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A Guide to Pump and Treat Ground-Water Remediation Technology

This fact sheet summarizes how to use available hydrogeological and chemical data to determine when, where, and how pump-and-treat technology can be used successfully to contain and remediate contaminant plumes. It is based on the Office of Research and Development's *Basics of Pump-and-Treat Ground-Water Remediation Technology*, EPA/600/8-90/003.

OVERVIEW

While there are several ground-water containment and cleanup options available to choose from, this fact sheet focuses on pump-and-treat technology. The pump-and-treat process is the most commonly used ground-water remediation technology at hazardous waste sites. The objectives of pump-and-treat are to reduce the concentration of contaminants to an acceptable level during cleanup or to contain contaminants in order to protect the subsurface from further contamination. Pump-and-treat systems capture contaminated ground water for surface treatment. This fact sheet outlines the basic requirements for an effective pump-and-treat system, which include identifying the contaminant, characterizing the subsurface, designing a capture system, installing extraction wells, and monitoring the remediation progress. Here the "pump" portion of the pump-and-treat process is emphasized. Recent research has identified complex chemical and physical interactions between contaminants and the subsurface media that may limit the effectiveness of the extraction phase. These important limitations of pump-and-treat technology are also described in this fact sheet.

CHOOSING PUMP-AND-TREAT REMEDIATION

The first step in determining whether pump-and-treat is an appropriate remedial technology is to conduct a site characterization investigation. If the risk assessment shows the need for remedial action, then site characteristics, such as hydraulic conductivity, will determine the range of remedial options possible. Sources of ground-water contamination can include leaky tanks, leachate from landfills, spills, chemicals dissolving from nonaqueous phase liquids (NAPLs), and chemicals desorbing from the soil matrix. Sites with ground-water contamination will almost always include some form of pump-and-treat remediation. Chemical properties of the site and plume need to be determined to characterize transport of the contaminant and evaluate the feasibility of a pump-and-treat system. To determine if pump-and-treat is appropriate at a given site, one needs to know the history of the contamination event, properties of the subsurface, ground-water flow characteristics, and biological and chemical contaminant characteristics. Identifying the chemical and physical site characteristics, locating the ground-water contaminant plume or NAPL in three dimensions, and determining aquifer and soil properties are necessary in designing an effective pump-and-treat strategy. Several remedial methods may be combined into a "treatment train" to attain cleanup goals. The criteria listed below outline the information necessary to determine if pump-and-treat systems are applicable to a site.

Criteria to Determine if Pump-and-Treat will be Effective

I) History of the contamination:

A history of the contamination event should be prepared to define the types of wastes present at the site and quantify their loading to the system.

II) Characteristics of the subsurface flow system:

Ground-water flow systems vary with time, season, and pumping strategy. Understanding where ground water recharges and discharges (mass balance), the laws governing flow (Darcy's law), and geologic framework through which the flow passes makes it possible to determine ground-water flow characteristics. Other subsurface flow system characteristics include hydraulic conductivity, storage coefficient, mineralogy, organic content, and aquifer thickness.

III) Chemical and biological characteristics of the contaminant:

Chemical characteristics of contaminants include solubility, density, reactivity, ion exchange capacity, and mobility in aqueous solution. Biological characteristics of contaminants include the potential for naturally occurring transformation and biodegradation.

PUMP-AND-TREAT REQUIREMENTS

Four basic components need to be developed for a successful pump-and-treat system.

- ❑ **Goals and objectives**
- ❑ **System design**
- ❑ **Operational rules and monitoring**
- ❑ **Termination criteria**

The first component consists of defining the remediation goals and objectives (remedial action objectives) to be accomplished at a given site. This involves gathering enough background site information and field data to make assessments of remedial requirements and possible cleanup levels. The first determination is whether cleanup or containment will be the most appropriate pump-and-treat remedial action. If cleanup is chosen, the level of cleanup must be determined according to maximum contaminant levels (MCLs) and alternate contaminant levels (ACLs), state laws, or other criteria selected for the site. If containment is chosen, pump-and-treat technology is used as a hydraulic barrier to prevent off-site migration of contaminant plumes. The goals and objectives chosen at this stage determine the course of the remediation plan.

The next component consists of the design and implementation of the pump-and-treat system based on data evaluated in setting the goals and objectives. The system must be chosen and designed based on field data. Selection of a system is also dependent on whether pump-and-treat is sufficient or more than one remedial action will be used. The criteria for well design, pumping system, and treatment are dependent on the physical site characteristics and contaminant type. The system may then be installed, including extraction wells, injection wells, drain intercepts, and barrier walls, if necessary.

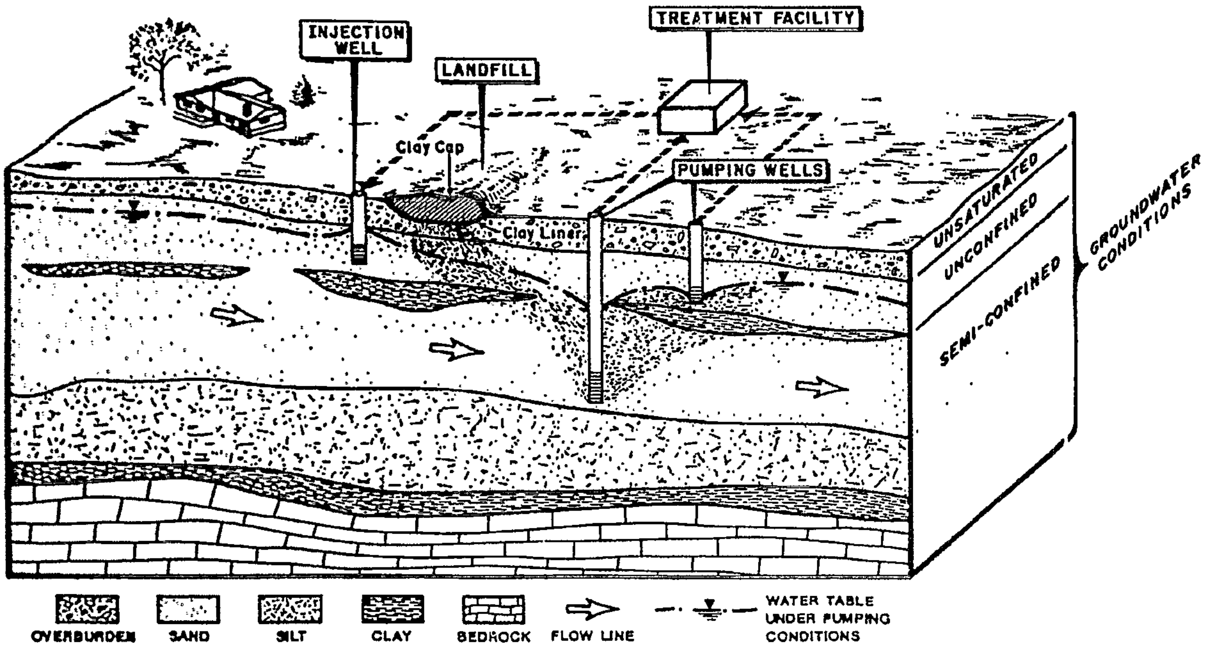
The third and most significant component for ensuring the long-term effectiveness of pump-and-treat is frequent monitoring of progress to verify if the remedial strategy is meeting remedial action objectives. Monitoring the remedial process with wells and piezometers allows the operator to make iterative adjustments to the system in response to changes in subsurface conditions caused by the remediation.

The final component in the pump-and-treat process is determining the termination requirements. Termination requirements are based on the cleanup objectives defined in the initial stage of the remedial process. The termination criteria are also dependent on the specific site aspects revealed during remedial operations.

DATA COLLECTION

Collecting as much background site data as possible initially may reduce the amount of time spent gathering data in the field. Accurate information on the type of contaminants present and their loading capacity will promote a well-designed remediation plan. Contaminant information needed consists of: 1) source characterization, including the volume released, the area infiltrated, and duration of release; 2) concentration distribution of contaminants and naturally occurring chemicals in ground water and soil; and 3) processes affecting plume development, such as chemical and biological reactions influencing contaminant mobility. Each step of the pump-and-treat strategy is dependent on the decisions reached in the previous step. Therefore, it is vital that each step is carefully planned and monitored to allow for modifications.

Example of a Pump-and-Treat System



Understanding the hydrogeology and extent of contamination at a site are important in planning successful field studies. The hydrogeologic aspects listed in Table 1 (below) are vital in determining if a pump-and-treat system would be an appropriate remedial technology for a particular site. These aspects include determining the size of the contaminated aquifer, depth to water table, hydraulic conductivity of surrounding aquifer material, and local ground-water use. Methods for determining aquifer properties include a slug test, pump test, and a borehole flowmeter test. The pump test consists of pumping one well and measuring the water level response of surrounding wells. Pump tests sample large aquifer sections. A slug test measures the rate at which the water level in one well returns to its initial state after inducing a rapid water level change by introducing or withdrawing a volume of water. The borehole flowmeter test measures flow direction and rate in a borehole. These tests can indicate the spatial variability of hydraulic conductivity.

Once data have been collected, the information must be accurately interpreted. There are numerous tools that can be used to interpret data, including geochemical analysis, geostatistical analysis, and mathematical models. Geochemical analysis uses ion speciation models to interpret chemical changes in the aquifer. Geostatistical methods may be used to determine the relationship among various parameters and define the statistical probability of a particular condition. Mathematical models may be used to simulate ground-water flow patterns, contaminant transport, and the changes resulting from a pump-and-treat system.

Water in a well bore seldom represents that of the adjacent aquifer. Therefore, when sampling ground water, pH, temperature, and conductivity should be measured and allowed to stabilize before a sample is taken to more accurately reflect the ground-water quality.

SYSTEM DESIGN

An effective pump-and-treat system depends on careful design of the pumping and treatment components based on the hydrogeologic information gathered at the site. Design considerations include type and location of wells, pumps, and piping; drilling methods; and well design and construction. Extraction wells may be used with injection wells if the hydraulic conductivity of the site material is high. Drains may be used if the contaminated aquifer is close to the surface. Intercept drains may be appropriate when a shallow aquifer is surrounded by material with low hydraulic conductivity. A long-term aquifer test (longer than a few days) can provide useful information and serve as a prototype for the pump-and-treat system design.

Table 1. Aspects of Site Hydrogeology

Geologic
1. Type, thickness, and areal extent of aquifer.
2. Type of porosity (primary: intergranular pore space, or secondary: bedrock).
3. Presence or absence of impermeable units and confining layers.
4. Depth to water table, thickness of vadose zone.

Hydraulic
1. Pressure conditions: confined, unconfined, or leaky confined.
2. Ground-water flow direction, hydraulic gradients, and average linear velocity.
3. Recharge and discharge area.
4. Ground-water and surface water interactions.
5. Seasonal variations of ground-water conditions.

Ground Water Use
1. Existing or potential underground sources of drinking water.
2. Existing or near-site use of ground water.

Special care is required to avoid potential problems with well-construction materials, especially when dealing with NAPLs. Wells should be designed so that screens may be easily flushed and clogging problems commonly caused by oxidation of manganese and iron can be treated. Aspects to consider when selecting pumps are failure rates, reactivity with contaminants, and ease of maintenance. Backup equipment should be available in the event of failure.

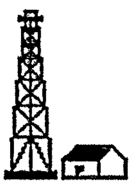
The types of pumping used at a site include continuous and pulsed pumping. Continuous pumping maintains an inward gradient, constantly drawing ground water towards it. Pulsed pumping consists of alternating periods of time when the pumps are on and when they are off.

Depending on site characteristics and contaminant properties, injection wells may be installed along with extraction wells to reduce cleanup time. Injection wells increase the hydraulic gradient by flushing contaminants towards the extraction well.

The pump-and-treat system should be evaluated periodically to determine if the goals and standards of the design criteria are being met. Monitoring the remedial process allows for operational modifications to be made. One modification that may improve the efficiency of contaminant recovery is to switch from continuous to pulsed pumping. The non-pumping period during pulsed pumping allows the contaminants to diffuse and desorb from less permeable zones into adjacent zones of higher hydraulic conductivity, permitting more efficient contaminant extraction when pumping resumes.

Another design modification is to cycle pumping at selected wells in order to bring stagnant zones into active flow paths for remediation. When less soluble contaminants (NAPLs) are trapped in soil pores by interfacial tension, the flow rates during remediation may be too rapid for the contaminant to reach chemical equilibrium. The non-pumping stage at selected wells provides time for sorbed and residual contaminants in the stagnant zone to reach equilibrium with the ground water. Duration of pumping and non-pumping periods are site-specific and can only be optimized through continuous monitoring.

Ideally, the contaminant source would be completely removed for proper aquifer remediation using pump-and-treat technology. Unremoved contaminants will continue to dissolve into the ground water and prolong cleanup. It may be advantageous to have multiple extraction wells pumping at a low rate rather than one at a high rate. Analytical and numerical modeling techniques can be used to evaluate alternative designs, optimal well spacings, pumping rates, and cleanup times. Models can calculate ground-water flow paths, locate contaminant plume fronts, and attempt to simulate contaminant transport. Proper design will ensure that wells are placed in the desired stratigraphic layer so that the correct area will be



OPERATION AND MONITORING

Once remedial action objectives are established and a system is built to meet these objectives, then a monitoring program should be designed to evaluate the success of the remedial system. Uncertainties in subsurface characterization make monitoring a necessary step in pursuing a remedial strategy. Continual monitoring of the pump-and-treat system allows timely modifications to be made when it is clear that the system is not achieving prescribed goals.

Monitoring should consist of analyzing the water quality and contaminant movement, and supervising the mechanical operation of the pump-and-treat system. If monitoring shows that the cleanup objectives are not being met, then changes to the pump-and-treat system must be specified and implemented to meet specified goals. There are three basic components involved in monitoring.

1) Design an appropriate monitoring program to suit the pump-and-treat system.

2) Actively monitor the system to verify that the remedial strategy is meeting the objectives and that equipment is functioning properly.

3) Modify the remedial strategy to adjust for unexpected contingencies. Specify alternate acceptable goals or change the remediation strategy to meet the original goals.

Monitoring criteria important in establishing a successful monitoring scheme for a site can be divided into three categories, chemical, hydrodynamic, and administrative.

- *Chemical:* A risk-based criterion, including maximum contaminant levels (MCLs), alternate contaminant levels (ACLs), detection limits, and natural water quality.

- *Hydrodynamic:* Includes preventing infiltration through the vadose zone, maintaining an inward gradient at the boundary of the contaminant plume, and providing minimum flow to surface water bodies.

- *Administrative Control:* Includes reporting requirements, frequency and character of operational and post-operational monitoring, and land use restrictions, such as drilling and other access-limiting restrictions.

The location of the monitoring wells is critical to any successful monitoring program. Water level fluctuations and water quality should be measured. Injection and extraction wells change the subsurface in complex ways, requiring continuous monitoring. Determining the flow pattern generated by a pump-and-treat system requires field evaluations during the operational phase.

A pump-and-treat system may require modifications during the operational phase due to the uncertainties involved in subsurface characterization. Reasons for possible modifications resulting from operational monitoring are:

- Improved estimates of hydraulic conductivity requiring a change in pumping rate or well location.

- Information on chemistry and loading to the treatment facility requiring changes in treatment.

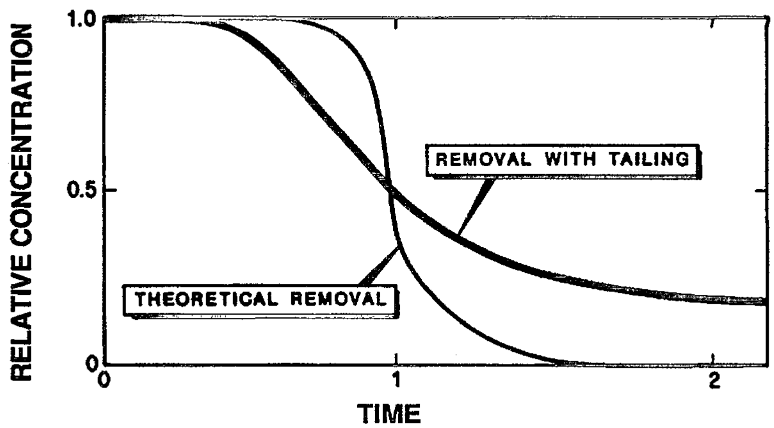
- Mechanical failure of pumps, wells, or subsurface plumbing.

- Adjusting pumping rate or well location to remediate a stagnant zone (a hydrodynamically isolated zone) as the contaminant plume is remediated, or to enhance extraction if anticipated progress is not achieved.

SOLUTE TRANSPORT ASPECTS

Assessing the chemical properties of the contaminant plume is necessary to characterize the transport of the chemical and evaluate the feasibility of pump-and-treat. Movement of non-reactive dissolved contaminants in saturated media is controlled primarily by advection and somewhat by dispersion. Advection causes the plume to move at the rate and direction of ground-water flow. Properties that control the transport of chemicals in ground water should be considered when evaluating pump-and-treat systems.

Dispersion is the combined effect of mechanical mixing and chemical diffusion. Dispersion causes the plume volume to increase and its maximum concentration to decrease. Reactive contaminant transport is also affected by sorption, desorption, and chemical and biochemical reactions. Studying sorption-desorption and transformation processes is essential in understanding migration rates and concentration distributions of contaminants. The plume of a reactive contaminant tends to expand more slowly than that of a non-reactive contaminant, increasing cleanup time.



Effects of tailing on pumping time

Necessary modifications resulting from the monitoring results should be implemented. The system design should be flexible enough to allow for easy adjustments to quicken cleanup. Keeping the possibility of modifications in mind when constructing the pump-and-treat system will promote the speed and efficiency of remediation.

The pump-and-treat system is terminated when the cleanup objectives are met. Monitoring is needed to ensure that desorption or dissolution of residuals does not cause an increase in the level of contamination after operation of the pump-and-treat system has ceased. Post-operational monitoring may be required for two to five years after termination depending on site conditions. Calculating the cleanup period for a site is necessary to estimate termination time and potential length of post-operational monitoring (See example on this page).

LIMITATIONS OF PUMP-AND-TREAT TECHNOLOGY

Reducing ground-water concentrations to standards required by the Safe Drinking Water Act or Land Disposal Restriction is difficult using available technology for many contaminants. There are several inherent limitations that hinder effective pump-and-treat site remediation. These include the potentially long time necessary to achieve the remediation goal; system designs failing to contain the contaminant as predicted, allowing the plume to migrate; and failure of surface equipment.

Research has substantiated other limitations with the use of pump-and-treat technology. These limitations include contaminant residual saturation, chemical sorption of the contaminant, and low hydraulic conductivity causing tailing effects.

1. *Residual saturation*

The presence of nonaqueous phase liquids greatly complicates contaminant behavior. Movement of contaminants in a separate, immiscible phase is not well understood either in saturated or unsaturated zones. A less soluble contaminant moves in response to pressure gradients and gravity and is influenced by interfacial tension, volatilization, and dissolution.

Residual saturation or irreducible saturation is the limit of drainage, where a certain pore volume will always remain. Both the type of immiscible fluid involved and the pore size distribution of the material determine the extent of residual saturation. Residual saturation reduces the overall amount of contaminant that enters and migrates within the saturated zone and acts as a source of long-term miscible contaminant.

Additional data required to determine proper remediation strategies for NAPLs include fluid specific gravity, viscosity, and contaminant thickness and distribution. Substances that are particularly difficult to remediate are halogenated aliphatic hydrocarbons, halogenated benzenes, phthalate ethers, and polychlorinated biphenyls. Data on relative permeability are readily available for many petroleum applications, but not for liquids usually found at hazardous waste sites.

2. *Sorbed chemicals*

Mobile, non-reactive compounds are most effectively treated using pump-and-treat technology. Contaminants easily sorbed onto the soil matrix are more difficult to remediate effectively. The volume of

AN EXAMPLE OF CALCULATING CLEANUP TIMES

Assume that the area of ground-water contamination is ten acres; the aquifer is permeable and 55 feet thick; water in storage is 30% of the aquifer's volume; and the water is contaminated with a nonreactive substance. Under these conditions it would be possible to exchange one pore volume of water in this ten acre plume in about a year with a pumping rate of 100 gallons/minute:

Volume of contaminant = 10 acres x 43,560 ft^2 / acre x 55 ft. x 7.48 gal/ft^3 x 0.3 = 5.4 x 10^7 gallons.

The pumping rate to remove this volume in one year = 5.4 x 10^7 gallons/365 days/1440 min./day = 102 gallons per minute. However, it will take longer than one year to completely remediate the contaminant due to the tailing effect often observed when using pump-and-treat technology. Tailing is the asymptotic decrease of contaminant concentrations in water removed in the cleanup process. Several phenomena may cause tailing, including the presence of a highly soluble and mobile contaminant that migrates into less permeable zones of the geologic material, a reactive, easily sorbed compound, and desorption. Sites with tailing effects require longer pumping times and greater pumping volumes to reach the same level of remediation.

pumped water required to remove the contaminant depends on the sorption capacity, the geologic material through which it flows, and the ground-water flow velocity during remediation.

If the ground-water flow velocity induced by pumping is too rapid, the contaminant concentration levels will not reach equilibrium. This results in decreased efficiency of contaminant removal (See diagram on the right). The retardation factor of a chemical (contaminant velocity relative to the water velocity) can be determined to estimate potential sorption capacity and remediation time.

3. *Hydraulic conductivity*

Hydraulic conductivity is another factor influencing the effectiveness of pump-and-treat remediation. Favorable conditions for pump-and-treat activities are high hydraulic conductivity—greater than 10^{-5} cm/sec—and homogeneity of the surrounding aquifer material. Determining pump-and-treat feasibility is specific to a site. The same range of hydraulic conductivities may allow a pump-and-treat system to be applied at one site but not at another depending on physical site characteristics and chemical properties of the contaminant.

These limitations are not insurmountable if accurate data collection and careful planning are employed when designing and operating a pump-and-treat system.

This Guide to Pump-and Treat Ground-Water Remediation Technology is a publication of the Technology Innovation Office, Office of Solid Waste and Emergency Response, US EPA, Washington, D.C.

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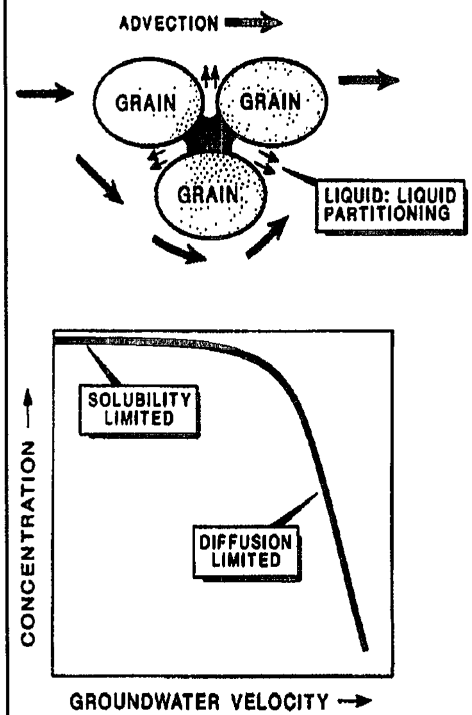

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To obtain the *Basics of Pump-and Treat Ground-Water Remediation Technology* call or write the Center for Environmental Research Information; Cincinnati, Ohio 45268. Ask for publication EPA/600/8-90/003.

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