CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

Status Report

Advances in Remediation Technologies at Sites Contaminated with Volatile Organic Compounds

Introduction

The purpose of the staff report is to inform the Board about advances in remediation technologies that are being used to more effectively and efficiently cleanup sites. This status report focuses on sites contaminated with volatile organic compounds (VOCs) because they are the most common contaminant class at the sites we oversee. VOCs also tend to be more toxic and difficult to clean up. A status report to the Board in October 2018 covered advances in investigation technologies.

Background

Widespread soil and groundwater contamination was initially discovered in our Region in the early 1980s. At that time, the cleanup industry relied on what we now call conventional remediation technologies, such as soil excavation and groundwater extraction. In the late 1980s, soil vapor extraction started becoming more common. Remediation methods evolved during the 1990s as new technologies were developed and as we learned more about how contaminants break down.

VOCs migrating through soil and groundwater take the path of least resistance. These more permeable pathways tend to be buried stream channels, coarse-grained layers (e.g., sand), and backfill around underground utilities. On their journey, VOCs get stuck in fine-grained materials (e.g., clay). Conventional remediation technologies like groundwater and soil vapor extraction do a good job removing VOCs from the more permeable pathways but are often ineffective at removing contaminants from the tighter fine-grained materials, such as silts and clays. As a result, some areas of contamination can be missed.

Climate change and drought are threatening existing drinking water supplies; therefore, groundwater remediation that is more expeditious and thorough is increasingly important to protect current and future groundwater drinking water supplies. Additionally, development pressure in the Bay Area has resulted in residential and commercial properties built over groundwater plumes and soil contamination that threaten public health from exposure to contaminant vapor intrusion from the subsurface into buildings where people live or work. Ecological health is also at risk at sites where contaminants have or may migrate from the site into nearby creeks, wetlands, or the Bay. Finally, as sea level rises, groundwater near and inland from the Bay will rise and may exacerbate the water quality, public health, and ecological impacts from subsurface and groundwater contaminants.

Remediation Technologies

The following table lists some of the more common remediation technologies and the media they address. The table is separated into conventional and innovative remediation technologies.

Remediation Technologies			
Technology	Media		
	Soil Vapor	Groundwater	Soil
Conventional			
Excavation	X		X
Soil Vapor Extraction	X		X
Groundwater Extraction		X	
Innovative			
Chemical Oxidation		X	
Permeable Reactive Barrier		X	
Thermal Remediation	X	X	X
Bioremediation		X	

Conventional Remediation Technologies

The following technologies are referred to as conventional because they have been in use since the 1980s.

Soil Excavation: Excavation of contaminated soil involves digging it up for above-ground treatment or disposal in a landfill. The excavation is conducted using standard construction equipment such as a backhoe.

Soil Vapor Extraction: Extraction wells are installed into contaminated soil above the shallow groundwater. A blower is attached to the wells and creates a vacuum that removes the contaminated vapor. The vapor is then pumped to the ground surface and treated by a carbon-filled canister that adsorbs the contaminants. The purified vapor is then discharged to the atmosphere.

Groundwater Extraction: This technology is also known as pump and treat. Extraction wells with pumps are installed into the contaminated groundwater. The contaminated groundwater is pumped to the surface. The groundwater is then treated either by a carbon-filled canister or an air stripper. Sometimes the extracted groundwater is discharged directly to the sanitary sewer if it meets effluent limits.

Challenges with Groundwater Extraction

Soil excavation and soil vapor extraction are still widely used today. The use of groundwater extraction has significantly declined due to the following challenges.

Cost: Groundwater extraction has high capital costs from installing the extraction wells, pumps, piping, and treatment system. It also has high operating costs for the electricity to run the pumps, which causes generation of greenhouse gases, and for the monitoring of the treatment system.

Difficult Removal of Contaminants from Clay: VOCs have an affinity for soil and sediment, and over time can diffuse deep into the pore spaces in silts and clays. Groundwater extraction pulls water from the more permeable sand layers. Contaminants in the tighter silts and clays cannot be directly reached and slowly dissolve back into the groundwater making it difficult to fully clean up.

Contamination Transferred from One Medium to Another: If the groundwater is treated by a carbon-filed cannister, the contaminants are transferred to the carbon. The carbon must then be regenerated by exposing it to very high temperatures that destroy the contaminants. This process creates contaminated ash that must be managed. If the groundwater is treated by air stripping, the contaminants are transferred to the air. This causes the contamination to be transferred from groundwater to air.

Innovative Remediation Technologies

Over the last 25 years, advances in remediation technologies have enabled faster and more effective cleanup at our sites. If a site is adequately characterized, these newer technologies can provide a more targeted remediation while the contaminants are still in the ground. The following technologies are examples of innovative remediation technologies.

Chemical Oxidation: An oxidant such as hydrogen peroxide is injected into the groundwater using a pump. The oxidant causes a chemical reaction that destroys the contaminants. If contaminant concentrations begin to climb back up, or rebound, then additional oxidant is injected. Rebound may occur if the injected oxidants did not reach all the contamination, or if the oxidant is used up before all the contamination is treated.

Permeable Reactive Barrier: An underground wall is placed across the flow path of contaminated groundwater. The wall is built either by digging a long, narrow trench or by drilling boreholes. The trench is filled with a reactive material such as iron, limestone, or a carbon source to remediate the groundwater. For example, iron particles can react with certain VOCs and convert them to harmless byproducts.

Thermal Remediation: Heating elements are installed into contaminated soil and groundwater and heat contaminants to very high temperatures. The heat vaporizes the contaminants, enabling them to move more easily through the soil. Vapor extraction wells then remove the contaminated soil vapor for treatment. At high enough temperatures, the heating elements can also destroy some of the contaminants in place.

Bioremediation: Specific types of bacteria can eat and digest contamination, breaking it down into harmless byproducts. To enhance this process, an organic carbon source is usually injected into the contaminated groundwater to provide additional energy for the bacteria. Molasses, vegetable oil, and cheese whey are examples of organic carbon sources used to enhance the bacterial process. Bacteria can also be injected into the groundwater if the right types of bacteria are not present.

Bioremediation is the most widely used out of the above four innovative technologies.

<u>Advantages of Bioremediation</u>

> *Cost Savings:* Bioremediation usually costs less than groundwater extraction due to less equipment costs for pumps, piping, and above-ground treatment. It requires less electricity and generates less greenhouse gases.
>
> *Enhanced Removal of Contaminants from Clay:* Bioremediation may accelerate the breakdown of contaminants that are attached to clay. This is due to several characteristics of bioremediation that reduce the strength of the connection between the contaminant and the clay. This may shorten the overall time needed for cleanup.
>
> *Contamination Not Transferred from One Medium to Another:* Natural bacterial processes break down the contamination beneath the ground surface, so it is not transferred to other media.

<u>Limitations of Bioremediation</u>

> *Water Chemistry Must Be Favorable for Bacteria Growth:* Groundwater levels for pH, oxygen, temperature, and certain other parameters must be maintained in an optimal range for the bacteria to flourish.
>
> *Breakdown Products Must Be Managed:* As the bacteria break down the pollutants, the bacteria sometimes generate other pollutants that must be successively broken down. This breakdown process can sometimes stall. If that happens, additional carbon source or bacteria need to be injected. In addition, methane gas may be produced as a byproduct of the bioremediation. Methane is combustible and potentially explosive when present at high concentrations (known as the Lower Explosive Limit, or LEL). A conservative value of 10% of the LEL is often used as an action level to evaluate additional methane monitoring and mitigation measures, which may include collection and venting of the methane.

Implications for the Cleanup Programs

There have been significant advances in remediation technologies since we started overseeing the cleanup of contaminated soil and groundwater in the 1980s. The innovative methods allow a more targeted and efficient remediation with less waste to manage. Under the Water Code, the choice of remediation methods is up to the discharger. However, we can encourage the use of innovative remediation technologies and require that they be evaluated against other methods. We will continue to make dischargers aware of their remediation options and encourage them to use innovative methods where appropriate. As we and dischargers advance and use more options and innovative methods, we will better protect water quality, public health, and aquatic habitat ahead of irreversible damage and climate change impacts.

Resources

The following resources provide more detailed information about remediation technologies.

- CLU-IN website with detailed descriptions of remediation technologies
  https://clu-in.org/remediation/
- CLU-IN website with fact sheets on remediation technologies
  https://clu-in.org/products/citguide/
- ITRC website with guidance documents on remediation technologies
  https://www.itrcweb.org/Guidance
- ITRC website with references on remediation technologies
  https://rmcs-1.itrcweb.org/4-adaptive-site-management/