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Soil Remediation is vital to site cleanup because chlorinated dry cleaning solvents in the unsaturated soil beneath a facility can remain a significant source of ground water contamination for many years after the initial release. Removal and/or treatment of the source area greatly enhance the efforts to cleanup ground water contamination since the source is no longer contributing to the ground water plume. Soil remediation techniques are classified as either in-situ (in the ground) or ex-situ (out of ground).

Ex-situ soil remediation typically involves simple excavation of the contaminated soil for direct off-site disposal or above ground treatment with off-site disposal of the treated soil or it reuse as fill material in the original excavation. Excavation of contaminated soil is typically the simplest and most cost-effective remedial alternative for small areas where the contamination is not too deep. The major factors to consider when evaluating soil excavation as a remedy is the potential for disrupting tenant activities, damage to buildings and infrastructure, and worker health and safety. Also, excavation of PCE contaminated soil will result in the generation of a hazardous waste, triggering special waste management requirements (e.g., storage in tanks and containers). The outcome of this technique is more assured when compared to other remedial alternatives that are dependent upon the many uncertainties associated with the physical, chemical, and/or biological properties of the affected media to achieve success.

A very common technique for **in-situ** soil remediation is **soil vapor extraction (SVE)** which involves the installation of a series of "wells" in the contaminated soil above the water table and placing a negative pressure on wells in the vadose zone to pull contaminated soil vapors from the subsurface soils. The vapor extraction wells are typically connected via a header system to collect the contaminated vapors for discharge to the atmosphere, with or without first being treated to remove the PCE, depending on the quantity emitted. Soil vapor extraction is not very effective in low permeability soils such as silts and clays.

A relatively new technique for conducting **in-situ** soil remediation is the direct injection of treatment materials into the subsurface to accomplish biological and/or chemical treatment of contaminated soil in both the saturated and unsaturated zones. In many areas of the state, the subsurface soil contains natural microorganisms that can effectively degrade chlorinated solvents through a process called reductive dechlorination. In each reductive dechlorination step, a hydrogen molecule replaces a chloride molecule and the solvent is eventually reduced to a relatively innocuous constituent called ethene. Enhanced bioremediation is the use of various products injected into the subsurface to optimize the growth of microorganisms, and thus enhance the degradation of PCE. The injected products are generally intended to either provide additional food sources for the microorganisms to increase the population and/or materials that will ferment in the ground and generate large volumes of hydrogen that help ensure the reductive dechlorination process continues all the way to ethene. The biology/chemistry of these reactions is well understood and can often result in a very rapid decrease in contaminant concentrations in soil.

In-situ chemical oxidation is the injection of chemicals into the subsurface that are intended to directly break down the contaminants via chemical reaction and convert them to harmless byproducts. The most common products used during chemical oxidation projects are: **Fenton's Reagent, hydrogen peroxide, ozone, potassium permanganate and sodium permanganate**. A key design consideration for chemical oxidation is that the reactions are exothermic and have the potential to give off large quantities of heat and generate unacceptable pressure levels. The major issue in designing and implementing any in-situ remedy is the delivery of the treatment chemicals to the contamination in the subsurface. Oftentimes the high concentrations of PCE in the soil are sorbed to low permeability silts and clays that the injected chemicals cannot penetrate. This situation may require multiple injections of chemicals over a long period of time to ensure thorough treatment.

Groundwater Remediation, traditionally, groundwater remediation at dry cleaning facilities has been accomplished using a ground water **pump and treat method**. A series ground water extraction wells or an infiltration gallery is installed near the source area and/or along the facility property boundary and the contaminated ground water is pumped to the surface. The contaminated ground water is then treated in an air stripper and/or granular activated carbon vessel prior to discharge to the public sewer or surface water (via a discharge permit). Ground water pump and treat systems can be enhanced via multi-phase extraction where extraction systems are designed to remove soil vapor and water at the same time, attempting to enhance the removal of both media with one system. These remediation methods typically have a high initial capital expense to install and protect the equipment and are also very expensive to operate. The systems must often run for a long period of time and will not often result in complete elimination of the contamination.

There are currently a wide variety of **Innovative Technologies** being being applied for remediating ground water. As noted above under the soil remediation discussion, in-situ techniques are proving very effective at remediating releases of dry cleaning fluids via enhanced bioremediation or direct chemical oxidation.

Bioremediation ground-water treatment systems enhance the existing in situ natural biological organisms by providing a food source or other key ingredients necessary for the organisms to thrive. Common products that are injected into an aquifer include: Zero Valent Iron, vitamins Hydrogen Release Compound® (HRC), dextrose, ethyl lactate, molasses, sodium lactate, cooking oil, ethanol and potassium lactate. Anaerobic

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bioremediation, specifically reductive dechlorination reducing PCE to ethane, is typically achieved by introducing oxygen scavengers to reduce the oxidation-reduction potential and the presence of oxygen within the subsurface. Once the aquifer is conditioned for treatment, the addition of foreign microbes may be required to completely reduce breakdown products to ethane at sites where minor microbial activity is present.

Chemical oxidation typically involves the injection of chemicals into the contaminated ground water to facilitate a reaction that converts the contaminant to harmless byproducts. A major consideration for chemical oxidation is the amount of oxidant that will be required to treat the contamination. The contaminant in the ground water will be competing for the oxidant with naturally occurring materials that also consume oxidants, such as iron, arsenic, methane and living and dead biological matter, so enough chemical must be injected to account for their presence. Multiple injections of oxidants will likely be required since the oxidants tend to decompose rapidly once in the environment. Chemicals in common use as oxidants include: Fenton's Reagent, hydrogen peroxide, ozone, potassium and sodium permanganate. The water chemistry should be well enough understood to predict whether the addition of chemical oxidants may negatively impact the local permeability of the aquifer.

Depending on site conditions, plume control may be achieved with the construction of a permeable reactive barrier using zero valent iron in conjunction with other amendments. This may be accomplished using iron filings installed within a "funnel and gate" barrier wall, injecting iron particles into the formation through which water must pass, the iron which behaves more like an **in-situ** chemical treatment and a biological amendment.

Remedial Delivery: As discussed above under soil remediation, the major concern with **in-situ** techniques for ground water is the ability to actually deliver the treatment chemical to the contamination. Fracturing techniques may be used to alleviate the problem of low permeability, or "tight" soils or aquifer materials and increasing the radius of influence for treatment chemicals. **Fracturing** is accomplished by injecting pressurized air or liquid into the ground to force open existing fractures, or to create new fractures to increase permeability. The injected liquid can contain fine sand to ensure the new fractures remain propped open and can also include the treatment chemicals for enhanced bioremediation or chemical oxidation so that multiple steps are not required. Fracturing has been demonstrated to work above and below the water table and in both unconsolidated materials and bedrock.

Non-Aqueous Phase Liquid Remediation - At some dry cleaning sites, the volume of dry cleaning fluid released may have been so large that areas of pure product/waste could have accumulated in the soil and/or aquifer material beneath the facility. The areas of free phase liquid can exist as thick lenses or thin stringers in the soil or aquifer that can be very difficult to detect. As precipitation infiltrates through the soil, or ground water flows through the aquifer, the water dissolves this free phase contamination and continues to degrade ground water quality until it is depleted, removed, or isolated from the environment.

If these areas are accessible, the most effective remediation method is excavation of as much of the free phase liquid and highly contaminated soil and aquifer material as possible. However, since it is unlikely that all of the free phase contamination can be removed, other remediation techniques have been developed to address the issue.

In-situ flushing is the process of promoting movement of contaminants by displacing the contamination using a co-solvent or surfactant. The technology loosens the free phase liquid and allows it to be mobilized for recovery in pumping wells or dissolved in the surrounding ground water where it can be treated with the **in-situ** techniques described above.

Thermal treatment provides heat, via steam injection or electrical heating, to the impacted zones to turn the free phase liquid to vapor or a mobile liquid. The contaminant is then removed from the subsurface via vapor and/or ground water extraction wells.

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