Environment Canada | Ontario Region | Environmental Protection Branch

TABS ON CONTAMINATED SITES

Contaminated Sites Program - Federal Sites

This is one in a series of Technical Assistance Bulletins (TABs) prepared by Environment Canada-Ontario Region for Federal Facilities operating in Ontario.

TAB #24

Remediation Technologies For Groundwater Contamination

DESCRIPTION:
This TAB briefly describes technologies currently used for groundwater remediation at contaminated sites. Although each technology is discussed separately, a remediation program will often employ more than one technology to achieve the cleanup of a given site.

1. GROUNDWATER CONTAMINATION

Fundamentally, the objective of any groundwater cleanup (remediation) is to minimize the risk posed by contaminants to human health and the natural environment. This is accomplished by reducing the contaminant concentrations to acceptable levels or controlling the migration of contaminants to other sensitive receptors.

Groundwater contaminants are usually soluble, mobile chemicals including many soluble organics, soluble metals (e.g., arsenic, lead) and soluble radio-nuclides (e.g., tritium). In some circumstances, plumes of groundwater contaminated by such compounds emanate from a source. Examples include:

- shallow groundwater contaminated by hexavalent chromium (Cr^{+6}) from electroplating waste disposal;
- ferrous iron (Fe^{+2}) and toxic metals in acidic groundwater as a consequence of sulphide mineral oxidation in mine milling wastes;
- nitrate contamination from septic and sewage lagoon systems; and,
- contamination by constituents such as chloride and sulphate, and organics such as toluene and organic acids, from domestic landfills.

2. NATURAL ATTENUATION

Application of natural attenuation of groundwater is similar to that of soil (refer to **TAB # 23**).

3. OXYGEN ENHANCED BIODEGRADATION

Oxygen enhanced biodegradation of the groundwater involves pumping air, ozone, hydrogen peroxide, or other oxygen sources through injection wells to enhance aerobic degradation of organic contaminants.

Technology: *In-situ* destruction.
Status: Innovative.
Contaminants:

- Non-halogenated volatiles and semi-volatiles, fuel hydrocarbons.
- Less effective for some halogenated volatiles and semi-volatiles, pesticides.

Advantages:

- Can be a permanent solution.

- Low capital costs.
- Regulatory and public acceptance is moderate to high.

Disadvantages:

- Not effective in low permeability, heterogeneous soils.
- High iron content can reduce hydrogen peroxide concentrations
- High O/M costs.

4. PASSIVE TREATMENT WALLS

A permeable treatment wall is installed in front of a migrating contaminant plume, allowing the plume to passively move through the wall. The contaminants are degraded by interaction with a catalyst contained in the porous media of the wall.

Technology: I*n-situ* destruction
Status: Innovative
Contaminants:

- halogenated volatiles and semi-volatiles, inorganics.
- less effective for some non-halogenated volatiles and semi-volatiles, fuel hydrocarbons.

Advantages:

- Effective for treating chlorinated hydrocarbons.
- Low O/M costs.

Disadvantages:

- Applicable only in shallow aquifers with well established flow direction.
- The wall's reactive media must be replaced on a regular basis.
- High capital costs.

5. AIR SPARGING

Air is injected into the groundwater through a network of injection wells creating a subsurface air stripping system that separates contaminants from the groundwater through volatilization. Air sparging must operate in unison with a soil vapour extraction system to capture the volatiles.

Technology: *In-situ* separation.
Status: Innovative
Contaminants:

- Volatiles, fuel hydrocarbons.

Advantages:

- Low capital and low O/M costs.
- Can be a permanent solution.
- Regulatory and public acceptance is high.

Disadvantages:

- Channeling of air flow can occur in layered and fractured terrains, adversely affecting system performance.
- Not effective in low permeable soils.

6. FREE PRODUCT RECOVERY

Pumping or passive collection methods are used to remove undissolved liquid phase organics from the subsurface. This method is used primarily to extract light non-aqueous phase liquid hydrocarbons (LNAPLHs) floating on the water table.

Technology: *Ex-situ* removal
Status: Conventional
Contaminants:

- Non-halogenated semi-volatiles, fuel hydrocarbons.

Advantages:

- Low capital and low O/M costs.
- Can be a permanent solution.
- Regulatory and public acceptance is high.
- Effective for contaminants that float on water.

Disadvantages :

- Large draw down cones associated with pumping may spread the contaminant to lower levels of soil in the saturated zone.
- If dense non-aqueous phase liquids (contaminants that sink) are present, then pumping can make the problem worse.
- Reuse or disposal of the recovered free product is required.
- Dissolved plume requires treatment.

7. BIOREACTORS

Contaminated groundwater is extracted and treated with microbes ex-situ in bioreactors. The biological systems in a bioreactor may be suspended or attached. In suspended growth systems, groundwater is circulated through activated sludge where suspended particles promote microbe growth and aerobic degradation of contaminants. In attached growth systems contaminant degradation takes place on an inert support matrix such as trickling filters.

Technology: *Ex-situ* destruction
Status: Innovative
Contaminants:
- Non-halogenated volatiles and semi-volatiles, fuel hydrocarbons.
- Less effective for some halogenated volatiles and semi-volatiles, pesticides.

Advantages:
- Can be a permanent solution.
- Low O/M costs.
- Regulatory and public acceptance is generally high.

Disadvantages:
- Metals may need to be removed prior to treatment.
- Precipitation of inorganics (e.g. iron, calcium) may clog treatment systems.
- Solid residuals that settle out in sludge systems may require treatment and disposal.

8. AIR STRIPPING

Air stripping involves the extraction of groundwater and the trickling of the water through a device that volatilizes contaminants by inducing air counter-current to the water. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Technology: *Ex-situ* separation
Status: Conventional
Contaminants:
- Volatiles.
- Less effective for some semi-volatiles, fuel hydrocarbons.

Advantages:
- Treats high concentrations.
- Can be a permanent solution.
- Low capital costs.

Disadvantages:
- Off-gases and residual liquids may require treatment.
- Regulatory and public acceptance is low.
- Inorganics can clog the stripping column packing material which then requires washing or replacement.
- May require further treatment, by carbon adsorption on activated carbon, for example, to meet drinking water standards.

9. CARBON ADSORPTION

Carbon adsorption is an ex-situ process which involves pumping contaminated groundwater through a series of activated carbon cells. The activated carbon adsorbs dissolved organic contaminants from the groundwater.

Technology: *Ex-situ* separation
Status: Conventional
Contaminants:
- Semi-volatiles.
- Less effective for some halogenated volatiles, fuel hydrocarbons, pesticides, Inorganics.

Advantages:
- Can be a permanent solution.
- Low capital costs.
- Regulatory and public acceptance is high.

Disadvantages:
- Activated carbon requires periodic regeneration or disposal.
- Metals can clog the activated carbon.
- High O/M costs.
- Too expensive for high concentration contaminants, therefore, often used after contaminants are first reduced by air stripping.

10. UV OXIDATION

UV oxidation is an ex-situ process where contaminated groundwater is exposed to ultraviolet radiation to destroy organic contaminants. Ozone or hydrogen peroxide are commonly used to enhance the oxidation and destruction of the contaminant. Off-gases are treated by an ozone destruction unit.

Technology: *Ex-situ* destruction
Status: Innovative

Contaminants:
- Halogenated volatiles and semi-volatiles, pesticides.
- Less effective for some non-halogenated volatiles, fuel hydrocarbons.

Advantages:
- No residual produced.

- Low O/M costs.

Disadvantages:

- Inorganics and naturally occurring soil organics can adversely affect system performance.
- High capital costs.

11. SLURRY WALLS

A vertically excavated trench is filled with a bentonite-water slurry to form an impermeable subsurface barrier. These walls are used to contain migrating contaminant plumes that pose an imminent threat to surrounding receptors. They are also used to redirect a contaminant plume to targeted extraction zones.

Technology: *In-situ* containment
Status: Conventional
Contaminants:

- All.

Advantages:

- Usually a rapid method of dealing with migrating contaminants.
- Relatively simple to implement.
- Low O/M costs.

Disadvantages:

- Full contaminant containment is difficult in high groundwater flow regimes.
- Bentonite may be degraded by some organic compounds and acid, base, and salt solutions.
- Regulatory and public acceptance is low.
- High capital costs.

12. PERMEABILITY ENHANCED GROUNDWATER EXTRACTION

Fractures are induced into impermeable sediments or bedrock to improve permeability and the pumping efficiency of extraction wells. This is accomplished by injecting pressurized water (hydro-fracturing) through injection wells or by blasting a linear zone.

Technology: *In-situ* containment
Status: Innovative
Contaminants:

- All dissolved or light non-aqueous phase liquid contaminants (less dense than water).
- More caution required for dense non-aqueous phase liquid contaminants (heavier than water).

Advantages:

- Effective for groundwater extraction in highly impermeable materials such as bedrock.

Disadvantages:

- Care must be taken not to fracture an underlying or adjacent uncontaminated zone into which contaminants could spread.
- Blasting has high capital costs. Monitoring of “groundwater capture effectiveness” will increase costs.
- Regulatory and public acceptance is low for blasting methods.

13. COST ESTIMATES

Table 1 shows the relative capital and O & M costs for some of the individual remediation technologies that have been cited.

SOURCES

Absalon, J. R. and Hockenbury, M. R. (1983). *Treatment Alternatives Evaluation for Aquifer Restoration*.

Canadian Council of Ministers of the Environment (1994). *Subsurface Assessment Handbook for Contaminated Sites*.

Malroz Engineering Inc. (1996). *Soil and Groundwater Remediation of Industrial Waste Lagoon Contamination*.

U.S. Environmental Protection Agency (1994). *Innovative Treatment Technologies: Annual Status Report*. Sixth Edition.

TABLE 1: GROUNDWATER REMEDIATION COSTS

Remediation Technology	**Type**	**Status**	**Costs** [1]
Natural Attenuation	In-situ Destruction	Conventional	No capital or O/M costs. Sampling, analysis, modeling, and monitoring costs.
Oxygen Enhanced Biodegradation	In-situ Destruction	Innovative	$1.10-$3.70/1,000 litres design, installation, O/M costs.
Passive Treatment Walls	In-situ Destruction	Innovative	Inadequate information.[2]
Air Sparging	In-situ Separation	Innovative	<$1.10/1,000 litres design, installation, O/M costs.[2]
Free Product Recovery	Ex-situ Removal	Conventional	<$1.10/1,000 litres design, installation, O/M costs.[2]
Bioreactors	Ex-situ Destruction	Innovative	<$1.10/1,000 litres design, installation, extraction, O/M costs.[2]
Air Stripping	Ex-situ Separation	Conventional	<$1.10/1,000 litres design, installation, extraction, O/M costs.[2]
Carbon Adsorption	Ex-situ Separation	Conventional	>$3.70/1000 litres design, installation, extraction, O/M costs.[2]
UV Oxidation	Ex-situ Destruction	Innovative	$1.10-$3.70/1,000 litres design, installation, extraction, O/M costs.[2]
Slurry Walls	In-situ Containment	Conventional	<$1.10/1,000 litres design, installation, O/M costs.[2]
Permeability Enhanced Groundwater Extraction	In-situ Containment	Innovative	Inadequate information.

Notes:

1. Costs are changing and in many cases have decreased in the past few years.
2. U.S. Environmental Protection Agency (1993). "Remediation Technologies Screening Matrix and Reference Guide", Version I. Converted from US to Canadian dollars: $1.00 US = $1.40 CAN.
3. Canadian Petroleum Products Institute (1991). "Manual of Petroleum Contaminated Soil Treatment Technologies", CPPI Report No. 91-9.

U.S. Environmental Protection Agency (1994). *Superfund Innovative Technology Evaluation Program*, Technologies Profiles Seventh Edition.

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