, ethyl benzene, xylenes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohols, acetone, MEK, ketones, phenol Dissolved heavy metals (Pb, Zn, Ni) NO$_3$^-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 7.2](image)

*Figure 7.2* Possible configurations of single gate funnel and gate system.
The type of treatment processes potentially applicable at the gate include:

- air stripping, volatilization
- microbial degradation
- adsorption (carbon or ion exchange)
- chemical oxidation
- metal enhanced dechlorination
- metals precipitation

As can be seen from the above list, most treatment processes used in an above-ground pump and treat system can be implemented in an in situ reactor by carefully designing a funnel and gate system. In addition, physical recovery techniques for LNAPL and DNAPL recovery can also be implemented within the gate.

The funnel and gate geometry required to direct all the contaminated groundwater through the gates and the ease of installation of the selected configuration will determine the applicability in most cases. Selected mass removal reactions to address the specific contaminants and the ease of implementation will also influence the applicability of funnel and gate systems. Table 7.2 describes the potential mass removal reactions for various contaminants that could be implemented within the reactor gate.

When dealing with a groundwater plume that contains multiple contaminants, two or more gates in series may be required to implement different mass removal reactions. For example, a plume containing trichloroethylene (TCE) and acetone may require a gate with an air injection and extraction system (for removing TCE) to be followed by a fixed film bioreactor gate (for degrading acetone). If the same plume has pentachlorophenol (PCP) in it, a third gate with activated carbon may be required for PCP removal. Gates in series are shown in Figure 7.4.
### Table 7.2 Potential Mass Removal Reactions for Various Contaminants in the Gate

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Air stripping volatilization</th>
<th>Microbial degradation</th>
<th>Adsorption (carbon, ion exchange)</th>
<th>Chemical oxidation ((O_3, H_2O_2))</th>
<th>Metal enhanced dechlorination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorinated aliphatics (TCE, PCE, DCE)</td>
<td>•</td>
<td></td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Benzene, toluene, ethyl benzene, xylenes</td>
<td>•</td>
<td></td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Chlorinated aromatics (pentachlorophenol)</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Alcohols, ketones, phenols (acetone, MEK, phenol)</td>
<td>•</td>
<td></td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Dissolved heavy metals (Pb, Ni, Zn, Cd)</td>
<td></td>
<td></td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>1,4-Dioxane</td>
<td></td>
<td></td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7.4** Illustration of reactive gates in series.

**Figure 7.5** Multiple gate configuration of a funnel and gate system.
7.2.2.2  Multiple Gate System

When the contaminant plume is relatively wide, multiple gates may be required to direct contaminated groundwater to flow through the gates (Figure 7.5). Multiple gate systems can be installed as fully penetrating or hanging gates as dictated by the depth of contamination. When designing a multiple gate system, a balance between maximizing the size of the capture zone for a gate and maximizing the retention time in the gate should be achieved. In general, capture zone size and retention time are inversely related.¹

Mass removal reactions discussed in Table 7.2 can also be implemented in multiple gate systems. The width and depth of the funnel (cut-off wall), the required number of gates, and the total width of the gates play a significant role in deciding whether this technique is the most cost-effective alternative to address a given contaminated site.

7.3  DESIGN APPROACHES

As noted earlier, design of in situ reactive walls is influenced by site geologic and hydrogeologic conditions and the type, concentrations, and vertical and lateral distribution of the contaminants. Optimal system geometry will be influenced by the geologic and hydrogeologic conditions as well as by the contaminant distribution. Selection and design of the reaction processes in the gate will be influenced by the contaminant type and concentrations.

7.3.1  System Geometry

System geometry is a simplified term describing the dimensions of the cut-off walls, gates, and the trench and the number of gates in parallel or in series. The orientation of the system in relation to the contaminated groundwater flow direction will also influence the system geometry considerations. The designer has to balance several conflicting criteria when designing an in situ reactive wall system. For example, the designer has to balance the need for more gates to better control groundwater flow with the need to minimize the number of gates to be cost-effective in implementing the required reaction processes. In most cases construction of the gates is far more expensive than the cut-off walls. Hence the optimum design will minimize the number and width of gates while still accommodating flow from the entire contaminated plume and providing adequate residence time within the gate.

As a result, the designer should rely upon groundwater flow and transport models to evaluate the most effective configuration from both technical and economic viewpoints. Iterative modeling simulations and particle tracking should be performed to arrive at the optimum configuration.

The factors that should be evaluated during the modeling exercise include the following:

- Total width of the wall and the minimum number of required of gates
- Particle tracking for the selected configuration to ensure complete capture of the plume
- Residence times through the gates
- Back-pressure development when the number of gates are inadequate and the resulting “dam” effect
- Potential for fouling with time and hence increased resistance to flow through the gates
- Impacts due to water table fluctuations and natural variation in flow directions
- Any geologic/hydrogeologic anomalies that may lead to preferential flow within the contaminated plume
- If the proposed system is a hanging gate system (Figure 7.3B), the potential for any underflow of the contaminated water
- Model calibration and sensitivity to the site-specific hydrogeologic parameters such as hydraulic conductivity and transmissivity

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Selection of optimal system geometry for the permeable reactive trench system is much simpler than for the funnel and gate system. Since the trench is constructed with a much more permeable media than native soils, there will be less hydrogeologic concerns for achieving complete capture of the plume. Constructibility of the trench in a cost-effective manner will determine the depths to which this system can be installed.

### 7.3.1.1 Funnel Width and Angle

Increased funnel (cut-off wall) widths provide a larger capture zone, and thus the required flow capacity through the gates will have to be increased accordingly. Beyond the localized influence around the cut-off walls, the width of the capture zone is generally proportional to the flow through the gate for a given site. The required capture zone will determine the optimum funnel width and the number of gates.

It has been shown that the maximum discharge and capture occurs when the funnel is perpendicular to the groundwater flow direction,\(^1\) Figure 7.6A. The effective width of the funnel decreases when the funnel is not straight and has an apex angle. U-shaped funnels provide a smaller capture zone in comparison to a straight funnel of the same length (Figure 7.6B).

### 7.3.1.2 Gate Width

As the total width of the gate(s) increases, via a single gate or multiple gates, relative to the total funnel width, the absolute and relative flow and the width of the capture zone increase. The *absolute flow* is defined as the flow through the gate(s) at a given time. The *relative flow* is the fraction of flow intersected by the funnel width which flows through the gate(s). It is calculated by dividing the flow through the gate(s) by the flow through a section of the aquifer equal to the width and depth of the funnel at an upgradient location in the absence of the funnel and gate system.

A gate that is as wide as possible is always desirable. However, economic considerations may limit this desirable objective.

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\(^1\) Figure 7.6
Illustration of effective width of a funnel and impact on capture zone by the funnel configuration. a) Comparison between straight- and apex-angled funnels. b) Comparison between straight- and U-shaped funnels.
7.3.1.3  Gate Permeability

It is easy to understand that when the permeability of the gate is higher, the flow through the gate also will be higher. However, it has been reported that there is relatively little increase in flow through the gate when the gate permeability is greater than 10 times that of native soils of the aquifer. This is due to the fact that flow is limited by the transmissivity of the aquifer upgradient and downgradient of the gate. While there is a general tendency among designers of funnel and gate systems to make the gate permeability as high as possible, very high values are not required for proper functioning of the system and may not be desirable due to the potentially shortened residence times. However, consideration should be given to the potential fouling of the gate media due to microbial growth and/or inorganic precipitation, and the eventual decrease in gate permeability. In addition, mass removal reactions such as adsorption or biodegradation via immobilized biomass may require increased surface area in the reactor media. Under these circumstances, the porosity of the media that will provide a higher permeability will have to be balanced with the need to have a higher available surface area. Media with higher available surface area will be of finer particles and thus will have a lower porosity.

7.3.2  System Installation

In addition to being cost-effective, in situ reactive wall systems should be able to last for years with little or no maintenance. System installation objectives should also be cost-effective in order to enable the in situ reactive wall technology as the preferred remediation alternative at a given site. In situ reactive walls may require a high initial capital investment in some cases, but long-term life cycle cost savings will be realized from greatly reduced operating, maintenance, and monitoring costs.

7.3.2.1  Permeable Reactive Trenches

Construction of a permeable reactive trench will be very much influenced by the depth to which the trench has to be excavated. The biggest drawback for choosing this technique is the cost of disposing the contaminated soil removed during excavation. The deeper the trench has to be, the wider it may need to be to facilitate installation. In certain situations, a portion of the contaminated soil can be backfilled on top of the more permeable media such as pea gravel (Figure 7.7) and soil vapor extraction (SVE) can be installed to remediate VOC-contaminated soil. If in situ air stripping or aerobic biodegradation is the selected technology to be implemented in the trench, an SVE system may have to be installed anyway to collect the stripped vapors.

There are various methods to install a trench. Backhoes, or trenchers (also known as ditchers), can be used to excavate the trenches. Depending on the depths of excavation and location of the trenches, shoring techniques may have to be implemented to prevent trench collapse. If the trench has to be excavated near a building, shoring may be required to ensure the safety of the building foundations. Application of a biodegradable slurry has been used in the recent past to minimize the cost of shoring. The slurry helps to stabilize the slopes until the backfill material is placed in the trench. The slurry will be completely biodegraded within a short time frame and the trench will, thus, function as a permeable trench.

Various backfill materials, depending on the reactive processes taking place in the trench, can be used as the porous media in the trench. Table 7.3 describes the various porous media that can be used as the backfill material.

7.3.2.2  Types of Funnel Walls

There are various types of impermeable or less permeable subsurface barriers that can be used as cut-off walls in a funnel and gate system. The purpose of the cut-off walls is to
erect a continuous impermeable barrier to direct the contaminated groundwater to flow through the gates to be remediated. Slurry walls, sheet pile walls, and geomembranes are commonly used techniques to construct the cut-off walls.

### 7.3.2.2.1 Slurry Walls

Slurry walls are a means of placing a low-permeability, subsurface cut-off wall. They consist of vertically excavated trenches that are initially filled with low permeability materials. These walls are described by the material used to backfill the slurry trench. Soil–bentonite walls are composed of soil materials (often the trench spoils) mixed with bentonite slurry. Cement–bentonite walls are constructed using a slurry of Portland cement and bentonite and set to form a permanent, low-permeability wall. Diaphragm walls are installed of precast or cast in place reinforced concrete panels (diaphragms) installed during slurry trenching. Each of these, as well as hybrids of the three, have different characteristics and applications.

Deep soil mixing can also be used in the construction of slurry walls. Deep soil mixing walls are installed using large overlapping augers equipped with mixing paddles. As the group of augers is advanced into the ground, additives such as bentonite or cement are injected and mixed with the soil. Construction costs for deep soil mixing are compatible with slurry walls. In general, soil–bentonite slurry walls are less permeable and more resistant to chemical degradation than cement–bentonite walls. Slurry walls can be constructed to significant depths (150 to 200 ft).

Due to the subsurface nature of construction, there could be some construction and postconstruction defects encountered during slurry wall construction. These defects include zones of the wall that may not provide the same resistance to groundwater flow as the good,
intact portions of the same wall; poorly mixed backfill; trapped pockets of slurry; and loss of the filter cake in portions of the trench wall. Postconstruction defects include cracking due to change in moisture, temperature, consolidation and stress as well as increase in permeability due to chemically aggressive contaminants.

Table 7.4 presents the estimated permeability of various slurry walls. As expected, laboratory results performed under controlled conditions exhibit much lower permeabilities than field conditions.

<table>
<thead>
<tr>
<th>Material</th>
<th>Permeability (lab) cm/s × 10⁻⁸</th>
<th>Permeability (field) cm/s × 10⁻⁸</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentonite slurry</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Cement—bentonite</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Compacted soil—bentonite</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Soil—cement</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>Cement—grout</td>
<td>0.1</td>
<td>1,000</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.1</td>
<td>—</td>
</tr>
<tr>
<td>Silicate grout</td>
<td>47</td>
<td>10,000</td>
</tr>
</tbody>
</table>


It is known that some contaminants can react with barrier materials and potentially cause significant increases in permeability over time. Bentonite-based slurry walls tend to fare poorly with some organic contaminants. However, proprietary mixes of treated bentonite may provide satisfactory performance under appropriate conditions.

A structural cap may have to be installed to maintain the strength and integrity of the slurry walls. At a site with significant vehicular traffic, a structural cap on the wall will be required.

### 7.3.2.2 Sheet Pile Walls

An impermeable or low-permeable cut-off wall can be installed using closely spaced steel sheet piles in a longitudinal direction. However, the space between adjoining sheet piles may allow leakage of contaminated groundwater without being deflected toward the gate for treatment. The concept of driving sheet piles and sealing the joints between adjacent piles was recently introduced, specifically for the purpose of installing funnel and gate systems. This proprietary technique, known as the Waterloo Barrier™, incorporates a sealable cavity into the pile interlocks (Figure 7.8). Extensive field-scale tests conducted indicate that bulk hydraulic conductivity values of less than 10⁻⁸ cm/s can be achieved with this arrangement.

The sheet pile cut-off wall can be installed using conventional pile driving techniques. Vibratory or impact pile drivers can be used depending upon the soil conditions. Vibratory equipment is suitable for most soil conditions, but better results can be achieved with impact equipment in certain cohesive soils. A foot plate at the toe of each larger interlock prevents most of the soil from entering the sealable cavity during driving. After the pile driving is done, the cavities are water jetted to remove the loose soil caught up in the interlocks. A number of clay-based, cementitious polymer and mechanical sealants are available to meet a variety of site conditions.

Potential leak paths through the barrier are limited to the sealed joints, and therefore the joints should be inspected before the sealing operation to confirm that the complete length of the cavity is open and can be sealed. Each joint should be sealed from bottom to top, facilitating the emplacement of sealant into the entire length of the joint.
7.3.3 Applicable Reactive Processes

Construction and operation of the in situ reactor is the key to successful implementation of any in situ reactive wall system. Several types of in situ reactors can be installed.

7.3.3.1 Air Stripping

Application of air stripping in below-ground, in situ systems is often called air sparging. The application of this technology in specially designed subsurface reactors or trenches should be considered as equivalent to operating an in situ air stripper.

Volatile organic compounds (VOCs) can be easily stripped from contaminated groundwater by injecting air into specially designed in situ reactors. Strippability of dissolved contaminants is governed by the Henry’s law constant (Appendix C). In general, the higher the Henry’s law constant, the more readily a compound would partition to the vapor phase.

In situ air strippers can be installed in the form of sparging trenches (Figure 7.9) or sparging gates/wells. The most economical configuration of a sparging gate is shown in Figure 7.10 and Figure 7.11 for shallow and deeper depths, respectively. The system shown in Figure 7.10 was installed at a site where the depth to the confining bedrock layer was less than 15 ft. A concrete vault with two chambers was constructed as the reactor gate. Clean sand and pea gravel were filled on both sides of the reactor gate to facilitate the flow of water through the gate. The chamber with packing material was provided as a means to develop a bacterial culture to enhance the microbial degradation of the contaminant at this site.

Figure 7.11 shows the configuration of an air stripping well, where the contaminated groundwater water is directed to flow through the well into which compressed air is injected. Injected airflow rates can be optimized to achieve the required stripping efficiencies. Due to the groundwater velocities encountered at most of the sites, the residence time in the in situ air strippers will be more than sufficient to achieve the required stripping efficiencies. The stripped contaminants can be easily collected, via a vapor extraction system, and treated prior to discharge to the atmosphere.

7.3.3.2 In Situ Bioreactors

When the contaminants present in the groundwater are aerobically biodegradable, implementation of an in situ bioreactor will minimize the overall system cost by minimizing the need for treatment of stripped contaminants or the replacement of adsorption media.

The configurations shown in Figures 7.9 and 7.10 can be easily converted into a bioreactor when the conditions are shallow. Air injection rates required for the operation of the bioreactor will be significantly lower than those required for air stripping. At steady state, most or all of the contaminant mass will be biodegraded, and hence the need for capturing the injected air can be eliminated. If the in situ reactive wall system is to function as a bioreactor, the
porous media used in the trenches or the gate should be able to support the growth of the biomass. The rough surface of oyster shells is an example, where the enhanced attachment will increase the biomass per unit volume of the reactor.

A single well as shown in Figure 7.11 will not be able to achieve complete biodegradation of the contaminants due to insufficient reactor volume. Growth of biomass in a small reactor volume will also increase the resistance to flow through the gate. Multiple wells placed parallel to each other (Figure 7.12) will be adequate to maintain an in situ bioreactor, especially under deep situations.

Inoculation or seeding of the biomass into the in situ reactor should be accomplished with a microbial population acclimated to the contaminants present in the groundwater. A small above-ground tank filled with contaminated groundwater, collected from the source area of the plume, should be aerated with increasing levels of contamination for a few weeks. The water in the tank should be emptied into the in situ reactor when it becomes cloudy with a significant microbial population.

Contaminants that are readily degraded under anaerobic or anoxic conditions can also be treated in an in situ bioreactor. The same configurations shown in Figures 7.9, 7.10, and 7.11 can be used for the implementation. However, the dissolved oxygen or other electron acceptors, such as NO$_3^-$, and SO$_4^{2-}$ present in the incoming groundwater may have to be removed prior to the entrance into the bioreactor. Injection of an innocuous readily biodegradable (labile) compound such as sugar into the surrounding trenches or in an upgradient location will maintain anaerobic or anoxic conditions in the reactor.
7.3.3.3 Metal-Enhanced Abiotic Dechlorination

Metal-enhanced abiotic dechlorination is a new twist on the age-old corrosion process. The use of zero-valence metals in the degradation of chlorinated aliphatic compounds and the potential application in an *in situ* environment have been studied at the University of Waterloo during the last few years.\(^6^,^7\) Reductive dechlorination of pesticides was reported as early as 1972.\(^8\)

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\(^8\) Reprinted with permission from CRC Press, LLC.
The mechanism of reductive dechlorination is explained by the following equation.\(^9\)

\[
Fe^0 + RCl + H^+ \rightarrow Fe^{2+} + RH + Cl^-.
\]  

(7.1)

Alkyl chlorides, RCl, can be reduced by iron and, in the presence of a proton donor such as water, they will undergo reductive dechlorination. The reaction represented by the above equation is a well-known member of a class of reactions known as dissolving metal reductions.\(^9\)

The net reductive dechlorination by iron (equation (7.1)) is equivalent to iron corrosion with the alkyl chloride serving as the oxidizing agent. The characteristic reaction of iron corrosion, shown by the following equation, results in oxidative dissolution of the metal at or neutral pH.\(^10\)

\[
Fe^0 - 2e \leftrightarrow Fe^{2+}.
\]  

(7.2)

In the absence of strongly oxidizing solutes, dissolved oxygen, when present, is the preferred oxidant, resulting in rapid corrosion.

\[
2Fe^0 + O_2 + 2H_2O \leftrightarrow 2Fe^{2+} + 4OH^-.
\]  

(7.3)

Further oxidation of Fe\(^{2+}\) by O\(_2\) leads to the formation of rust (ferric hydroxide). Water alone can serve as the oxidant under anaerobic conditions according to the following equation.

\[
Fe^0 + 2H_2O \leftrightarrow Fe^{2+} + H_2 + 2OH^-.
\]  

(7.4)

Both reactions (7.3) and (7.4) result in increased pH, and this effect is more pronounced under aerobic conditions due to the rapid rates of corrosion. The pH increase favors the formation of iron hydroxide precipitates, which may form a surface layer on the metal, thus inhibiting its further dissolution.

The above discussion suggests\(^9\) three general pathways leading to dechlorination of alkyl chlorides. The first pathway (Figure 7.13) involves the metal directly and implies that reduction occurs by electron transfer from the Fe\(^0\) surface to the adsorbed alkyl chloride\(^9\) according to equation (7.1). The second pathway involves further oxidation of Fe\(^{2+}\) that is an immediate product of corrosion in aqueous systems (Figure 7.13).

\[
2Fe^{2+} + RX + H^+ \leftrightarrow 2Fe^{3+} + RH + X^-.
\]  

(7.5)

The third pathway for reductive dechlorination by iron involves the hydrogen produced during corrosion (Figure 7.13).

\[
H_2 + RX \rightarrow RH + H^+ + X^-.
\]  

(7.6)

Determining the relative importance of these three dechlorination pathways will be essential to predicting field performance of iron-based remediation technologies.

Since dechlorination apparently occurs at the iron–water interface, the following transport and reaction mechanisms influence the dechlorination process:\(^9\) (1) mass transport of the contaminant to the Fe\(^0\) surface; (2) adsorption of the chlorinated aliphatic contaminant to the surface; (3) chemical reaction at the surface; (4) desorption of the by-products; (5) mass transport of the by-products into bulk solution. Any one or a combination of these steps may
Figure 7.13 Three general pathways of dechlorination of alkyl chlorides.
be rate-limiting and, hence, careful consideration should be given to controlling those steps during system design.

Table 7.5 presents degradation rates, in the form of half lives, for various chlorinated aliphatic compounds. By-products formed as a result of incomplete dechlorination are also shown in Table 7.5. The rates presented in Table 7.5 seem to be rather slow compared to other observations reported in the literature.

As seen from Table 7.5, residence times required for complete dechlorination are very high even under slow-moving groundwater flow conditions. It should also be noted that due to the potential formation of anaerobic conditions in the in-site reactor, microbial (biotic) dechlorination also could take place in addition to the abiotic dechlorination. In addition, mixing of pH neutralizing reagents with the iron filings will also enhance the rate of dechlorination.

Configuration of the in situ reactors to implement metal-enhanced abiotic dechlorination can be accomplished as shown in Figures 7.9 through 7.12. The specific configuration will be very much influenced by the site-specific conditions and the required residence times to achieve complete reduction.

Another possible use of placement of iron filings in an in situ reactor is the conversion of the highly toxic and soluble hexavalent chromium (Cr(VI)) to much less toxic and less soluble trivalent chromium (Cr(III)). The reaction is quite rapid, occurring on the order of less than a minute. The reaction is probably driven by several processes, including reduction at the surface of metallic iron and in solution from the production of ferrous iron. The resultant Cr(III) precipitates out of solution as a chromic hydroxide precipitate. Hence design of the system should incorporate options to backwash or flush out the precipitates accumulated in the reactor after a certain period of operation.

Another variation of this technique includes adding palladium to iron. Contaminants such as cis-1,2-dichloroethene can be resistant to dechlorination by iron within reasonable residence times. Palletized iron has been reported to dechlorinate this compound within a few hours.

7.3.3.4 Adsorption

Adsorption mechanisms can be employed in the in situ reactors to remove a variety of contaminants. Liquid-phase granular activated carbon (GAC) can be used to remove many organics, especially those not easily removable by air stripping or biodegradation (e.g., pentachlorophenol and tetrachlorophenol). Ion exchange resins can be used to remove dissolved heavy metals present in the groundwater.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Half life (days)</th>
<th>Chlorinated by-products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloromethane</td>
<td>6.5</td>
<td>Dichloromethane (low concentration)</td>
</tr>
<tr>
<td>Tetrachloromethane</td>
<td>5.4</td>
<td>Trichloromethane, dichloromethane</td>
</tr>
<tr>
<td>Monochloroethene</td>
<td>14.9</td>
<td>None detected</td>
</tr>
<tr>
<td>1,1-Dichloroethene</td>
<td>55</td>
<td>None detected</td>
</tr>
<tr>
<td>cis-1,2-Dichloroethane</td>
<td>37</td>
<td>None detected</td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td>5.5</td>
<td>1,1-Dichloroethane</td>
</tr>
<tr>
<td>1,1,2-Trichloroethane</td>
<td>7.8</td>
<td>Trace of monochloroethane</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>7.1</td>
<td>cis-1-2-Dichloroethene</td>
</tr>
<tr>
<td>1,1,2,2-Tetrachloroethane</td>
<td>10.2</td>
<td>cis-1-2-Dichloroethene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trans-1,2-Dichloroethene</td>
</tr>
<tr>
<td>Tetrachloroethene</td>
<td>13.9</td>
<td>Trichloroethene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cis-1,2-Dichloroethene</td>
</tr>
</tbody>
</table>

7.3.3.4.1 Liquid-Phase Granular Activated Carbon (GAC)

During the adsorption process from aqueous solution, dissolved organics are transported into the solid sorbent (GAC) grain by means of diffusion and are then adsorbed onto the extensive inner surface of the activated carbon granules. Traditionally, the adsorption phenomenon has been categorized as physical adsorption and chemisorption. Physical adsorption is a rapid process, caused by nonspecific secondary binding mechanisms and is reversible. The adsorbate will desorb into the solution in response to a decrease in solution concentration. Chemisorption is more specific, because it entails the transfer of electrons between adsorbent and adsorbate and may or may not be reversible.

Due to the cost of liquid-phase GAC, only the configurations similar to those shown in Figures 7.10 through 7.12 will be preferred. The virgin carbon can be slurred into the reactor and the spent carbon can be vacuum slurried out of the reactor. Easily replaceable porous cassettes filled with carbon also can be retrofitted into the reactor (Figure 7.14).

Frequency of changeouts of the carbon bed can be estimated by performing a column isotherm study in the laboratory. Published information in the literature can also be used for this purpose. However, it should be noted that the estimated adsorption capacity of the \textit{in situ} bed can be compromised by the potential fouling caused by growth of microorganisms and deposition of inorganic precipitates within the bed. In addition, contaminant adsorptive capacity may be reduced due to the adsorption of natural organic matter such as humic substances and other micropollutants. Fouling of the carbon bed may also increase the resistance to flow through the gate. Design enhancements that provide the flexibility for periodic backwashing of the bed may overcome this problem. Design of an upflow configuration in the \textit{in situ} reactor will also alleviate some of the potential problems caused by inorganic fouling.

7.3.3.4.2 Ion Exchange Resins

An \textit{ion exchange reaction} may be defined as the reversible interchange of ions between a solid phase (the ion exchange bed) and solution phase, the ion exchange bed being insoluble...
in the medium in which the transfer is carried out. The important features characterizing ion exchange media are

- a hydrophylic structure of regular and reproducible form
- controlled and effective ion exchange capacity
- rapid rate of exchange
- chemical stability
- physical stability in terms of mechanical strength
- consistent particle size and effective surface area

Ion exchange reactions take place due to the preference of a specific ion to the media in comparison to the existing ion attached to the media. Most of the dissolved heavy metals present in groundwater are in the divalent or trivalent state cations, with the exception of hexavalent chromium. Depending on the heavy metal(s) to be removed, a strong acid or a weak acid ion exchange media may have to be used.

The most cost-effective use of the ion exchange method will be when the dissolved heavy metal concentrations in the groundwater are at low levels. At high concentrations, media replacement will be more frequent and the cost of disposal or regeneration of the spent media will be prohibitive.

The placement of the fresh ion exchange media in the in situ reactor can be carried out in the form of a wet slurry and the spent media can be vacuumed out as a slurry also.

Presence of other ions and nonoptimum pH conditions will significantly impact the loading capacity of ion exchange beds. The use of ion exchange beds in in situ reactive wall systems will be very specific and under very optimum conditions. The configurations similar to those shown in Figures 7.10 through 7.12 can be implemented for the use of ion exchange as the mass removal reaction.

### 7.3.3.5 Precipitation

Precipitation of dissolved heavy metals can be achieved by manipulating the pH and the Eh (redox) conditions of the contaminated groundwater as it flows through the in situ reactor. Heavy metals can be precipitated as hydroxide, carbonate, or sulfide precipitates. Precipitation of heavy metals has been successfully achieved in wastewater treatment processes. Hence, implementation of this process in an in situ reactor only needs creative design considerations. The biggest advantage in an in situ reactor is the availability of significantly higher residence times in comparison to wastewater treatment systems. Table 7.6 presents the various metals that can be precipitated as hydroxide, carbonate, and sulfide.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Type of precipitate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba</td>
<td>Hydroxide</td>
</tr>
<tr>
<td>Cd</td>
<td>Hydroxide, carbonate, sulfide</td>
</tr>
<tr>
<td>Cr³⁺</td>
<td>Hydroxide</td>
</tr>
<tr>
<td>Cu</td>
<td>Hydroxide, carbonate, sulfide</td>
</tr>
<tr>
<td>Pb</td>
<td>Hydroxide, carbonate, sulfide</td>
</tr>
<tr>
<td>Zn</td>
<td>Hydroxide, carbonate, sulfide</td>
</tr>
<tr>
<td>Hg</td>
<td>Hydroxide, sulfide</td>
</tr>
<tr>
<td>Ag</td>
<td>Hydroxide, sulfide</td>
</tr>
<tr>
<td>Ni</td>
<td>Hydroxide, carbonate, sulfide</td>
</tr>
<tr>
<td>As</td>
<td>Sulfide</td>
</tr>
</tbody>
</table>
Proper mixing of the added reagents and maintenance of optimum pH and Eh conditions are important to achieve complete precipitation of the heavy metals. Hence, the in situ reactor for precipitation has to be constructed like a reaction tank or rapid mixer in an underground vault (similar to Figure 7.10). Another gate in series has to be provided downstream to filter out the precipitates. This filter has to be designed in such a way to remove the filtered solids by backwashing. Due to the constructibility considerations, this reactor can be installed only under shallow water table conditions.

Metals precipitation can be achieved in configurations such as permeable reactive trenches too. Limestone can be used as the backfill materials to adjust the pH of the incoming groundwater and precipitate metals as metallic hydroxides. For instance, at an abandoned mine site, the pH of the groundwater was less than 3.0, and it had elevated concentrations of copper and zinc. A reactive wall providing a bed of limestone was able to precipitate the metals at a residence time of 1 h. In such situations, the potential problem of plugging by the precipitates will have to be overcome.

7.3.3.6 Chemical Oxidation

In the oxidative degradation of organic compounds, the compound is converted by means of an oxidizing agent into new harmless compounds typically having either a higher oxygen or lower hydrogen content than the original compound.

Use of hydrogen peroxide or ozone or a combination of both are common oxidative processes. Implementing an in situ oxidation system can be very cumbersome and can also raise safety concerns. Hence, the use of in situ oxidation systems should be chosen only when all other reactive processes are considered not effective to treat a specific contaminant. A compound that falls in this category is 1,4-dioxane. In situ oxidation reactors have to be built like an underground vault (or like a parshall flume), and hence will be applicable only under shallow water table conditions.

7.3.4 Residence Time

An important factor in designing an in situ reactive wall system is the relationship between the residence time of contaminated groundwater in the gate or the trench and the rate of contaminant degradation reactions. The average residence time in the reactor can be calculated by dividing the empty bed (or void) volume of the reactor and dividing it by the flow through the gate.

In situ reactive wall systems have the distinct advantage of providing significantly higher residence times in comparison to similar above-ground reactors. Increased residence times are possible due to the relatively slow flow rates through the gates and will be in the order of days, if not weeks, depending on the site-specific groundwater flow velocities.

Concentration of the contaminants in the incoming groundwater also has a significant impact on the required residence times. For degradation processes that are first-order reactions, the retention time necessary is given by the following formula:

\[
N_{1/2} = \frac{\ln\left(C_{\text{eff}} / C_{\text{inf}}\right)}{\ln \frac{1}{2}}
\]  

where \( N_{1/2} \) = number of half lives required
\( C_{\text{eff}} \) = desired concentration in the effluent
\( C_{\text{inf}} \) = concentration in the influent.
Faster and greater mass removal can be achieved by either faster reaction rates or longer residence times. Increased residence times require increased reactor volume and thus higher costs. Depending on the type of mass removal reaction employed in the reactor, both of these factors may have to be optimized. Processes such as air stripping and adsorption take place at such a fast rate that available residence times will be more than sufficient in most cases. If not, optimizing the air-to-water ratio or providing packing material to enhance the mass transfer efficiencies may be warranted for in situ air stripping.

Biodegradation processes are governed by the rate of biodegradation of specific contaminants. An empirical parameter used to estimate the allowable mass loading in biological treatment systems is the food-to-microorganisms ratio, the unit of which is mass of contaminants/mass of viable biomass. From this expression it can be noted that the higher the available biomass, the faster the reaction will be. Increased available surface area in the reactor for the attachment of biomass will increase the biomass concentration per unit volume of the reactor. In some cases increased retention times may be required and can be achieved by increasing the reactor volume or by having multiple gates to reduce the flow through each gate or by providing gates in series to achieve complete reaction.

Required residence time is a key factor for the design of metal-enhanced dechlorination systems. As seen from Table 7.5, half lives required for various contaminants are significantly higher in comparison to any other process. Residence times required for the precipitation and chemical oxidation processes are relatively small and will not be a concern in most situations.

7.4 CASE STUDY

Pentachlorophenol (PCP) and tetrachlorophenol (TCP) were detected in on-site groundwa-ter monitoring wells at a former wood treating facility in the western U.S. (Figure 7.16). The groundwater system consists of a shallow aquifer containing a heterogeneous mixture of marine deposits and artificial fill which is underlain by low-permeability siltstones and mudstone. The shallow aquifer ranges in thickness from 10 to 20 ft and averages 15 ft. Based on the results of the site investigation, it was determined that impacted groundwater had the potential to move off site and adversely affect downstream domestic water supply wells.

A number of remediation alternatives were evaluated, and an in situ reactive wall incorporating a slurry wall as the barrier and liquid-phase activated carbon (GAC) as the gate reactor was chosen as the preferred alternative. A number of studies were performed to evaluate the applicability of this technique at the given site. These studies focused on the potential for underflow beneath the barrier wall, the spatial relationship between gates(s) and funnel(s), mass loadings at the gate, and interferences with gate performance.

7.4.1 Groundwater Flow Patterns

A key site condition which that the funnel and gate system feasible was the high contrast between permeabilities in the water-bearing shallow aquifer and in the bedrock. To evaluate
the effect of a funnel-and-gate system on the horizontal distribution of water, a computer simulation of the hydrogeologic conditions in the impacted upper aquifer was developed. Using this model, various configurations of the funnel and gate were tried to optimize the configuration (Figures 7.17 through 7.20). The model provided for a design layout that routed the water from underneath the mill through the gates and avoided flow of contaminated water around the ends of the barrier.

With respect to minimizing the disruption of natural groundwater flow patterns, there were three key concerns that needed to be addressed. The first was the effect on water levels both up- and dowgradient of the wall. The modeling showed that pressure required to move water through the gate was slightly greater than the natural gradient and was a function of the gate configuration and permeability of granular activated carbon. The selection of a moderate carbon grain size and the design of the treatment gates shown in Figure 7.21 minimized the pressure...
loss across the treatment gate by presenting a large cross-section flow area through the carbon. This prevented water from backing up behind the gate and increasing the hydraulic head on the up-gradient side of the barrier. The pressure required to move the water through the gates corresponds to an increase in water differential of approximately 2 in. The treatment gates themselves therefore had a negligible effect on groundwater elevation.

The second concern was ensuring that water could readily access a treatment gate. Because of the nonuniform distribution of hydraulic transmissivities across the site, water could be impeded in its lateral movement toward and away from the gates, which could have resulted in undesirable hydraulic mounding behind the portion of the wall midway between gates. To minimize this effect, gravel-filled collection and distribution galleries were installed at each gate to collect water from the up-gradient side of the gate, guide it through the gate, and then redistribute it uniformly after treatment.

### 7.4.2 Underflow of Barrier

The potential for flow under the barrier wall was examined mathematically, using data collected during aquifer tests conducted at the site. Several test trenches were also excavated to evaluate the character of the bedrock along the alignment of the slurry wall. A comparison of the transmissivity of the shallow drinking-water aquifer with that of the underlying bedrock indicated that the hydraulic conductivity of the bedrock is approximately 1/1000 that of the overlying shallow aquifer. This resulted in a conservatively calculated underflow that is less than 1% of the total flow through the combined aquifers.
7.4.3 Number and Location of Gates

To determine the volume of water each gate is expected to treat, the total flux of water beneath the site was calculated using previously obtained aquifer data.

Because of the nonlinear configuration of the funnel-and-gate system, the flux across the barrier itself cannot be easily calculated. This is due to the influence of the funnel-and-gate arrangement on the flow lines across the site. However, the flow can be approximated by taking the cross-sectional flow of a region where the particle traces are relatively straight. This length is approximately 400 ft of potentially impacted aquifer.

The combined flow rate through all four treatment gates is the product of the transmissivity, the length of the cross-sectional area, and the hydraulic gradient. This results in a total flow of approximately 20 gpm. The flow through each gate is estimated as one fourth of the total flow, or 5 gpm per gate.

7.4.4 Gradient Control

Figure 7.22 shows the plan view of the treatment gate with collection and distribution galleries installed to guide water through the gates. Both galleries are downcut into the shallow aquifer and backfilled with gravel. Because the aquifer will tend to have higher horizontal permeability than vertical permeability, the collection and distribution galleries are downcut into the aquifer to expose a large cross-sectional area to groundwater flow. This minimizes the pressure required to move water from the aquifer to the carbon treatment gate. This is
Figure 7.19 Streamlines showing capture zone for three 3-ft-wide reactive gates.

Figure 7.20 Configuration of funnel and gate system.
especially important on the downgradient side of the wall, where infiltration of water will be limited by the infiltration rate of the gallery. The installation of these collection and distribution galleries further ensures that the pressure drops across the wall will minimally affect the natural groundwater gradients and flow patterns.

### 7.4.5 Gate Design

For the purpose of designing the carbon gates, a very large margin of safety was factored in to the mass of carbon installed in each gate. Factors of design, e.g., contaminant concentration, flow rate, and the time between carbon changeouts, were selected very conservatively to ensure that there is more treatment capacity than required. The design has inherent flexibility, should the actual conditions change during the life of the project. The estimated gate flow rate is 5 gpm. The time between changeouts has been selected to be 4 years, although more frequent changeouts could easily be accommodated. In the vicinity where the gates will be installed, concentrations of compounds of concern have ranged from nondetect to the low
parts per billion. A concentration of 200 µg/l was used in this design to account for the loading due to natural occurring wood-degradation compounds. Using the average carbon loading efficiency of 1% and the constraint of a relatively thin aquifer results in a carbon bed 4 ft tall placed within a cylinder 4 ft in diameter.

Monitoring points are located before, within, and after the treatment gate. Groundwater samples will be collected from the monitoring points located before each of the treatment gates. These samples will be analyzed for compounds of concern. Should any of these compounds be detected, a sample will then be collected from the monitoring point within the treatment gate to verify that the treatment gate is being effective in removing these compounds. There is a treatment buffer zone downstream of this midgate monitoring point to ensure that impacted water does not exit the gate prior to full removal of these compounds. Upon detection of a compound of concern at a concentration above water-quality objectives at the midgate measuring point, the carbon will be removed and replaced.

Carbon replenishment is a relatively easy procedure. Wet spent carbon will be vacuumed out as a slurry, using above-ground slurry pumps. Fresh carbon will be emplaced after dewatering the gate using the upgradient monitoring well, which is completed in the gravel packing adjacent to the gate. While water is being evacuated and the gate is dry, fresh carbon will be poured into the gate to the desired thickness.

7.5 LITERATURE REPORTINGS

Many research demonstrations of in situ reactive walls have been summarized by the U.S. Environmental Protection Agency.14 Some of these case studies have been excerpted below.

Demonstration Study 1

- Description of Demonstration: A series of large-diameter augered holes in a staggered three-row array were located within an aquifer to intercept a contaminant plume of chromate and chlorinated organics. A mixture (by volume) of 50% iron filings (two types), 25% clean coarse sand, and 25% aquifer material was poured down hollow-stem augers from 22 ft to 10 ft below ground surface. Each iron column was approximately 8 in. in diameter and a total of 21 columns were installed in a 60 ft² area. The mixed waste contaminant plume is between 14 and 20 ft below ground surface and the water table ranges from 5 to 6 ft below ground surface. One iron type was shown to be an effective reductant for chromate in a 2-year laboratory study, while other iron has been shown to be more effective in the reductive dechlorination of the organics. This field experiment is evaluating the effectiveness of this method of treatment wall emplacement and is providing additional in situ field data for full field-scale implementation.
- Wastes Treated: TCE, DCE, vinyl chloride, and Cr⁶.
- Status: The demonstration has been in operation since September 1994.
- Preliminary Results: Preliminary results show complete reduction of Cr⁶ to below detection (<0.01 mg/l) limits and greater than 75% reduction in initial TCE concentrations and reduction of vinyl chloride concentrations to less than 1 µg/l. These results are very promising, especially for the chlorinated organics, because the experiment was primarily designed to optimize chromate remediation, not the chlorinated organics.
Demonstration Study 2

- Description of Demonstration: An above-ground field test reactor containing 50% iron was installed at a semiconductor manufacturing facility to test the feasibility of installing an in situ permeable reactive zone. Groundwater was pumped through the reactor at a rate of 4 ft/day for 9 months. Initial concentrations of contaminants were 50 to 200 ppb trichloroethene (TCE), 450 to 1000 ppb cis-1,2-dichloroethene (cis-DCE), 100 to 500 ppb vinyl chloride (VC), and 20 to 60 ppb freon-113. The time required to degrade one half of the contaminant mass in the above-ground field test was less than 1.7 h for TCE, 1 to 4 h for cis-DCE, 2 to 4 h for VC, and less than 1.6 h for freon-113. Mineral precipitation, hydrogen gas production, and microbial effects also were evaluated.
- Wastes Treated: TCE, DCE, vinyl chloride, freon-113.
- Status: Based on the feasibility tests described above, a full-scale in situ permeable treatment wall was approved by the state regulatory agency and was installed in December 1994. The permeable reactive zone, which will be 4 ft thick, 40 ft long, 10 ft high, and about 25 to 30 ft deep, will contain 100% reactive iron. It will be installed using a trench box design. The cost is $175,000 to $200,000.

Demonstration Study 3

- Description of Demonstration: Researchers installed a permeable reactive wall containing an iron-based catalyst about 16.5 ft downgradient from the source of a contaminant plume to pilot test the capability of the wall to degrade halogenated organic compounds. The plume was about 6.5 ft wide and 3.3 ft thick with maximum concentrations along the axis of about 250,000 µg/l trichloroethene (TCE) and 43,000 µg/l tetrachloroethene (PCE). The source of the plume was located about 13 ft below ground surface and 3.3 ft below the water table.

  Using sealable joint sheet piling, a rectangular cell was constructed on the surface and driven to a depth of 32 ft, the cell was sealed and dewatered, and the native sand was replaced by the reactive material consisting of 22% by weight granular iron and 78% by weight course sand. The sand, which was coarser than the native materials, ensured that the wall would be more permeable than the surrounding sand. After installing the reactive material, the sheet piling was completely removed and natural flow conditions were achieved. The wall dimensions were 18 ft long, 5.2 ft thick, and 7.2 ft deep and it was positioned 3.3 feet below the water table.
- Wastes Treated: VOCs.
- Status: The pilot test was completed in 1993.
- Demonstration Results: Multilevel monitoring wells were located 1.6 ft up-gradient of the wall, in the wall at distances of 1.6 and 3.3 ft, and 1.6 ft downgradient of the wall for a total of 348 sampling points. Concentration distributions through the wall were determined on 13 occasions over 474 days, during which there was no decline in the effectiveness of the barrier. Most of the mass loss occurred within the first 50 cm of the wall; at greater distances into the wall, performance was below that expected. However, the reactive wall reduced the TCE concentration by 95% and the PCE concentration by 91%. No vinyl chloride was detected in the samples. Increased chloride concentrations downstream of the wall were consistent with the quantity of TCE and PCE that had been degraded. Only trace amounts of dichloroethene (DCE) were detected downstream of the wall.
REFERENCES