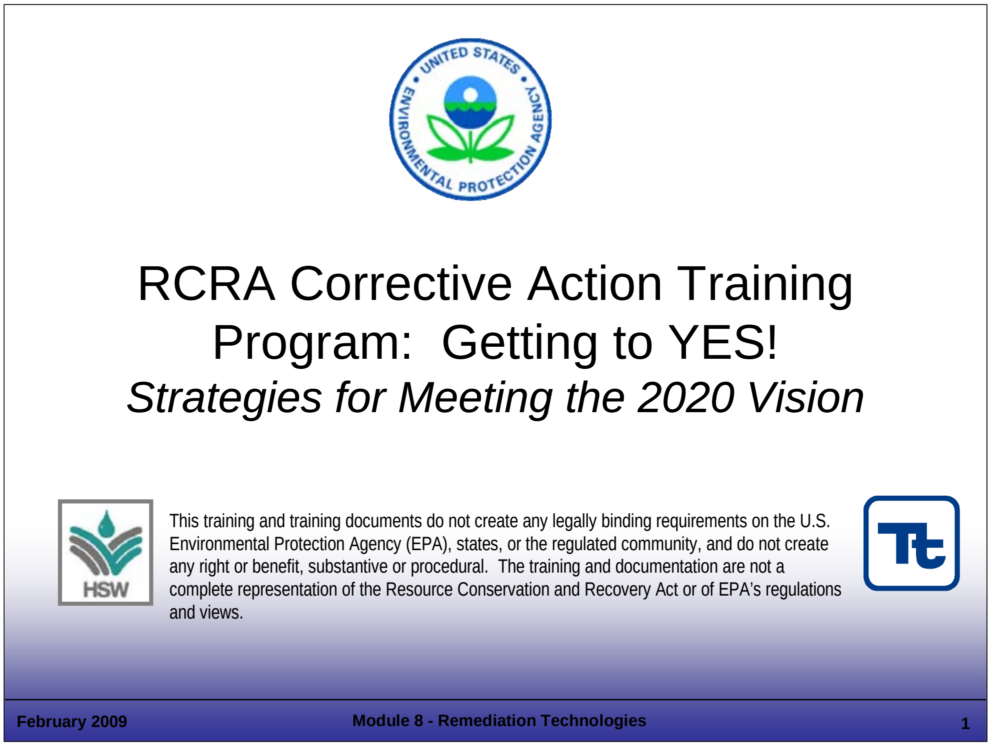
Module 08
Remediation Technologies



Notes:

Purpose of Slide

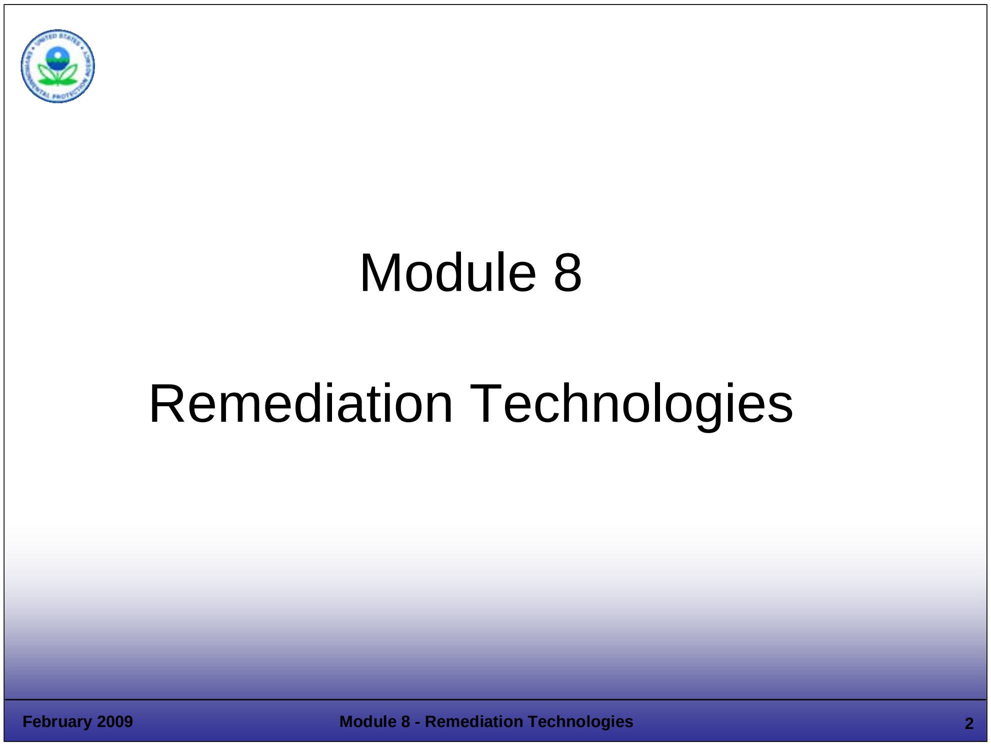
- Holder slide for Module 8, Remediation Technologies.

Key Points

- This is a holder slide. No specific key points.

References

- None.



Notes:

Purpose of Slide

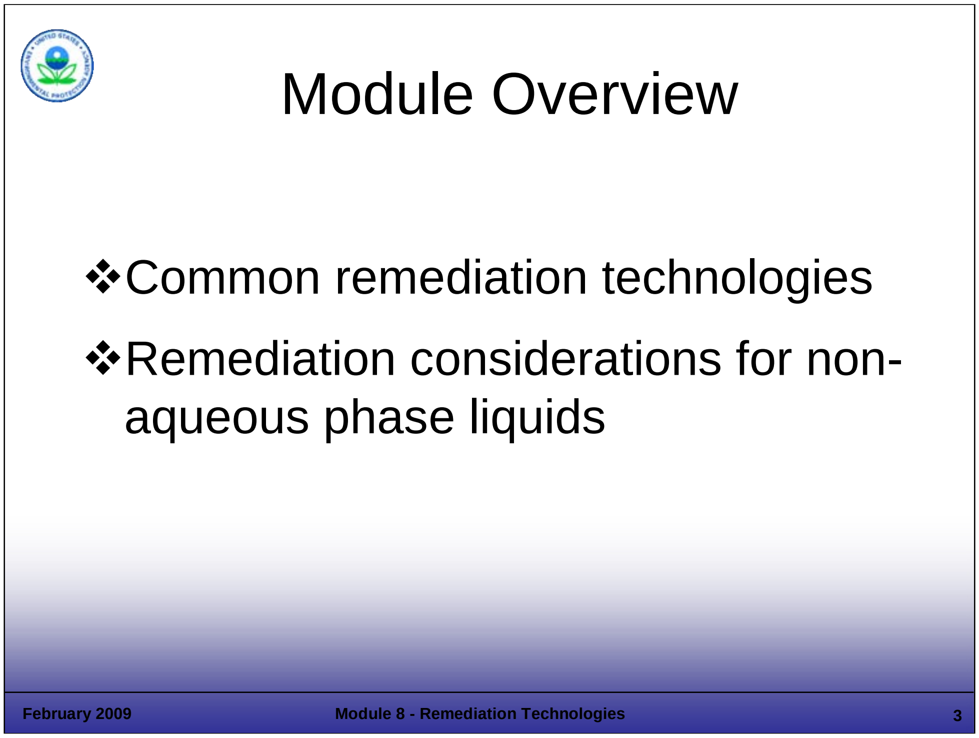
- Holder slide for Module 8, Remediation Technologies.

Key Points

- This is a holder slide. No specific key points.

References

- None.



Notes:

Purpose of Slide

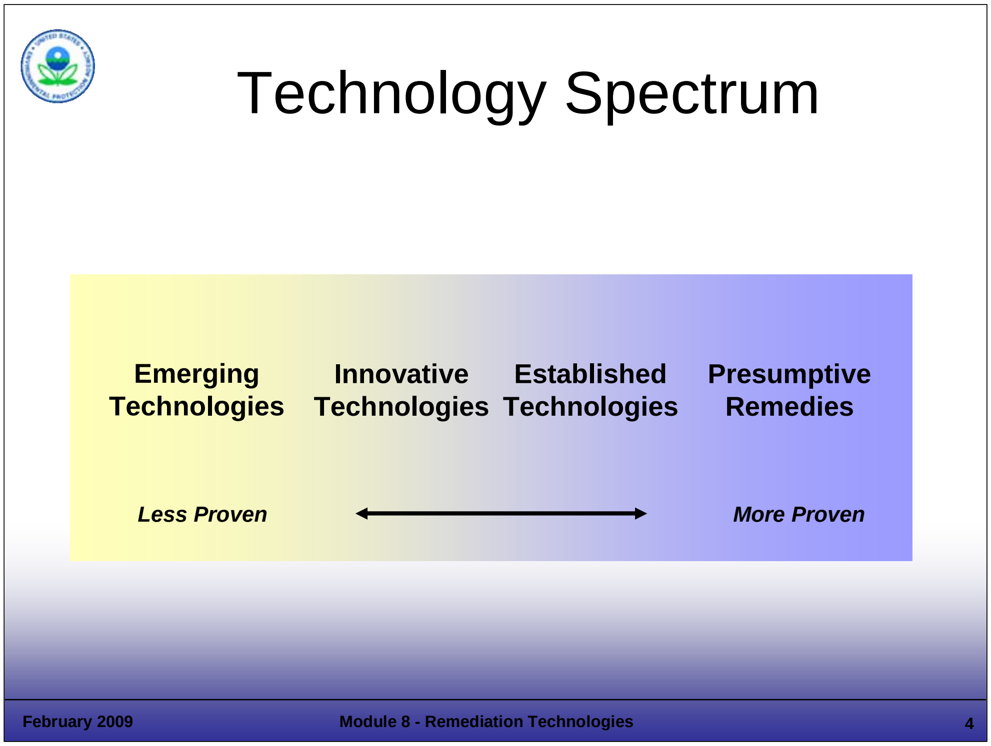
- Introduce Module 8, Remediation Technologies.

Key Points

- The primary purpose of this module is to present and discuss remediation technologies, which support existing CA and other remedies. Knowledge of these technologies is important to remedy selection, implementation, and achievement of the 2020 Vision. This module presents common remediation technologies primarily for soil and groundwater contamination found at corrective action (CA) sites. Sediment remediation will be touched on and most of the treatment technologies for soil (particularly ex situ) also are applicable to sediment. Many of these existing technologies will continue to be used in the foreseeable future.
- This module also discusses technologies and approaches associated with a special category of contamination, non-aqueous phase liquids (NAPLs).

References

- None.



Notes:

Purpose of Slide

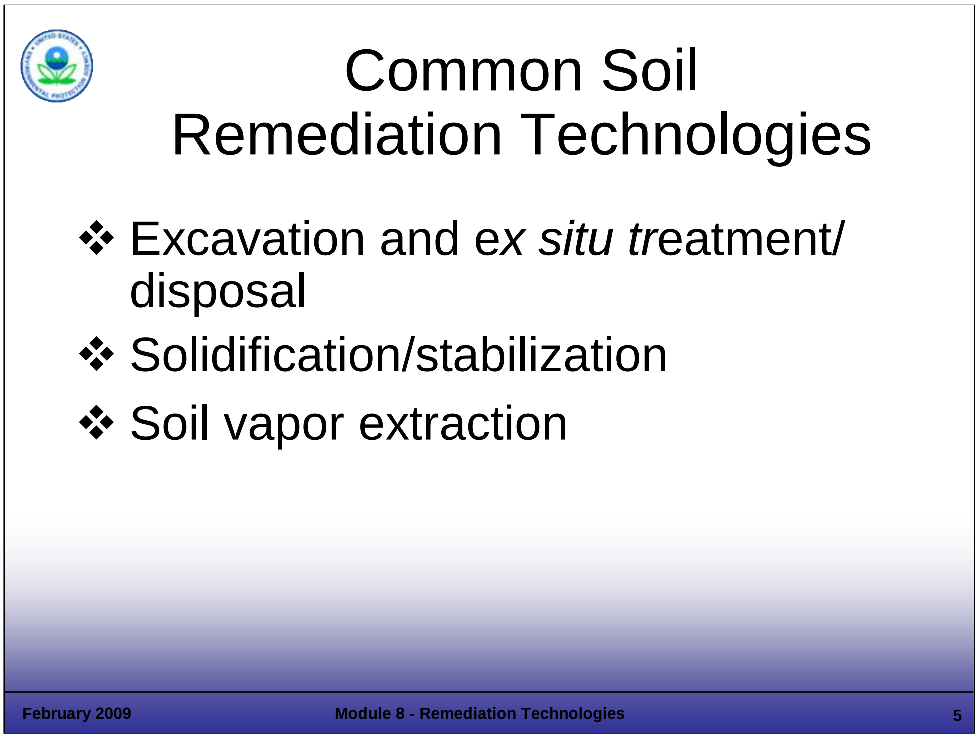
- Introduce the remedy, or technology, spectrum.

Key Points

- The remedy spectrum can be thought of as a progression from less proven, developing technologies to more proven technologies for remediation. The status of a technology depends both on technology (for example, bioremediation) and its application. Bioremediation may be presumptive and proven for wood treatment sites, but less developed and innovative for application at another type of site.
- "Presumptive remedies" is a Superfund tool that refers to standardized preferred response actions for municipal landfills, wood treatment, volatile organic compounds (VOCs) in soil, contaminated groundwater, and metals in soil. The U.S. Environmental Protection Agency (EPA) recognized that certain types of sites have similar characteristics that lend themselves to preferred technologies. These presumptive remedies streamline remedy selection and allow an early focus of data collection to support design and implementation of the remedy.
- Presumptive remedies include: (1) bioremediation, thermal desorption, or incineration for organics and immobilization for metals at wood treatment sites; (2) soil vapor extraction (SVE) for VOCs in soil; (3) a phased approach to groundwater remediation; and (4) reclamation and recovery or immobilization for metals in soil.
- An established technology is a technology for which cost and performance information is readily available. Only after a technology has been used at many different sites and the results have been fully documented is that technology considered to be established.
- An innovative technology is a technology that has been field-tested and applied to a hazardous waste problem at a site; but it lacks a long history of full-scale use. More cost and performance information is generally needed to evaluate the technology for wider use.
- An emerging technology is one that is undergoing bench-scale testing in which a small version of the technology is tested in a laboratory; these technologies generally have not been tested at full-scale use.

References

- EPA. 1996. Presumptive Response Strategy and Ex-situ Treatment Technologies for Contaminated Groundwater at CERCLA Sites. EPA-540-R-96-023. October.
- EPA. 2005. Road Map to Understanding Innovative Technology Options for Brownfield's Investigation and Cleanup. Fourth Edition. EPA-542-B-05-001. September.



Notes:

Purpose of Slide

- Introduce commonly used soil remediation technologies for CA cleanups.

Key Points

- These technologies – excavation, solidification/stabilization, and SVE – are some of the most commonly used technologies for addressing contaminated soils and source materials. Of the sites addressed under the EPA Superfund Program between 1982 and 2002, 89 percent of the soil remedies involved these three technologies.
- There are also a number of technologies that have been used less frequently; however, these also can be considered for soil cleanups. Examples of these technologies include: soil washing, in situ thermal treatment, and bioremediation. Descriptions of these technologies and their potential uses can be found on EPA's CLU-IN Website and various other government agency and non-government organization websites such as those provided by the Interstate Technology Regulatory Council (ITRC), Federal Remediation Technology Roundtable (FRTR), U.S. Army Corps of Engineers (USACE), and Department of Energy (DOE). Note that these newer technologies are innovative for some applications but can be presumptive for certain applications where they have been successfully applied over time (for example, bioremediation for wood treating sites).

References

- Clu-In Web Site. Accessed On-Line at: http://www.clu-in.org/.
- Federal Remediation Technologies Roundtable (FRTR) Website. Accessed On-line at: http://www.frtr.gov/.
- Department of Energy (DOE) Website. Accessed On-line at: http://www.em.doe.gov/pages/emhome.aspx.
- Interstate Technology Regulatory Council (ITRC) Website. Accessed On-line at: http://www.itrcweb.org/.

Soil Excavation

- Removes contaminated soil and commingled materials (waste, sludge, and debris) for management.
- Excavated soil can be treated by various *ex situ* technologies.
- On site placement of treated soil may be an option.

February 2009 Module 8 - Remediation Technologies 6

Notes:

Purpose of Slide

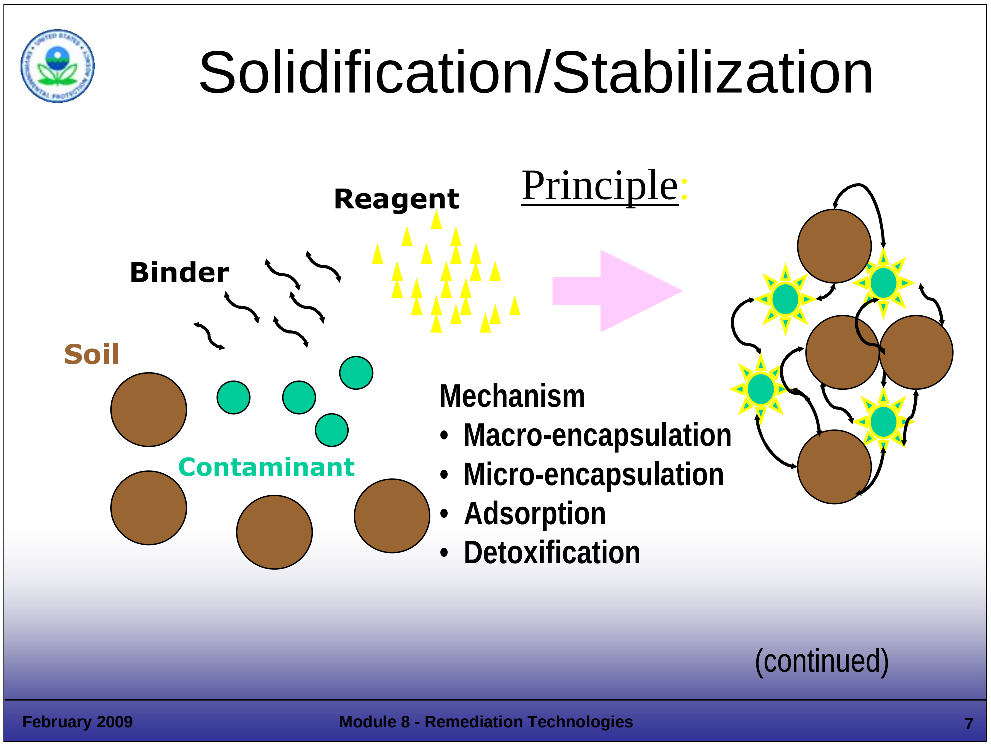
- Discuss soil excavation.

Key Points

- Excavation is primarily used to remediate small volumes of highly contaminated soil; however, it has also been used for large soil volumes when other, more-sophisticated technologies would be less effective or more costly.
- Excavation involves removing contaminated soil and commingled materials (for example, buried wastes and debris) for subsequent treatment and disposal or reuse.
- A number of methods are commonly used to manage excavated source material, including on-site or off-site solidification/stabilization, incineration, thermal desorption, and landfilling.
- Contaminated soil that exhibits a characteristic or contains a listed hazardous waste is subject to hazardous waste rules including Land Disposal Restrictions (LDRs). The Phase IV LDR Rule created a new treatability group, contaminated soil. The treatment requirements for this group are discussed in Module 9.
- After treatment, soil may be reused as backfill if it meets applicable site cleanup goals for soil (and is not otherwise regulated as a a hazardous waste, which is subject to LDR requirements). Soil that cannot be economically treated for reuse may require disposal, after appropriate treatment, in an appropriate land disposal unit.

References

- None.



Notes:

Purpose of Slide

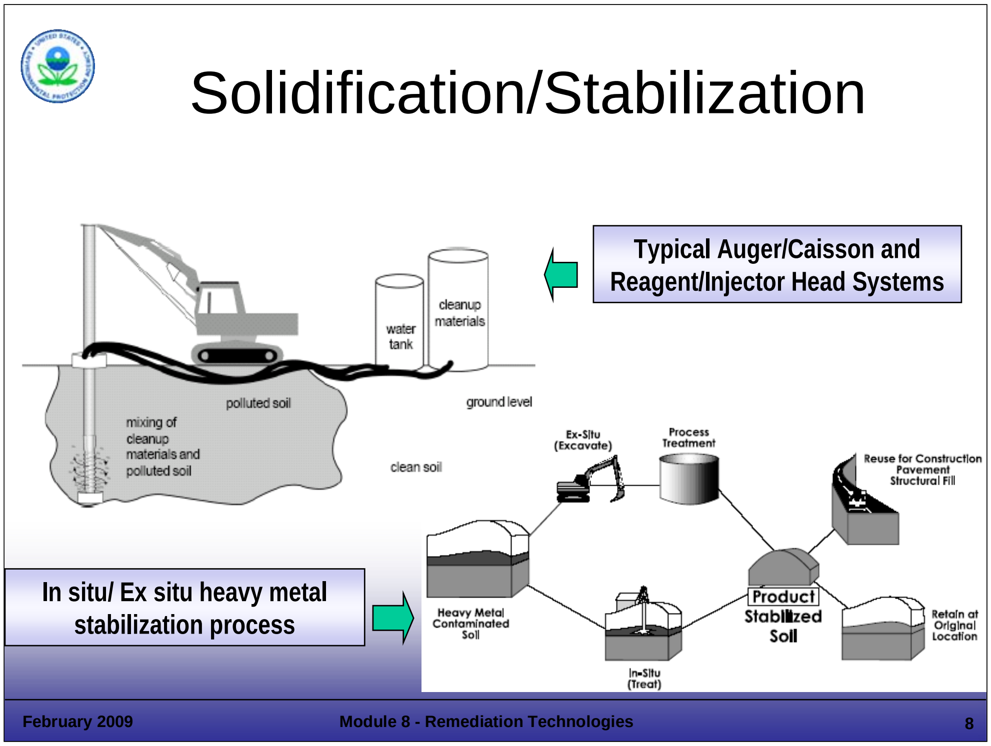
- Discuss Stabilization/Solidification (S/S) as a treatment process.

Key Points

- S/S refers to a group of cleanup methods that prevent or slow the release of harmful chemicals from polluted soil or sludge. S/S methods do not destroy contaminants, but act to eliminate or reduce the solubility or mobility of contaminants by generally decreasing the surface area of the soil or other material exposed to leaching.
- Solidification refers to processes that encapsulate a waste to form a solid material and to restrict contaminant migration by decreasing the surface area exposed to leaching and/or by coating the waste with low-permeability materials. Solidification can be accomplished by a chemical reaction between a waste and binding (solidifying) reagents or by mechanical processes. Solidification of fine waste particles is referred to as microencapsulation, while solidification of a large block or container of waste is referred to as macroencapsulation (Solidification/Stabilization Use at Superfund Sites).
- Stabilization refers to processes that involve chemical reactions that reduce the leachability of a waste. Stabilization chemically immobilizes hazardous materials or reduces their solubility through a chemical reaction. The physical nature of the waste may or may not be changed by this process (Solidification/Stabilization Use at Superfund Sites).
- These two methods are often used together to prevent exposure to harmful chemicals.

References

- Conner, J. R. 1990. *Chemical Fixation and Solidification of Hazardous Wastes.* Van Nostrand Reinhold. New York.
- EPA. 1999. Solidification/Stabilization Resource Guide. EPA-542-B-99-002. April.
- EPA. 2000. Solidification/Stabilization Use at Superfund Sites. EPA-542-R-00-010. September.
- EPA. 2001. A Citizen's Guide to Solidification/Solidification. EPA-542-F-01-024. December.
- LaGrega, M. D., Buckingham, P. L.,Evans J. C. 1994. *Hazardous Waste Management.* McGraw-Hill Series in water resources and Environmental Engineering.
- EPA. 2004. Record of Decision (ROD) for Avtex Fibers Site, including Stabilization of Soils with Metals. EPA-ROD-R03-04-601. Accessed On-line at; whttp://www.epa.gov/reg3hwmd/super/sites/VAD070358684/index.htm.
- Yong, R. N. 2000. *Geoenvironmental Engineering: Contaminated Soils, Pollutant Fate and Mitigation*, 307 pp. CRC Press, Boca Raton, FL.
- EPA. 2007. Annual Status Report. Twelfth Edition. EPA-542-R-07-012. September. Accessed at the Clu-In Website at: http://clu-in.org/asr/.
- Sanjay K. Mohanty. 2004. Powerpoint Presentation: Solidification/Stabilization. Civil & Environmental Engineering Department. University of Hawaii at Manoa. December.



Notes:

Purpose of Slide

- Discuss S/S applications.

Key Points

- S/S can be used to treat excavated soil. In most cases, excavated soil is mixed with treatment materials in a pug mill or by other means and the S/S soil is returned to the ground on the site, if rules allow such placement.
- Although less frequently used, a number of in situ S/S applications have also been developed. These include methods where the binders are introduced into the ground and mixed with the contaminated soil (for example, using vertical auger mixing, shallow in-place mixing, and injection grouting). The challenge with in situ S/S methods is achieving uniform mixing of soil and binders.
- To date, most S/S applications have been used to address metals in soil. The primary treatment binders have been Portland Cement, soluble phosphate, fly ash, lime, bitumen, asphalt, and proprietary blends.
- Limitations on the usefulness of S/S may include:
  - Most S/S technologies are not effective for organics;
  - S/S can significantly increase the volume of the materials that need to be disposed;
  - Cement-based agents can weather and disintegrate over time; thereby, releasing contaminants;
  - Future site use may be hindered by the presence of treated materials; and
  - Long-term effectiveness of S/S has not been demonstrated for many contaminants.

References

- See previous page.
- Sanjay K. Mohanty. 2004. Powerpoint Presentation: Solidification/Stabilization. Civil & Environmental Engineering Department. University of Hawaii at Manoa. December (used for slide).

Soil Vapor Extraction (SVE)

- Vacuum applied to soil in unsaturated zone
- Removes volatile organic compounds (VOCs) and some semi-volatile organic compounds (SVOCs)
- Can be used alone or combined with air sparging

February 2009 Module 8 - Remediation Technologies 9

Notes:

Purpose of Slide

- Introduce soil vapor extraction (SVE).

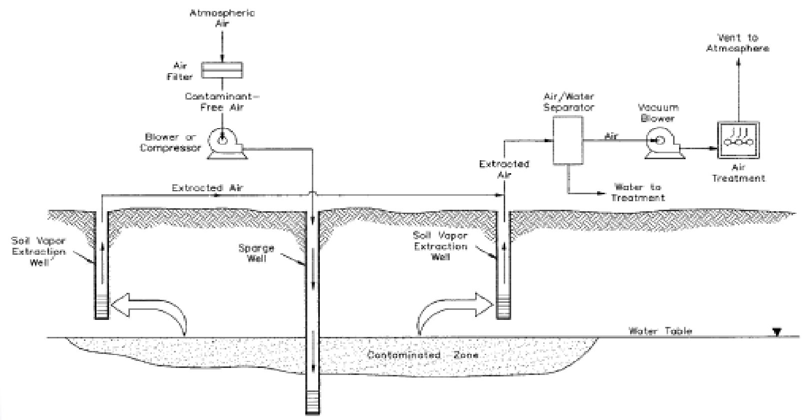
Key Points

- SVE is a technology used in situ in unsaturated (vadose) zone soils. A vacuum is applied to the soil using SVE wells to induce a controlled flow of air and remove VOCs and some semi-volatile organic compounds (SVOCs) from the soil.
- SVE can be used in conjunction with air sparging of underlying groundwater to extract mobilized contaminants or can be used as a stand-alone technology to treat soil contamination.
- Vertical SVE wells are typically used at depths of about 5 feet but have been successfully applied to much greater depths. Horizontal SVE wells (installed in trenches or horizontal borings) can be also be used, as applicable.
- This technology is considered the preferred presumptive remedy for VOCs in soil.
- A consideration in SVE application is that off gas may require treatment, such as by activated carbon, to eliminate possible ambient air impacts.
- Factors that may limit the applicability and effectiveness of SVE include:
  - Tight soils may not allow sufficiently high vacuums to remove contaminants;
  - Large screen intervals are required in extraction wells for soil with highly variable permeabilities or stratification; and
  - Soil with high organic content or that is extremely dry, has a high sorption capacity for VOCs, which results in reduced removal rates.

References

- EPA. 1996. User's Guide to the VOCs in Soils Presumptive Remedy. EPA/540/F-96/008. July. Accessed On-line at: http://www.epa.gov/superfund/policy/remedy/presump/finalpdf/vc.pdf.

SVE System



EPA. 1997. Analysis of Selected Enhancements for Soil Vapor Extraction. EPA-552-R-97-007. September.

February 2009 Module 8 - Remediation Technologies 10

Notes:

<u>Purpose of Slide</u>

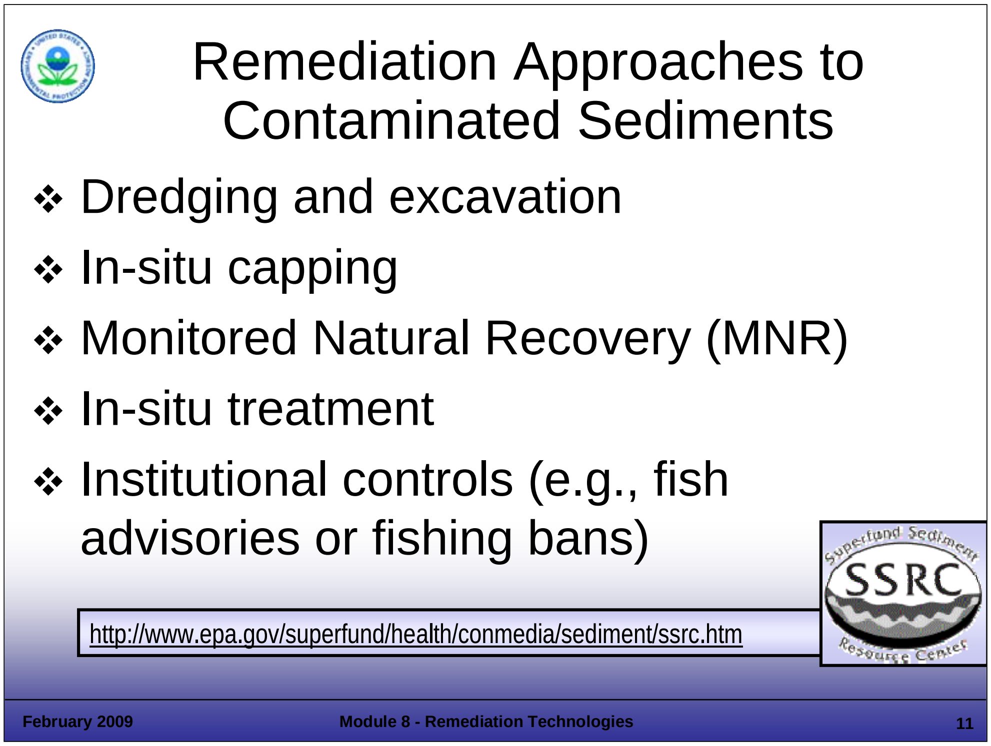
- Illustrate a SVE system.

<u>Key Points</u>

- This slide depicts a SVE system used in conjunction with an air sparging system to remediate contaminated groundwater. The central part of the slide depicts an air sparge source and a well that may be used in conjunction with the SVE system.
- A vacuum system collects vapor from subsurface wells (horizontal or vertical) and vents it to the atmosphere. Collected vapor may require treatment before release to the atmosphere.
- The vacuum source may be a liquid ring vacuum pump (very high vacuum), a positive displacement blower (moderate vacuum), or even a centrifugal blower (low vacuum).

<u>References</u>

- EPA. 1997. Analysis of Selected Enhancements for Soil Vapor Extraction. EPA-542-R-97-007. September.
- EPA. 2006. Off-Gas Treatment Technologies for Soil Vapor Extraction Systems: State of the Practice. EPA-542-R-05-028. March.



Notes:

Purpose of Slide

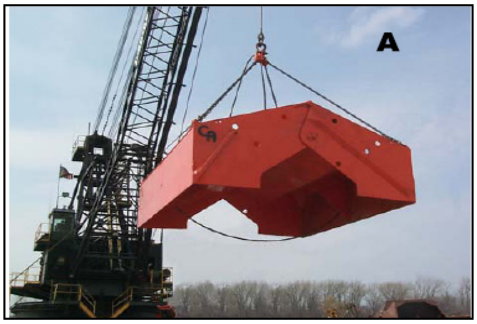
- Introduce various remedial approaches to sediment and compare these to soil remedial approaches.

Key Points

- Dredging and excavation are the most common means of removing contaminated sediment from a water body. Once excavated, ex-situ treatment and disposal remedies similar to those for soil can be employed.
- Capping technologies provide a separation barrier that (1) isolates contaminants from benthic organisms, (2) stabilizes sediment and prevents re-suspension and transport, and (3) chemically isolates contaminants to reduce dissolved and colloidal transport. Benthic organisms populate only the top few centimeters of sediment. The specific habitat conditions and associated capping requirements are evaluated as part of the feasibility study. Thin layer capping (compared to other caps that can be several feet thick) can be used to enhance monitored natural recovery (MNR) by providing some isolation and time for MNR to occur. Thin layers are often constructed of native material and may be only a few inches thick.
- MNR, with or without institutional controls (ICs), may be an appropriate remedy that uses natural processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants. MNR is terminology specific to sediments and differs from monitored natural attenuation (MNA) in that for MNR, isolation and mixing through natural sedimentation, versus transformation for MNA, is the process most relied on. An ecological risk assessment provides information important to MNR and other remediation approaches.
- In-situ treatment addresses sediment in place. For example, caps containing reactive materials (such as, activated carbon and zero-valent iron) further limit the transport of contaminants into the water column by bonding with the contaminants. Bio-enhancement amendments can be added (for example, an electron donor) to accelerate biodegradation processes.
- ICs may be required in addition to remediation approaches; for example, fish advisories or fishing bans may be instituted for a period of time.
- Resources like the Superfund Sediment Resource Center can provide Project Mangers with site specific support for challenging sediment remediation questions.

References

- EPA Contaminated Sediment web site. http://www.epa.gov/superfund/health/conmedia/sediment/ssrc.htm
- EPA. 2006. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012. December.
- Electrical Power Research Institute (EPRI). 2006. Reactive Capping for Non Aqueous Phase Liquid-Sediments: An In-Situ Evaluation of Effectiveness and Ease of Implementation.



Examples of Mechanical Dredges for Sediment

A. Cable Arm Corp. Dredge

B. Bean Company Horizontal Profiling Grab (HPG) Dredge, New Bedford Site

February 2009 Module 8 - Remediation Technologies 12

Notes:

Purpose of Slide

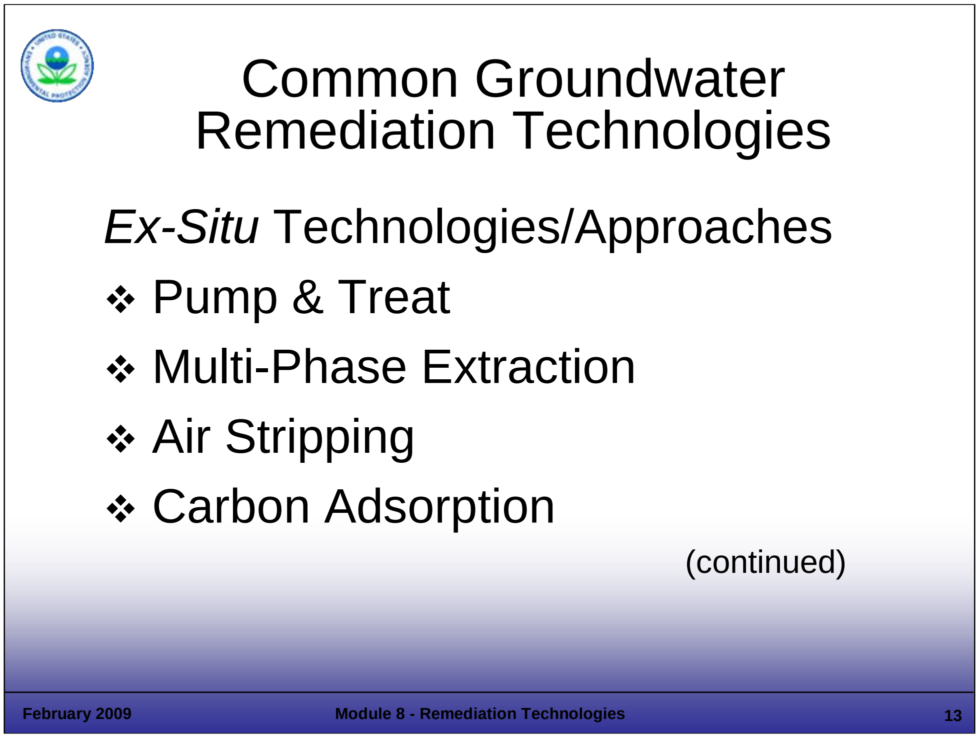
- Illustrate mechanical dredging.

Key Points

- This slide depicts mechanical dredging. The distinction between mechanical dredging and excavation is that the mechanical dredge operates on a floating platform.
- The source for the first photograph is Cable Arm, Corporation. The source for the second photograph is Barbara Bergen, EPA.

References

- EPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012. December



Notes:

Purpose of Slide

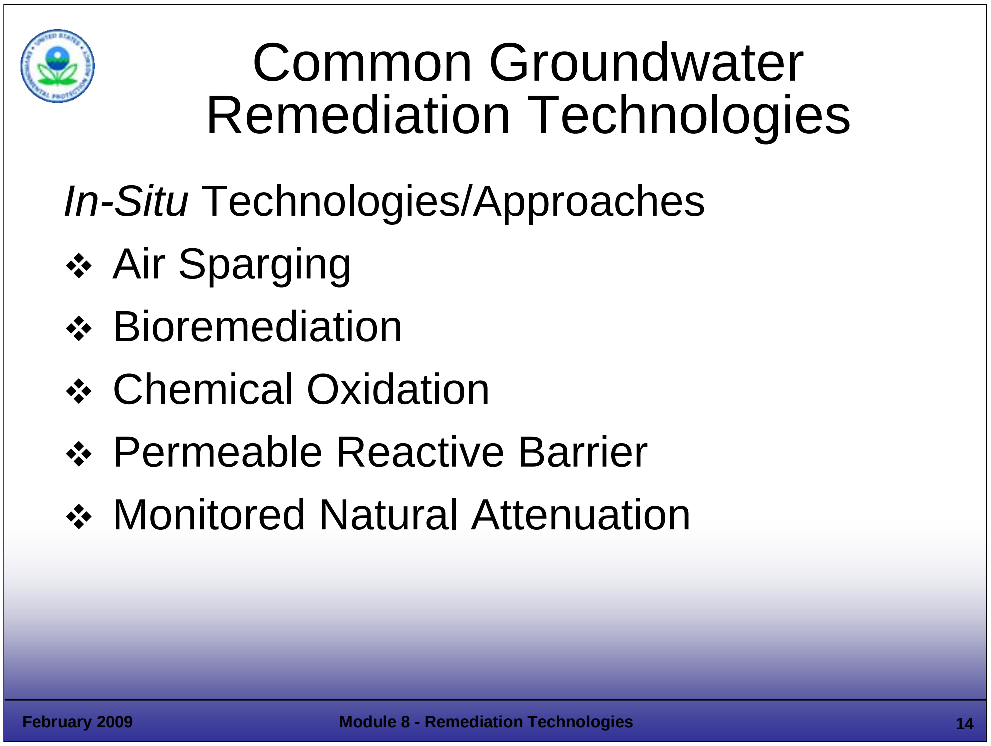
- Introduce common groundwater technologies likely to be encountered at CA sites.

Key Points

- This slide shows some of the common ex-situ groundwater remediation technologies in use. Each will be covered in this section.

References

- None.



Notes:

Purpose of Slide

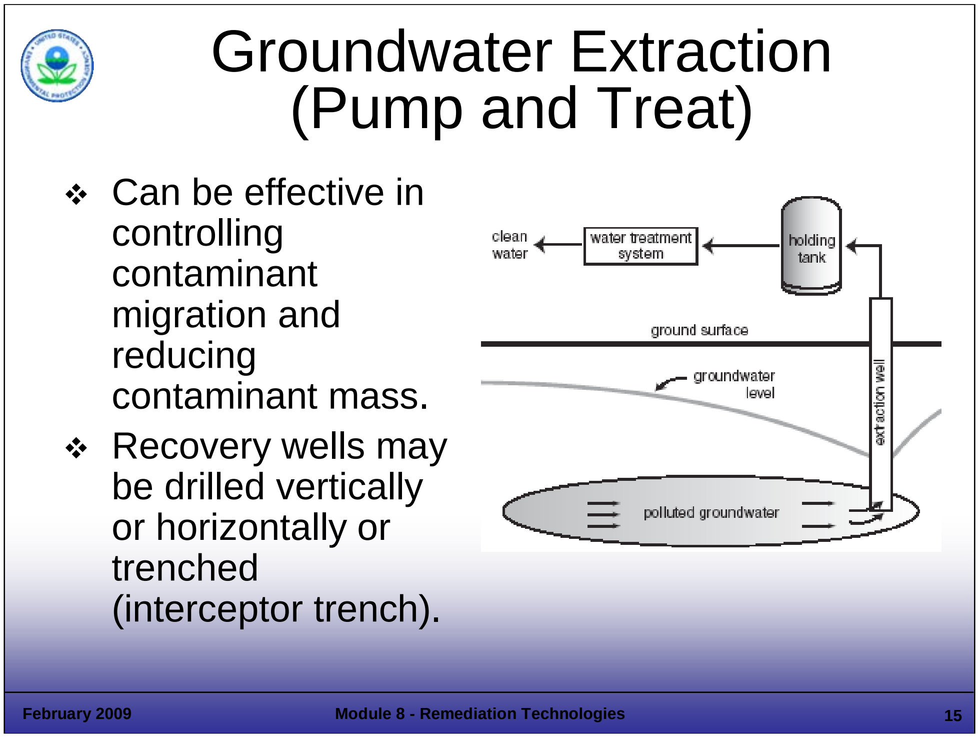
- Introduce common groundwater technologies likely to be encountered at CA sites.

Key Points

- This slide shows some of the common in-situ groundwater remediation technologies in use. Each will be covered in this section.

References

- None.



Notes:

Purpose of Slide

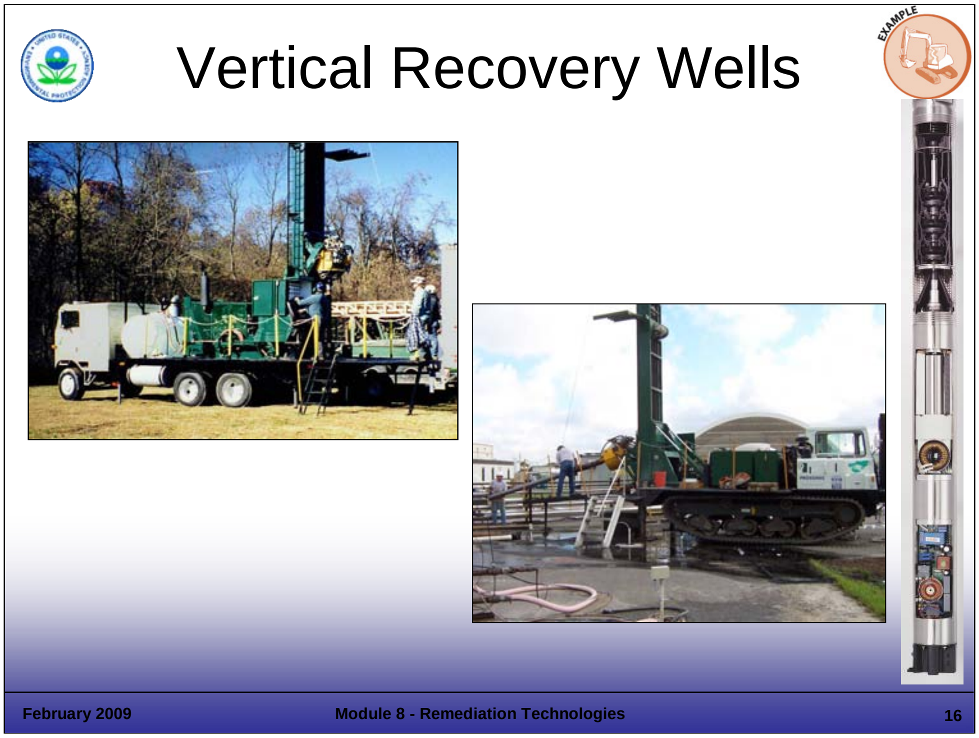
- Introduce pump and treat technology.

Key Points

- Groundwater pump and treat (P&T) systems are commonly used to contain dissolved phase contaminant plumes, reduce migration, and remove mass. P&T is not generally effective as the sole remedy for achieving groundwater cleanup criteria; however, experience has shown that it can be quite effective in reducing the size of a dissolved contaminant plume.
- In P&T systems, one or more groundwater recovery wells are used to extract (pump) groundwater that is then treated, usually in an on-site treatment system.
- P&T systems have been used for groundwater remediation at many RCRA CA facilities and over 90% of Superfund sites.
- Groundwater extraction systems may include vertical or horizontal recovery wells or infiltration trenches.
- Factors that may limit the applicability and effectiveness of groundwater P&T include:
  - Many contaminants tend to be absorbed in the soil matrix and cannot be removed completely by groundwater pumping;
  - P&T is not applicable to sites with high residual saturation and aquifers with low hydraulic conductivity;
  - The capital and on-going operating costs of treatment systems is generally high because the P&T system will likely require a long time to operate to achieve the groundwater cleanup goals; and
  - Biofouling of recovery wells and treatment system components is a common problem that can severely affect system performance.

References

- EPA. 2001. A Citizen's Guide to Pump and Treat. EPA 542-F-01-025. December.
- EPA OSWER. 1996. Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Groundwater at CERCLA Sites. Final Guidance. OSWER Publication 9283.1-12. EPA 540-R-96-023. October.



Notes:

Purpose of Slide

- Show drill rigs in action – vertical drilling.

Key Points

- A Rotasonic drill rig is a relatively recent drilling innovation that is used to install wells with minimal waste and to provide soil cores with little smearing. This technique uses a rotating drill bit vibrating at a high frequency as the bit is advanced. A wheel-mounted rig is shown on the left and a track mounted unit is shown on the right.
- A typical submersible pump used in recovery wells is shown in cross-section on the right of the slide.
- Pumps are selected based on well yield results and how much head is required to lift and transport the water.
    - Small, submersible, recovery pumps are usually single-phase electric motors (up to about 2-3 horsepower [HP]);
    - Larger recovery pumps are usually three-phase motors (as small as 1 HP and up to 100 HP or more); and
    - Pneumatic pumps (direct acting or piston type) may be used in some applications. They have unique advantages and work very well at low flow rates.

References

- None.

Notes:

Purpose of Slide

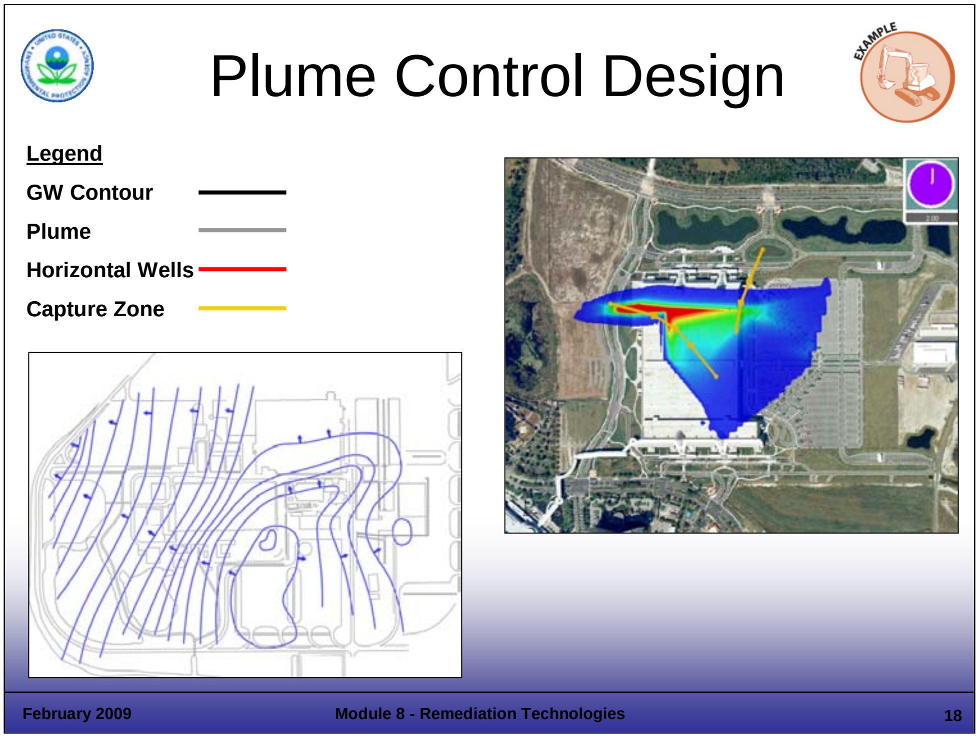
- Show installation of horizontal recovery wells.

Key Points

- Horizontal wells can be installed by conventional trenching techniques such as using a backhoe or by specialty machines similar to chain-type trenchers.
- The photograph on the left shows a trenched horizontal well being installed using a special machine (one-pass trencher) that lays the perforated or slotted pipe at the bottom of the trench. Backfill material (sand, soil, gravel) is continuously fed through the hopper to fill the trench as the machine advances. The depth of these horizontal wells is generally limited to 30 feet below grade; however, depths of up to 50 feet or more are possible with advanced equipment.
- The second photograph shows another technique for horizontal drilling, using a computer controlled, remotely-guided drill head to bore the hole. This method allows placement of wells under existing structures without interfering with operations. In this application, two horizontal wells - 900 feet and 1200 feet in length - were installed under an active defense manufacturing facility.
- For drilled horizontal wells, the drill head has an entrance point and exit point and, once begun, the borehole must be completed without stopping. The well casing may be steel or polyethylene pipe, which is connected to the drill rod at the exit hole and then pulled back through the hole.

References

- None.



Notes:

Purpose of Slide

- Demonstrate a model of plume spread then capture (video clip will be included).

Key Points

- This graphic shows a contaminant plume as it spreads under a manufacturing facility (gray shadow).
- Horizontal wells were installed under the facility to capture the plume (red lines).
- The plume shrinks as water is extracted, as shown by the changes in contour lines.
- The resulting capture zone is shown by the yellow lines.
- The resultant controlled plume with two horizontal wells operating is shown last.

References

- None.

Notes:

<u>Purpose of Slide</u>

- Show installation of groundwater extraction trench.

<u>Key Points</u>

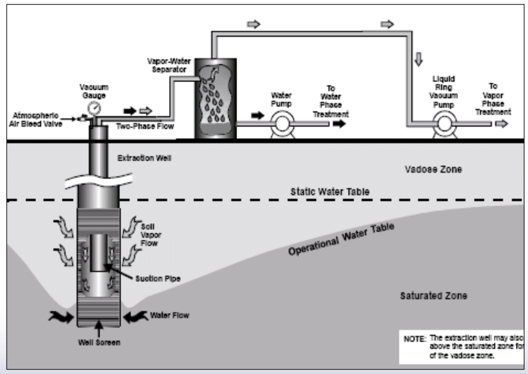
- Extraction trenches are similar to horizontal recovery wells, but are much simpler applications. They are installed by conventional trenching techniques such as a backhoe.
- This extraction system includes a trench and drain, a collection sump, and a submersible pump. This system was selected for this site, primarily because of the site's low groundwater flux. The system was constructed to capture a small, well-defined groundwater plume (more specifically, it captures groundwater moving downgradient in the zone perpendicular to the trench and drain and above a competent bedrock).
- The photograph on the left shows the extraction trench during installation. The trench was about 15 feet deep. The second step in constructing the trench and drain is completing the drain. A perforated drainage pipe was run along the length of the trench. It was suspended a few inches above the trench bottom (on a 3/4-inch-minus-drainage gravel bedding) and slopes toward the sump. The trench was backfilled with drainage gravel and a geotextile fabric was placed above the gravel to minimize transport of fine-grained soils into the 4-inch perforated drainage pipe bedded in the drainage rock. A clean-out port was installed at the upgradient side of the trench and drain to facilitate flushing of the drain pipe with water. This removes any solids accumulation from the pipe. A collection sump placed at the downstream end of the trench allows intermittent- and variable-rate pumping based on changes in groundwater flux. Modeling of the contaminants expected in the recovered groundwater indicated that concentrations would be below the limits established for discharge to the publicly-owned treatment works (POTW). Therefore, groundwater collected in the sump discharges to the City POTW in accordance with city discharge limitations. Discharges are monitored to verify concentrations meet discharge limitations.
- In this example, if it is determined that the VOC concentrations in the recovered groundwater exceed the City's discharge limits and cannot be accepted by the City under the terms of a variance, the facility will install an air stripper to pretreat recovered groundwater before discharge to the POTW.
- After installation, the trench and drain were backfilled above the drainage gravel and a berm was constructed. The berm helps to divert stormwater runoff from the area around the trench and drain.

<u>References</u>

- None.

Multi-Phase Extraction

- Vacuum applied to well to extract groundwater and vapor simultaneously
- Water table lowered around well, exposing previously saturated zone to vacuum extraction



February 2009 Module 8 - Remediation Technologies 20

Notes:

Purpose of Slide

- Introduce multi-phase extraction.

Key Points

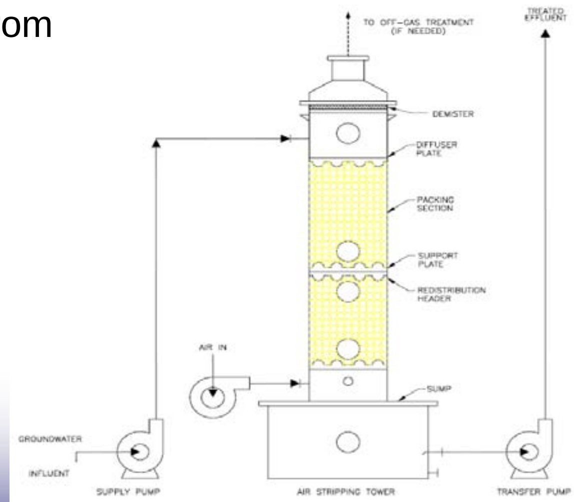
- Multi-phase extraction (MPE) is sometimes referred to as dual-phase extraction. In MPE, a vacuum is applied to recovery wells and is used to extract both groundwater and soil vapors simultaneously. The vacuum source may be a liquid ring vacuum pump or a dry pump.
- Groundwater is removed from the recovery well by a vacuum that is applied to a drop pipe in the well. Vapor is removed from the recovery well by a vacuum that is applied to the well above the water table. As groundwater is extracted from the well and the water level around the well drops, the well screen is exposed and vapors from the soil are drawn into the casing by the vacuum system.
- Factors that may limit the applicability and effectiveness of MPE include those applicable to groundwater P&T and SVE systems (including high operating costs and biofouling). As with SVE systems, a consideration in system application is the potential need for off-gas treatment.

References

- EPA. 1997. Presumptive Remedy: Supplemental Bulletin, Multi-Phase Extraction Technology for VOCs in Soil and Groundwater. EPA 540-F-97-004. April. Accessed On-line at: http://www.cluin.org/download/toolkit/finalapr.pdf.
- EPA. 1997. Analysis of Selected Enhancements for Soil Vapor Extraction. EPA-542-R-97-007. September. Accessed On-line at: http://www.cluin.org/download/remed/sveenhmt.pdf

Air Stripping

- ❖ Transfers VOCs from treated water to ambient air
- ❖ Fouling may be problem at some sites



February 2009 Module 8 - Remediation Technologies 21

Notes:

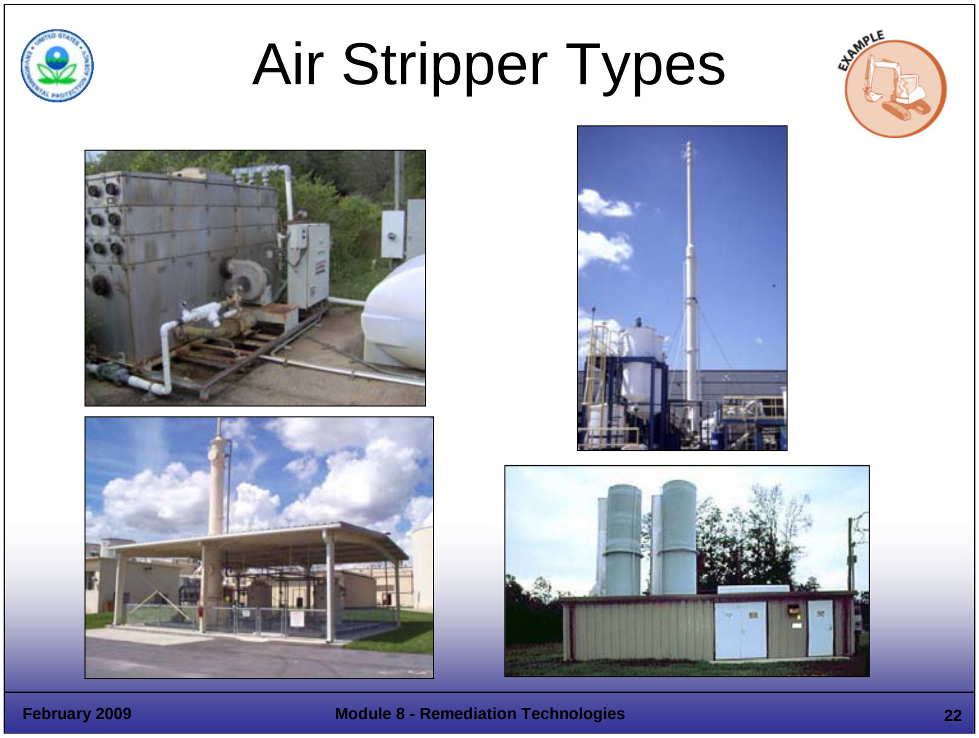
Purpose of Slide: Introduce air stripping.

Key Points

- Air stripping is commonly used for ex-situ treatment of recovered groundwater. It is usually the treatment part of P&T systems.
- Air stripping is a phase separation technology. Air is forced counter-current to water flowing through the stripper, which transfers VOCs from the water to the air.
- The stripability of a compound is a function of Henry's Law constant, an equilibrium constant that defines the behavior of the compound in relatively dilute contaminant concentrations.
- Air to water ratios are based on the specific compounds being removed. Typically, a ratio of air to water (volume) of 50:1 to 100:1 is used.
- Pretreatment of groundwater is sometimes required. Filtration is the most common pretreatment to remove suspended solids. Dissolved inorganics (such as calcium) may be treated in several ways to control fouling. Unoxidized iron may require special consideration, including: oxidation and filtration, sequestering agents, or frequent cleaning.
- This slide shows a typical vertical air striping tower (AST) known as a packed column; plastic packing material is used to create more surface area for air/water contact.
- Water enters the top of the tower through a spray nozzle and trickles down through the packing material in the column. Air is forced upward by a blower and exits through a baffle or mesh mist eliminator at the top.
- Treated water collects in the sump and is transported using a pump for further treatment (as necessary) and disposal.
- Off-gas treatment (usually granular activated carbon) and/or an air permit may be needed for operation of the air stripper. Air dispersion modeling using ISCST or TSCREEN is frequently used during design to plan for, and address, potential air impacts.
- The following factors may limit the applicability and effectiveness of the air stripping process:
  - Energy costs for operating air strippers are typically high;
  - Fouling of the packing material and other stripper components with minerals (iron, scale) and biological growth is a frequent problem. Fouling reduces efficiency of the stripper and may cause ineffective water treatment. Fouling can be addressed by pre-treatment of water or routine cleaning and packing change-out; and
  - Air stripping is not effective for inorganics or VOCs with low Henry's Law constants (for example, acetone and phenol).

References

- FRTR. 2002. Remediation Technologies Screening Matrix and Reference Guide. Version 4.0. January.



Notes:

Purpose of Slide

- Illustrate different types of air strippers.

Key Points

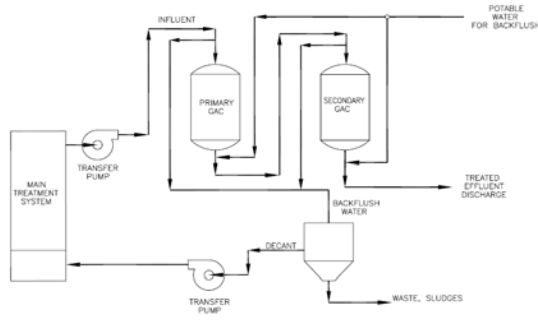
- Air stripping devices come in many shapes and sizes.
- Horizontal tray strippers use stacked trays with small holes to allow the water to flow downward while the air flows upward.
- Diffused aerators use sparge pipes with small diameter holes, submerged in tanks, to inject air into the water.
- The pictures above show clockwise, from upper left:
  - Horizontal tray stripper, 200 gallons per minute (GPM);
  - Packed column tower, 35 GPM, 75 feet high;
  - Two packed column towers, 300 GPM each; and
  - Packed column tower, 90 GPM, 45 feet high.

References

- None.

Granular Activated Carbon (GAC)

- ❖ Removes low contaminant concentrations in groundwater and off-gas streams
- ❖ GAC may be regenerated on site or off site



February 2009 Module 8 - Remediation Technologies 23

Notes:

Purpose of Slide

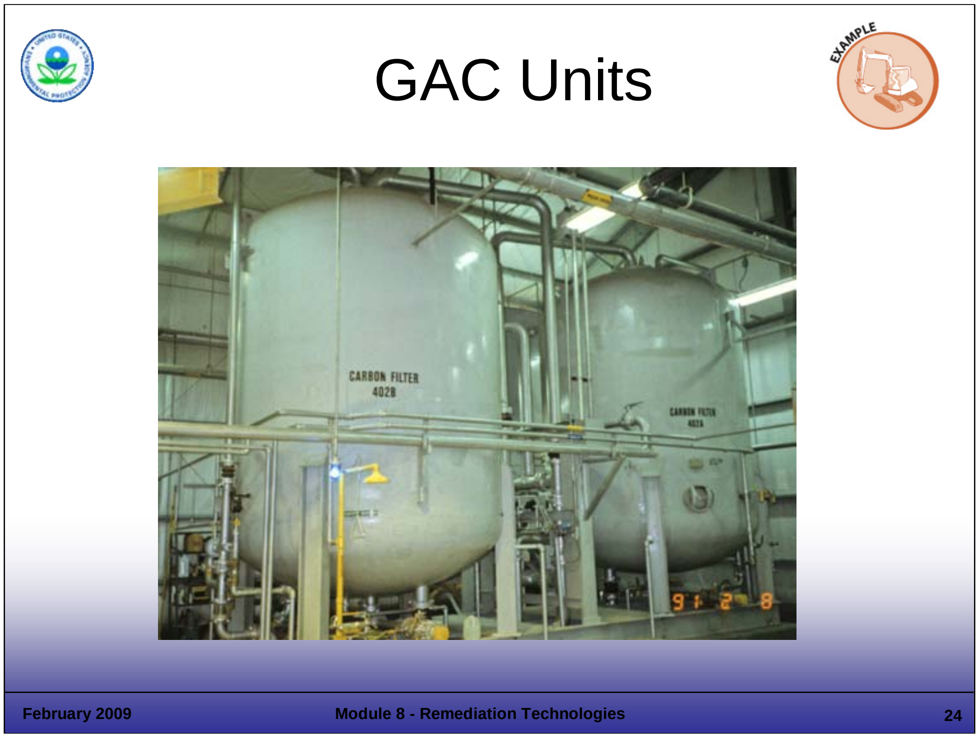
- Introduce carbon as a treatment technology.

Key Points

- Granular activated carbon (GAC) adsorption is a common technology that is used for primary or secondary treatment of effluent streams. As a secondary treatment, it is used to polish the effluent from a primary treatment system or to act as a backup system in case the primary treatment allows breakthrough. GAC is also a common adsorbent used to treat SVE and air stripper off-gases.
- GAC is used to treat a range of VOCs.
- The relatively low initial capital cost of GAC systems makes them particularly attractive for short-term SVE applications when dilute concentrations of VOCs are present.
- Carbon may be regenerated on site or may be taken to a treatment facility for processing.
- A schematic of a typical GAC system is shown in the slide, with primary and secondary units. After breakthrough occurs in the primary unit, the secondary unit takes over as the primary treatment unit. The spent primary unit is then regenerated or replaced and becomes the secondary unit. Potable water is used to backwash the GAC units to remove solids and some contaminants.
- The following factors may limit the applicability and effectiveness of the process:
  - The presence of multiple contaminants can impact process performance;
  - Streams with high suspended solids and oil and grease may cause fouling of the carbon and may require pretreatment;
  - Costs are high if used as the primary treatment on waste streams with high contaminant concentration levels; and
  - GAC is not effective for treating VOCs with high polarity (for example, alcohols and organic acids) or high vapor pressures (for example, vinyl chloride and methylene chloride).

References

- FRTR. 2002. Remediation Technologies Screening Matrix and Reference Guide. Version 4.0. January.



Notes:

Purpose of Slide

- Present a photograph of large carbon vessels.

Key Points

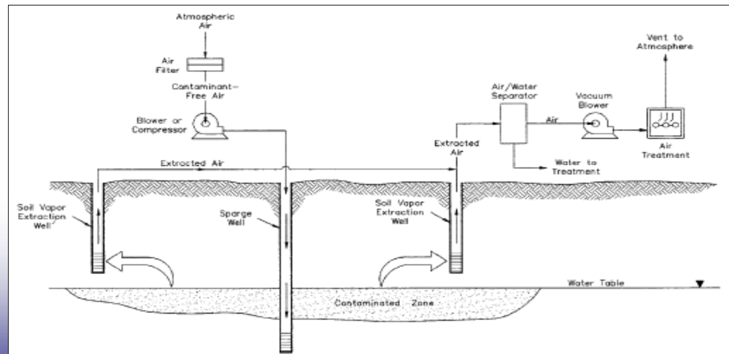
- These dual units each contain 20,000 pounds of GAC. They treat the groundwater effluent from an air stripping system prior to discharge to a POTW.
- The design flow rate for this system was 400 GPM. Concentrations were low at these units and the units were mainly intended as a final polish, not for primary removal.
- VOCs were removed in an air stripping system ahead of the GAC units. The GAC units also captured SVOCs not removed by air stripping.
- Size was selected based upon projected loading of the contaminants and the desired change-out frequency for the bed. In this case, only four change outs a year were estimated.

References

- None.

Air Sparging

- Air injected into aquifer
- Transfers dissolved and adsorbed VOCs into vapor phase
- Dependent on soil permeability
- Relatively inexpensive



February 2009 Module 8 - Remediation Technologies 25

Notes:

Purpose of Slide: Introduce in situ air sparging.

Key Points

- Air sparging is similar to air stripping except that the process operates in situ. Air is injected under pressure into a contaminated aquifer where it strips VOCs from the groundwater by volatilization. The volatilized VOCs are flushed up into the unsaturated zone. A SVE system is often used to remove the generated vapors from the unsaturated zone. A SVE system may not be needed where the water table is shallow, where there is no impervious overlying layer (like pavement), and where VOCs in the generated vapors do not exceed air discharge limits or present risks to human health and the environment.
- A significant advantage of air sparging over P&T for groundwater remediation is that contaminants desorb more readily into the gas phase than into groundwater, thereby overcoming the diffusion-limited extraction of VOCs from groundwater. Also, air sparging has relatively low operation and maintenance costs and therefore, is cost effective when large quantities of groundwater require treatment.
- A side benefit at some sites is the increased dissolved oxygen level in the groundwater from the aeration, which may enhance bioactivity.
- Air is injected through sparge points that are installed as traditional drilled wells or as small-diameter, direct push technology wells.
- The air source is usually a positive displacement blower or conventional air compressor.
- Factors that may limit the applicability and effectiveness of air sparging include:
  - Fine-grained, low permeability soils limit the migration of air in the subsurface; this limits the effectiveness of air delivery and vapor recovery;
  - Heterogeneity, due to lithologic variations or fractures, may cause channeling and create preferential flow paths away from the area of contamination. A low-permeability layer overlying the aquifer would prevent volatilized vapors migrating from groundwater to be captured by effectively the vapor extraction system; and
  - Aquifer clogging or plugging may occur when increased iron precipitation or biomass accumulation caused by oxygen injection changes aquifer characteristics.

References

- Groundwater Remediation Technologies Analysis Center. 1996. Technology Overview Report: Air Sparging. TO-96-04. October.

Notes:

Purpose of Slide

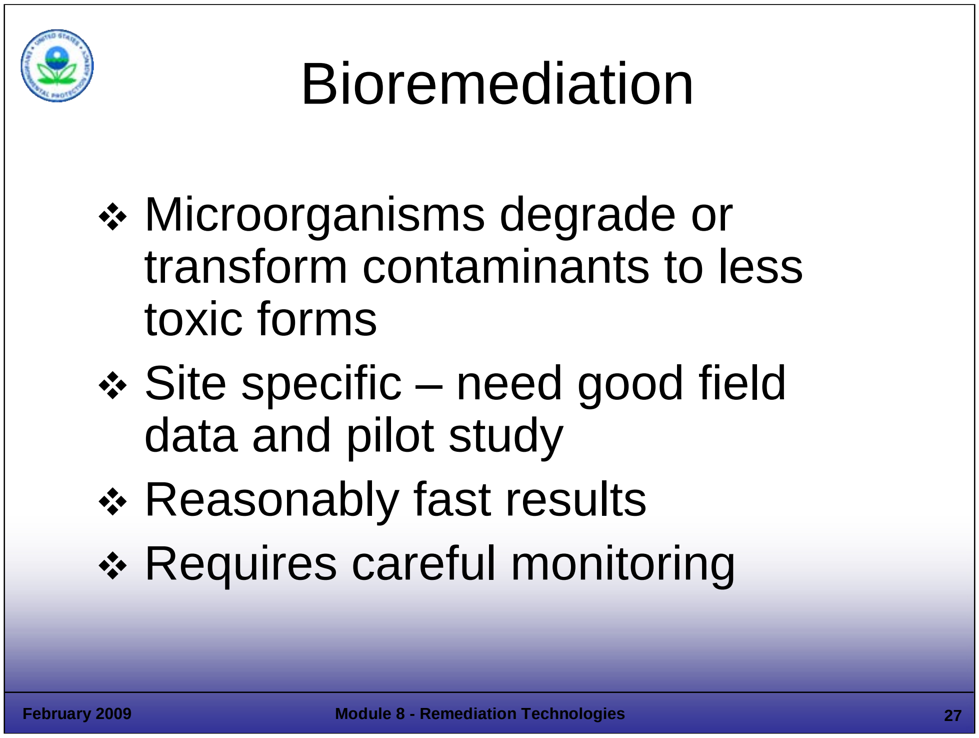
- Present photographs of mobile and permanently installed systems.

Key Points

- Sparging systems may be mobile, trailer, or skid mounted units for short term deployment or fixed units for longer term operation.
- Protection of equipment from weather is important to provide for cost effective operation and to avoid premature failure. Sun, rain, and temperature conditions should be considered.
- The unit on the left is a 2,000-pound trailer and can be easily relocated. An electric power drop is required, but this usually is a relatively low cost item.
- The unit on the right is a fixed system installation with weather protection. The expected service life is 4 to 5 years. However, the equipment has a longer usable life and could be relocated to another site.

References

- None.



Notes:

Purpose of Slide

- Introduce and discuss bioremediation of chlorinated solvents.

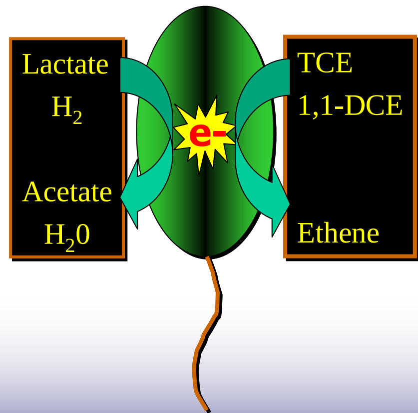
Key Points

- This process is commercially available.
- Bioremediation implementation can include specific requirements based on site conditions.
- This treatment can be a relatively fast process.
- This approach requires careful monitoring in order to control the process.

References

- EPA. 2000. Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications. EPA 542-R-00-008. July.
- Department of Defense Strategic Environmental Research and Development Program (SERDP). 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents. Prepared by Parsons Corporation for Strategic Environmental Research and Development Program (SERDP). August.

Biostimulation/Bioaugmentation



- Biostimulation is the injection of amendments
- Bioaugmentation is the injection of bacteria
- Unique applications for chlorinated solvents (TCE, 1,1,1-TCA, 1,1-DCE)

Source: Dr. Eric Petrovskis

February 2009 Module 8 - Remediation Technologies 28

Notes:

Purpose of Slide

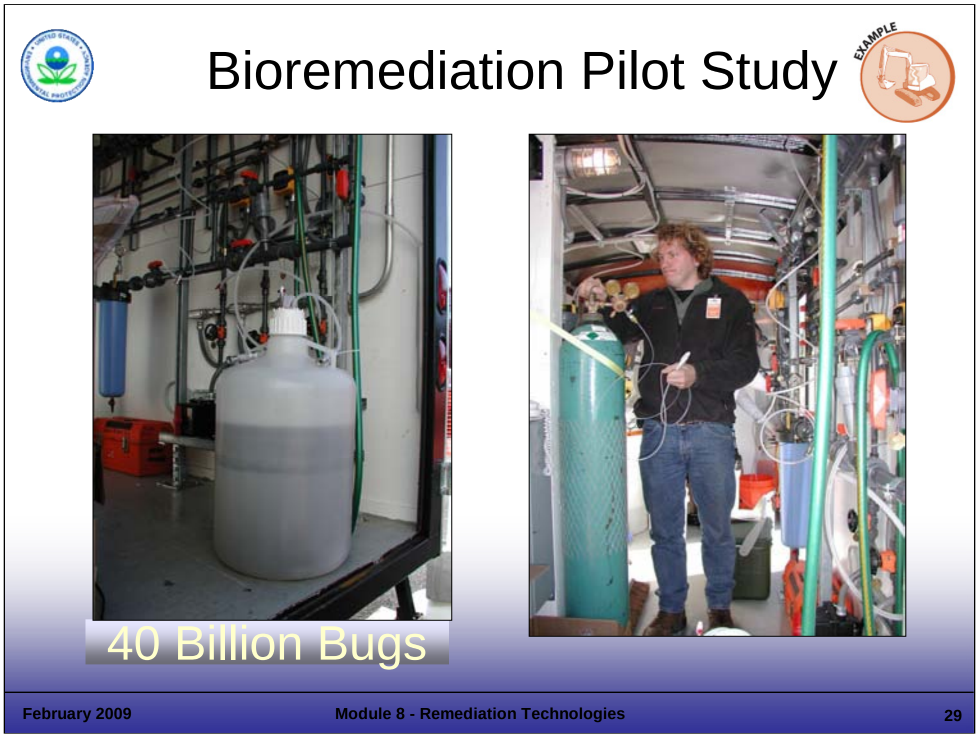
- Review the bioaugmentation and biostimulation processes.

Key Points

- Biostimulation is the practice of using existing on-site bacteria and stimulating their growth through the addition of food sources.
- Bioaugmentation involves the injection of active cultures into the contaminated area and requires careful monitoring of site conditions to ensure successful remediation. Pre-conditioning of the aquifer through a chemical amendment is required before injection of the microbes.
- For bioaugmentation, microbes convert chlorinated compounds as part of their digestive process.

References

- EPA. 2000. Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications. EPA 542-R-00-008. July.
- Department of Defense Strategic Environmental Research and Development Program (SERDP). 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents. Prepared by Parsons Corporation for Strategic Environmental Research and Development Program (SERDP). August.



Notes:

Purpose of Slide

- Provide an example of a bioremediation pilot study.

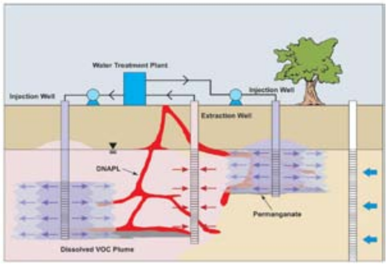
Key Points

- Limited scale bioremediation pilot studies can be performed from mobile units.
- Such tests have a low capital cost and moderate monitoring cost.
- Groundwater is extracted and processed through the bio-trailer. The groundwater parameters are logged (ORP, pH, temperature, flow rate), amendments are added to the stream, and the stream is then trickled back into the aquifer.
- For this site, the aquifer was first prepared with a re-circulating solution of lactate.
- Tracer tests were used to confirm flow paths and to ensure a good distribution of nutrients into the source area.
- Microbes were injected after favorable conditions were achieved (for example, anaerobic conditions, lactate distributed).
- At sites like this, biological fouling becomes an issue when the remediation is successful.
- The equipment required for such a bioaugmentation pilot study is minimal.
- For this site, the microbes in this unit were grown in a university laboratory in the Southeast. Similar cultures are now commercially available.
- Inert nitrogen is used as a gas blanket to protect anaerobic bacteria. Under slight pressure, the nitrogen assists in the transfer of the bacteria.

References

- None.

Chemical Oxidation



- Chemical oxidants destroy range of VOCs, SVOCs, PAHs, PCBs, pesticides
- Ozone, permanganate, hydrogen peroxide/iron (Fenton's reagent), persulfate
- Applied through injection or injection/recovery

February 2009 Module 8 - Remediation Technologies 30

Notes:

Purpose of Slide

- Discuss chemical oxidation.

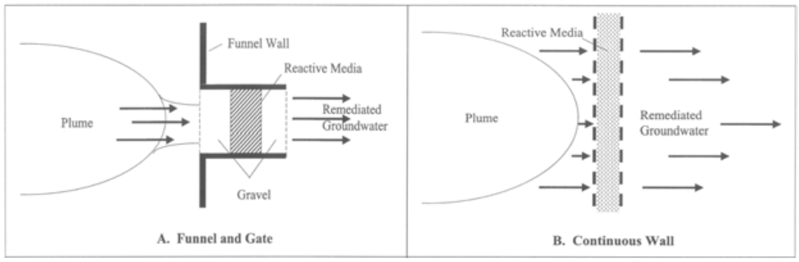
Key Points

- Chemical oxidation involves the treatment of contaminants in groundwater or soils to convert them chemically to nonhazardous or less toxic compounds. A wide range of organic contaminants are amenable to chemical oxidation including: volatile and semivolatile organics, polynuclear aromatic hydrocarbon (PAH) compounds, polychlorinated biphenyl compounds (PCBs), and pesticides.
- Commonly used chemical oxidants include: ozone, permanganate, hydrogen peroxide plus iron catalyst (or Fenton's reagent), and persulfate.
- Chemical oxidants are typically injected into the aquifer using direct push technology, injection wells, and fracturing/injection methods. In order to improve the distribution of chemicals in the aquifer, a recirculation system may be used (like the one pictured in the slide). One or more wells are used to distribute chemicals more evenly in the aquifer and to recover treated groundwater, which is then reinjected.
- Factors that may limit the applicability and effectiveness of chemical oxidation include:
  - Natural oxidant demand may be high in some aquifers due to organics and metals, which substantially increases the amount of oxidant required and the costs.
  - Some oxidants may contain elevated levels of heavy metals or may mobilize naturally occurring metals, creating groundwater quality issues;
  - Oxidation may mobilize and spread contaminants, so good hydraulic control is important;
  - Health and safety issues (heat, explosion) are associated with the handling of strong oxidants. The photograph in the slide shows a strong exothermic reaction created by a chemical oxidant; and
  - Aquifer permeability may be reduced by the reactions of some oxidants.

References

- EPA. 1998. Field Applications of In Situ Remediation Technologies: Chemical Oxidation. EPA 542-R-98-008. September.
- EPA. 2006. Engineering Issue: In Situ Chemical Oxidation. EPA 600-R-06-072. August.
- ITRC. 2005. *Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater.* 2nd edition (ISCO-2). In Situ Chemical Oxidation Team. Accessed On-line at: http://www.itrcweb.org/documents/isco-02.pdf.

Permeable Reactive Barriers



- Passive *in situ* technology that treats a variety of contaminants.
- Zero-valent iron is common reactive medium but other materials also used.
- Mineral precipitation over time may reduce system effectiveness.

February 2009 Module 8 - Remediation Technologies 31

Notes:

Purpose of Slide: Present permeable reactive barriers.

Key Points

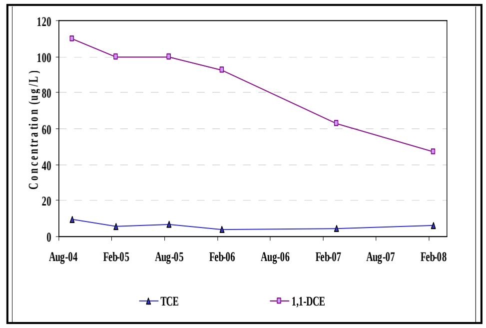
- Permeable reactive barriers (PRBs) are in situ, permeable treatment zones designed to intercept and treat contaminated groundwater.
- PRBs use reactive metals or other media to treat a variety of chlorinated organics, metals, and radionuclides. Zero-valent iron is one of the most commonly used media, but PRBs have also used GAC, limestone, compost, oxygen release compounds, zeolites, and other materials.
- As shown in the above diagrams, PRBs are designed to create a flow path or conduit for contaminated groundwater. The most commonly used PRB configuration is a continuous trench in which the treatment material is backfilled. The trench is perpendicular to, and intersects, the groundwater plume. Another frequently used configuration is the funnel and gate, in which low-permeability walls (the funnel) direct the groundwater plume toward a permeable treatment zone (the gate).
- Typical PRB installation methods include excavation using slurry wall methods, continuous trenching machines, and vertical hydrofracturing.
- A typical lifespan for a PRB is 10 to 30 years. Because a PRB is a passive technology, long-term operation and maintenance costs are small compared to active groundwater remediation systems.
- Factors that may limit the applicability and effectiveness of PRBs include:
  - Precipitation of minerals such as calcium and carbonates can reduce PRB reactivity and permeability over time;
  - Preferential pathways may be produced in the reactive media due to different permeabilities between PRBs and the surrounding aquifer materials; and
  - Capital costs may be high.

References

- EPA. 1998. Permeable Reactive Barrier Technologies for Contaminant Remediation. EPA 600-R-98-125. September.
- ITRC. 2005. Permeable Reactive Barriers: Lessons Learned/New Directions. February.

Monitored Natural Attenuation

- MNA relies on naturally occurring processes
  - Biodegradation and abiotic degradation
  - Volatilization
  - Sorption and chemical stabilization
  - Dispersion and dilution



(continued)

February 2009 Module 8 - Remediation Technologies 32

Notes:

Purpose of Slide

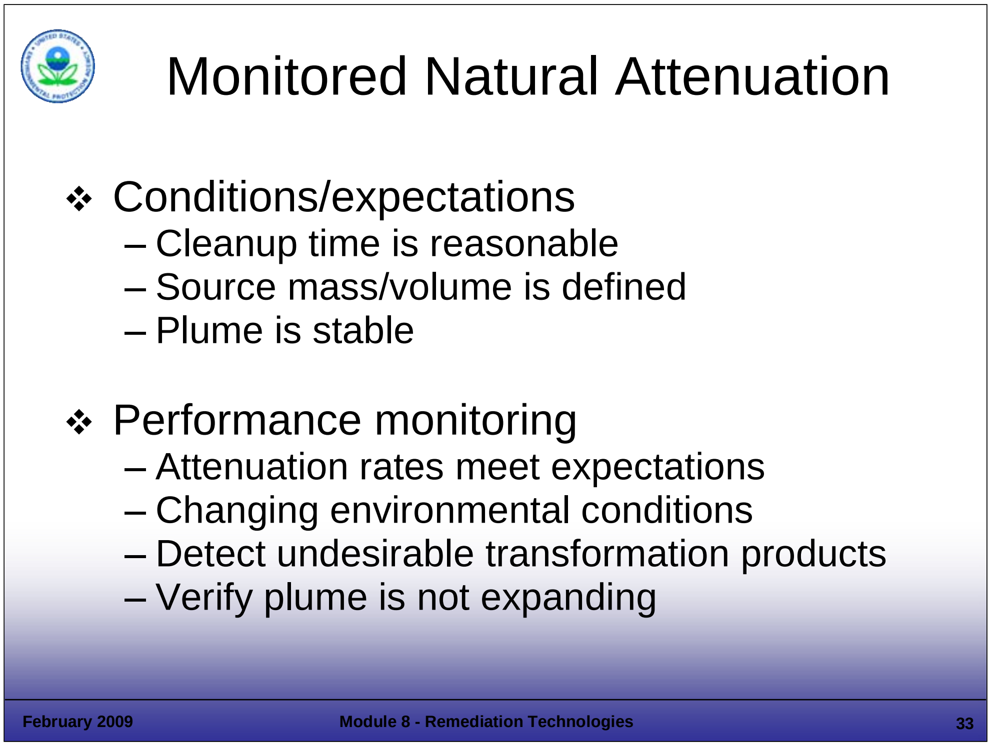
- Introduce monitored natural attenuation (MNA).

Key Points

- MNA refers to the use of natural attenuation processes as part of the overall site remediation.
- MNA includes various physical, chemical, or biological processes that, under favorable conditions, act to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater.
- These naturally occurring processes can include biodegradation and abiotic degradation, volatilization, soprtion, chemical stabilization, dispersion, and dilution.

References

- EPA. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA 600-R-98-128. September.
- EPA. 2004. Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action. EPA530-R-04-030. Update. April.
- EPA. 1999. Use of Monitored Natural Attenuation at Superfund, RCRA CA, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P. April.



Notes:

Purpose of Slide

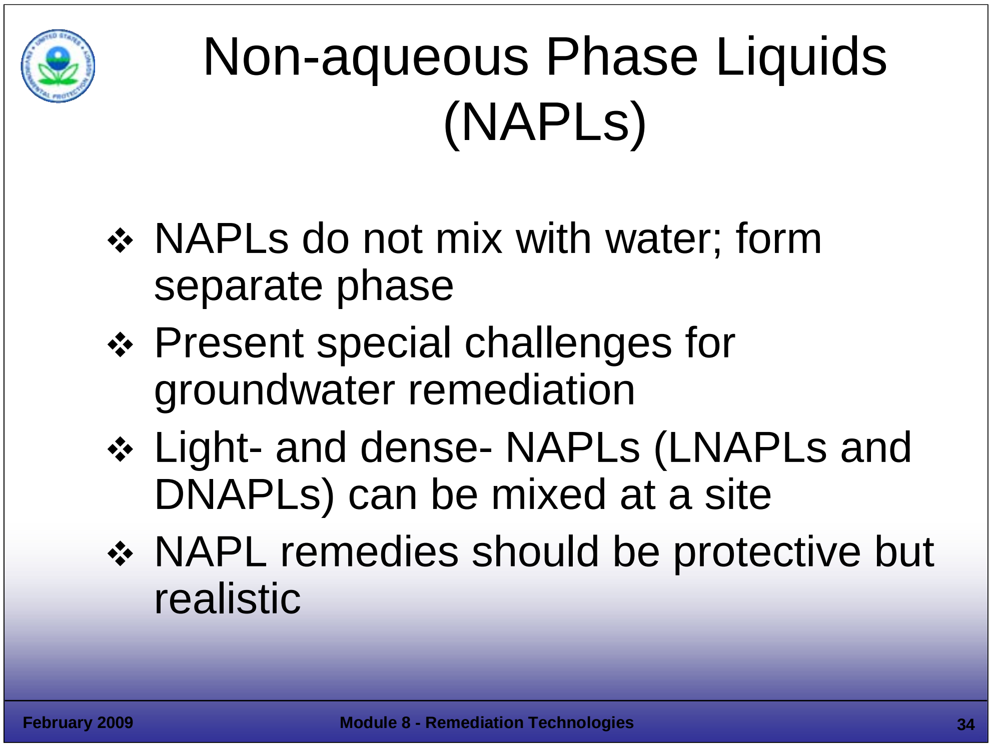
- Continue discussion of MNA.

Key Points

- MNA can be an appropriate remedial option when the facility can demonstrate that the remedy is capable of achieving facility-specific groundwater cleanup criteria in a reasonable cleanup timeframe compared to other active remediation alternatives.
- Site assessment must be detailed because beneficial site information associated with active remediation will not be available.
- A fundamental premise is that the plume is not expanding (that is, it is either naturally stable, shrinking, or actively controlled).
- Monitoring is important to compare the stated expectations and modeling results (if performed) to actual results.
- Changing environmental conditions can impact natural attenuation. For example, changing water quality parameters such as dissolved oxygen (DO) and pH can have an impact.
- Potentially undesirable transformation products that may be recalcitrant can be present and may need to be addressed.

References

- EPA. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA 600-R-98-128. September.
- EPA. 2004. Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action. EPA530-R-04-030. Update. April.
- EPA. 1999. Use of Monitored Natural Attenuation at Superfund, RCRA CA, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P. April.



Notes:

Purpose of Slide

- This slide introduces non-aqueous phase liquid (NAPL) remediation.

Key Points

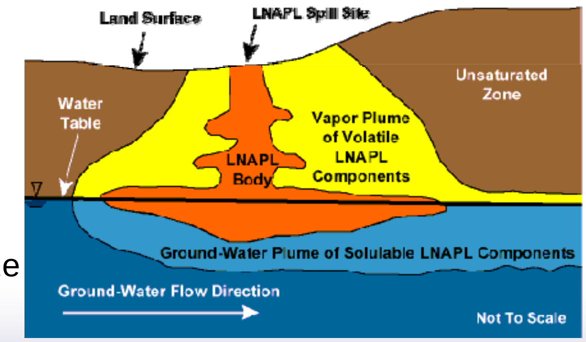
- NAPLs are liquids that are sparingly soluble in water.
- Because NAPLs do not mix with water, they form a separate phase, which greatly complicates remediation of NAPL-impacted groundwater.
- NAPLs can be lighter than water – light non-aqueous phase liquids (LNAPLs) or more dense than water – dense non-aqueous phase liquids (DNAPLs).
- Common LNAPLs include: fuels, lubricants, and petroleum-based chemical feed stocks.
- Common DNAPLs include: chlorinated solvents, such as tetrachloroethylene and trichloroethylene (TCE).
- If the type of waste released at a facility would form NAPL, then the presence of NAPL should be assumed. Some sites with large source areas of NAPL have plumes that have migrated for miles.
- Some sites can have both LNAPLs and DNAPLs present – for example, a hazardous waste treatment facility that managed both chlorinated solvents (for example, TCE, a DNAPL) and non-chlorinated solvents (for example, benzene, a LNAPL). If these solvents become mixed, they can form a neutrally buoyant mixture that is extremely difficult to locate in the subsurface because of its unpredictable behavior – it neither floats on the water table nor sinks to the top of a confining layer.
- EPA's general expectation for remediation of NAPL sites is that the remedy be protective but realistic. In some cases, this will mean removing sufficient contaminant mass to stabilize the NAPL and make sure the problem is not getting worse. In other cases, it may not be feasible to locate the NAPL for a number of reasons such as geologic complexity of the site. In these cases, the remediation goals for the facility should reflect the possibility that low cleanup criteria may not be achievable because of the continuing presence of NAPL.
- We will discuss LNAPL and DNAPL remediation approaches and issues in the next few slides.

References

- EPA. 1995. EPA Groundwater Issue: Light Nonaqueous Phase Liquids. EPA/540/S-95/500.
- EPA. 2004. DNAPL Remediation: Selected Projects Approaching Regulatory Closure. EPA 542-R-04-016. December.
- Interstate Technology Regulatory Council. 2003. Technology Overview. An introduction to Characterizing Sites Contaminated with DNAPLs. September.
- ITRC. 2000. Technology Overview. DNAPLS: Review of Emerging Characterization and Remediation Technologies. June.

LNAPLs

- Fuels, lubricants, and petroleum-based chemical feed stocks
- "Float" on the aquifer (like an iceberg)
- Continuous source of groundwater contamination
- Difficult to characterize and remediate



February 2009 Module 8 - Remediation Technologies 35

Notes:

Purpose of Slide

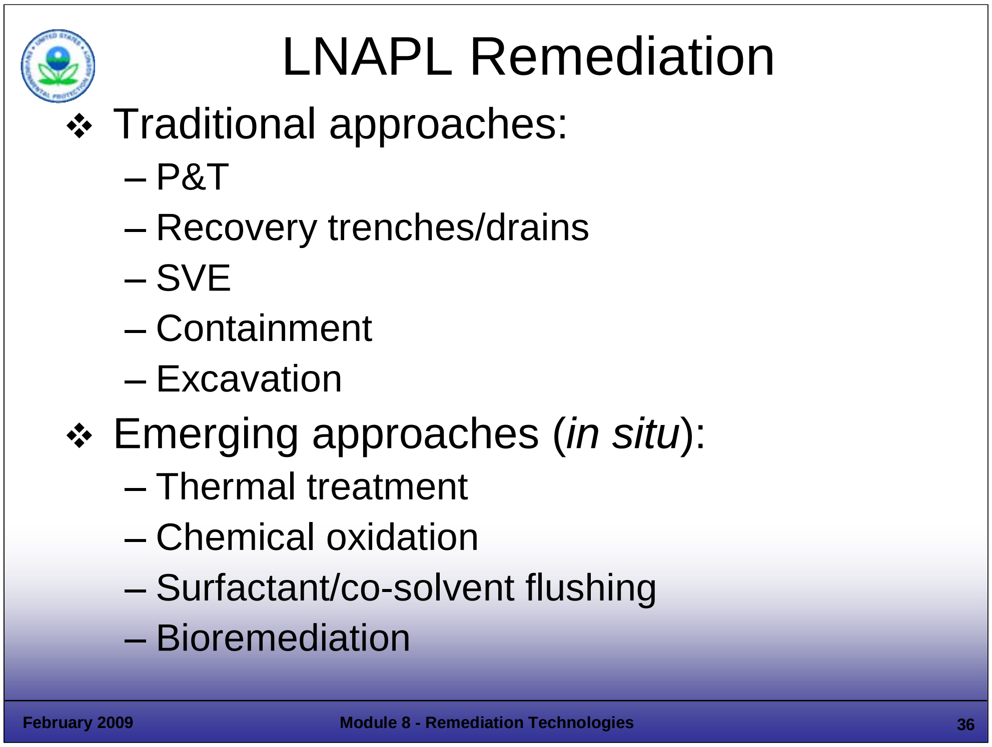
- Introduce LNAPL remediation.

Key Points

- Most LNAPLs consist of commonly used hydrocarbon fuels, lubricants, and chemical feed stocks. Petroleum refineries and facilities with releases of spent non-halogenated solvents (for example, benzene, ethyl benzene, toluene, styrene, xylene) would represent common types of RCRA CA sites with LNAPL problems. Hazardous constituents that are soluble in hydrocarbons (for example, some pesticides and pentachlorophenol) may be associated with LNAPL at some sites.
- As shown in the figure, LNAPL migrates downward through the subsurface under the influence of gravity. Above the water table, volatile LNAPL forms a vapor plume near the source area. If it reaches the water table, the LNAPL spreads laterally and begins to dissolve slowly in groundwater. Because LNAPL is less dense than water, it tends to accumulate at the groundwater surface.
- LNAPL at or near the water table will move vertically as the ground-water elevation fluctuates. This phenomenon, known as "smearing", can distribute LNAPL over a significant vertical interval above or below the water table at any given time. LNAPL here can act as a continuing residual source of contamination.
- The physical properties of LNAPLs, including low solubility, low specific gravity, and a tendency to adsorb to aquifer materials, make LNAPL contamination very difficult to characterize and remediate in the subsurface.

References

- EPA. 1995. EPA Groundwater Issue: Light Nonaqueous Phase Liquids. EPA/540/S-95/500.
- Interstate Technology Regulatory Council. 2003. Technology Overview. An introduction to Characterizing Sites Contaminated with DNAPLs. September.
- ITRC. 2000. Technology Overview. DNAPLS: Review of Emerging Characterization and Remediation Technologies. June.



Notes:

Purpose of Slide

- Introduce different remediation technologies for LNAPL sites.

Key Points

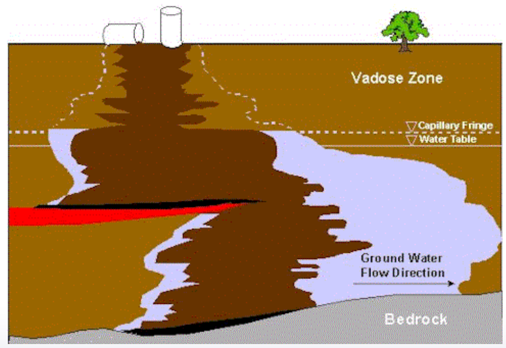
- The basic theory behind LNAPL source removal is that it will reduce the mass of material contributing to the release associated the source and reduce the cost and duration of achieving site closure. It follows that, after removing the source area (area containing or inferred to contain LNAPL), residual groundwater plumes may be amenable to further remediation approaches (for example, MNA). Both traditional and emerging approaches to LNAPL remediation will be discussed.
- A number of remediation technologies are applicable to LNAPLs including such traditional approaches as: P&T, recovery trenches and drains, SVE, dual phase extraction, containment, and excavation.
- Emerging technologies that are being used for LNAPL remediation include thermal treatment, chemical oxidation, surfactant/co-solvent flushing, and bioremediation.
- Emerging refers to technologies that are subject to greater on-going research and development.
- Descriptions of some of these technologies have already been presented and several others will be described in the following discussion of DNAPL remediation technologies.
- Many of the same technical challenges that face DNAPL remediation will be associated with LNAPL remediation. These will be discussed in the following slides.

References

- FRTR. 2002. Remediation Technologies Screening Matrix and Reference Guide, Version 4.0. January.
- Interstate Technology Regulatory Council. 2003. Technology Overview. An introduction to Characterizing Sites Contaminated with DNAPLs. September.
- ITRC. 2000. Technology Overview. DNAPLS: Review of Emerging Characterization and Remediation Technologies. June.

DNAPLs

- Primarily chlorinated solvents and PAHs
- Sink in aquifer
- Continuous source of groundwater contamination
- Extremely difficult to characterize and remediate



Notes:

Purpose of Slide

- Introduce DNAPL remediation.

Key Points

- Remediation of DNAPLs is one of the greatest technical problems associated with cleanup of many RCRA CA sites.
- Most DNAPLs consist of commonly used chlorinated solvents, such as PCE and TCE, and PAHs (such as pentachlorophenol and benzo(a)pyrene).
- The physical properties of DNAPLs, including low solubility, high specific gravity, and a tendency to adsorb to aquifer materials, make them very difficult to characterize and remediate in the subsurface.
- Because DNAPLs are more dense than water, they tend to migrate downward in the aquifer until they encounter an impermeable layer where they accumulate. They then act as a continuing source of groundwater contamination as they slowly dissolve in the surrounding groundwater.
- As will be discussed in the next few slides, DNAPLs are extremely difficult to characterize and remediate at most sites.

References

- Interstate Technology Regulatory Council. 2003. Technology Overview. An introduction to Characterizing Sites Contaminated with DNAPLs. September.
- ITRC. 2000. Technology Overview. DNAPLS: Review of Emerging Characterization and Remediation Technologies. June.

DNAPL Remediation

- Traditional approaches:
  - P&T (for containment of dissolved)
  - Containment
  - Excavation
- Emerging approaches (*in situ*):
  - Thermal treatment
  - Chemical oxidation
  - Surfactant/co-solvent flushing
  - Bioremediation

February 2009 Module 8 - Remediation Technologies 38

Notes:

Purpose of Slide

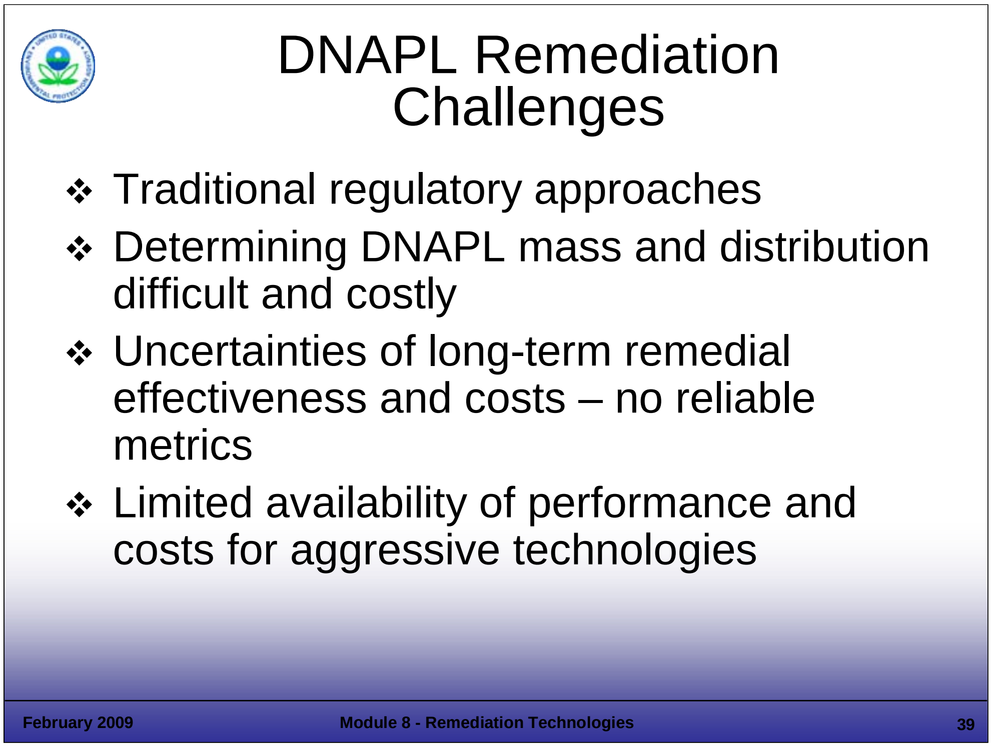
- Introduce different remediation technologies for DNAPL sites.

Key Points

- The basic theory behind DNAPL source removal is that it will reduce the mass of material contributing to the release associated with DNAPL and reduce the cost and duration of achieving site closure. It follows that, after removing the source area, residual groundwater plumes may be amenable to further remediation approaches (e.g., such as MNA). Both traditional and emerging approaches to DNAPL remediation will be discussed.
- There was a time when traditional P&T technology was considered to be a viable remedy for DNAPL sites. With experience, however, it has been found that DNAPLs tend to adsorb strongly on soils in the aquifer and that the relatively small contaminant mass removed by most P&T systems in most geologic settings will not significantly deplete DNAPL source areas over time, which leads to extremely long cleanup timeframes.
- P&T has been used effectively at some sites, however, to contain the spread of groundwater contamination downgradient of DNAPL source areas.
- Other containment measures that have been used at DNAPL sites include cutoff walls, such as slurry walls, and PRBs. These passive containment measures have the benefit of low O&M requirements but they must be maintained for long periods of time.
- In cases where the extent of DNAPL is small and has been well characterized, excavation of DNAPL-containing soil above and below the water table (and subsequent treatment and disposal) has been used.
- EPA has identified several emerging DNAPL source reduction technologies as being promising in achieving regulatory closure at a number of DNAPL sites. These closures were associated with a wide range of approved closure and cleanup criteria, many of them risk-based, with target cleanup levels varying as much as five orders of magnitude. The technologies included:
  - In situ thermal treatment technologies such as steam injection, six-phase heating, in-situ thermal desorption, and radio-frequency heating;
  - In situ chemical oxidation, such as Fenton's reagent, ozone, and sodium permanganate;
  - In situ surfactant/so-solvent flushing, which involves injection of aqueous solutions (e.g., alcohols or electrolytes) that aid in solubilizing the DNAPL and subsequent extraction of the solubilized DNAPL for above-ground treatment; and
  - In situ bioremediation, involving injection of electron donors and microbial populations.

References

- EPA. 2004. DNAPL Remediation: Selected Projects Approaching Regulatory Closure. EPA 542-R-04-016. December.
- Interstate Technology Regulatory Council. 2003. Technology Overview. An introduction to Characterizing Sites Contaminated with DNAPLs. September.
- ITRC. 2000. Technology Overview. DNAPLS: Review of Emerging Characterization and Remediation Technologies. June.



Notes:

Purpose of Slide

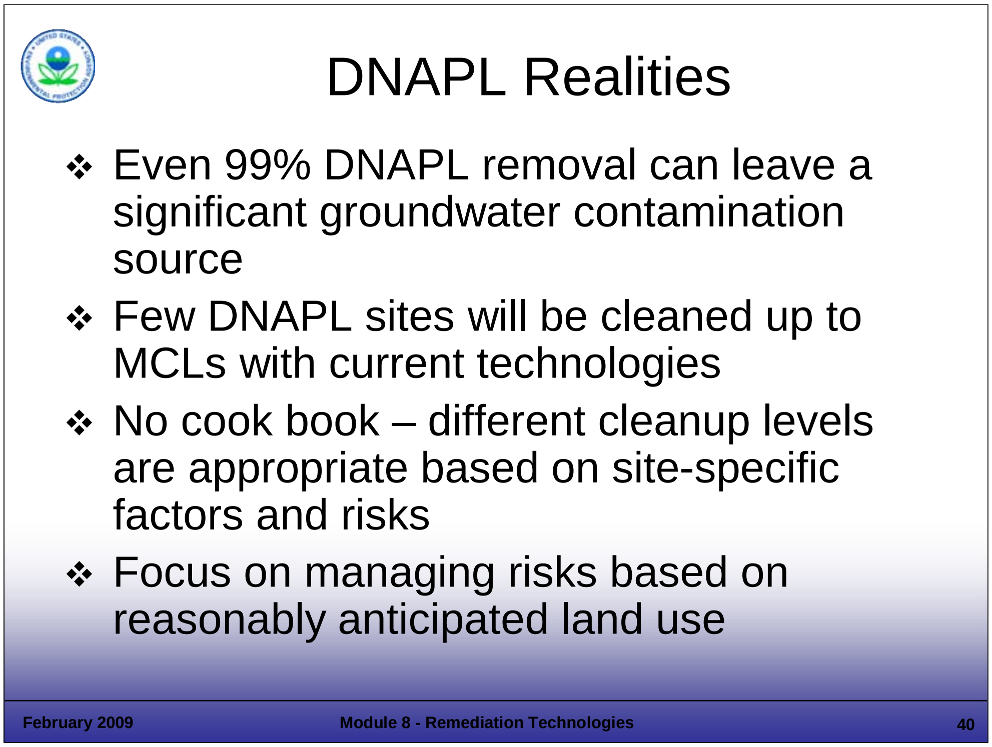
- Discuss various DNAPL remediation challenges.

Key Points

- Traditional EPA policy (for example, the 1996 ANPR) has generally supported active remediation of DNAPL source areas, which may or may not be stable. However, practical experience, groundwater modeling, and laboratory studies by EPA suggest that DNAPL cannot be totally removed and that containment is a viable option to control DNAPL releases.
- EPA's groundwater policies have traditionally stressed groundwater restoration to maximum contaminant levels (MCLs). However, experience has shown that meeting MCLs at almost all DNAPL sites is technically infeasible. EPA's technical impracticability (TI) guidance reflects that understanding (Slide 12 of Module 7). Under RCRA, you do not need to establish cleanup criteria that lead to TI, but for states that require MCLs as cleanup criteria for groundwater, a TI waiver may be necessary.
- A number of technologies have been applied to assess DNAPL, including direct push technology, surface geophysics, and membrane interface probes. However, because of the unpredictable nature of DNAPL distribution in the subsurface and the need for very complete information on its nature and extent before it can be remediated, DNAPL assessments are often time consuming and expensive.
- Even among experts, there is great uncertainty and disagreement as to the effectiveness and ultimate costs of DNAPL remediation. There are no reliable metrics (for example, mass removal versus groundwater concentrations) at this time to measure the overall effectiveness of DNAPL remediation.
- Because most of the aggressive remedial technologies for DNAPLs are emerging, there is scarce cost and performance information for full-scale cleanups. These uncertainties in costs, coupled with uncertainties in performance, can be disincentives for the regulated community to pursue active DNAPL remediation.

Reference

- FR. 1996. ANPR. 61FR19432. May 1.
- EPA. 2004. Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action. EPA530-R-04-030. April.
- Interstate Technology Regulatory Council. 2003. Technology Overview. An introduction to Characterizing Sites Contaminated with DNAPLs. September.
- ITRC. 2000. Technology Overview. DNAPLS: Review of Emerging Characterization and Remediation Technologies. June.



Notes:

Purpose of Slide

- Present some of the current realities we are faced with in addressing DNAPL sites.

Key Points

- There is an ongoing debate regarding the utility of partial DNAPL source removal. Some studies have shown that leaving even a tiny fraction of the source area will contribute to an ongoing groundwater contamination problem.
- It is apparent from the current state of DNAPL remediation technologies that very few sites will be able to close with MCLs met in all aquifers.
- Because of the unpredictable nature of DNAPL contamination at most sites and the inherent difficulties in remediation of DNAPLs, assessment and remediation will not generally lend themselves to standardized approaches. Instead, the challenge will be to address each site in terms of its unique characteristics and the potential risks presented by DNAPLs at the site. EPA's position has been that remediation of DNAPL should focus primarily on containment and stabilization of DNAPL source areas, coupled with remediation of the dissolved portion of the plume to meet cleanup criteria.

References

- None.

DNAPL Excavation

EXAMPLE

February 2009 Module 8 - Remediation Technologies 41

Notes:

Purpose of Slide

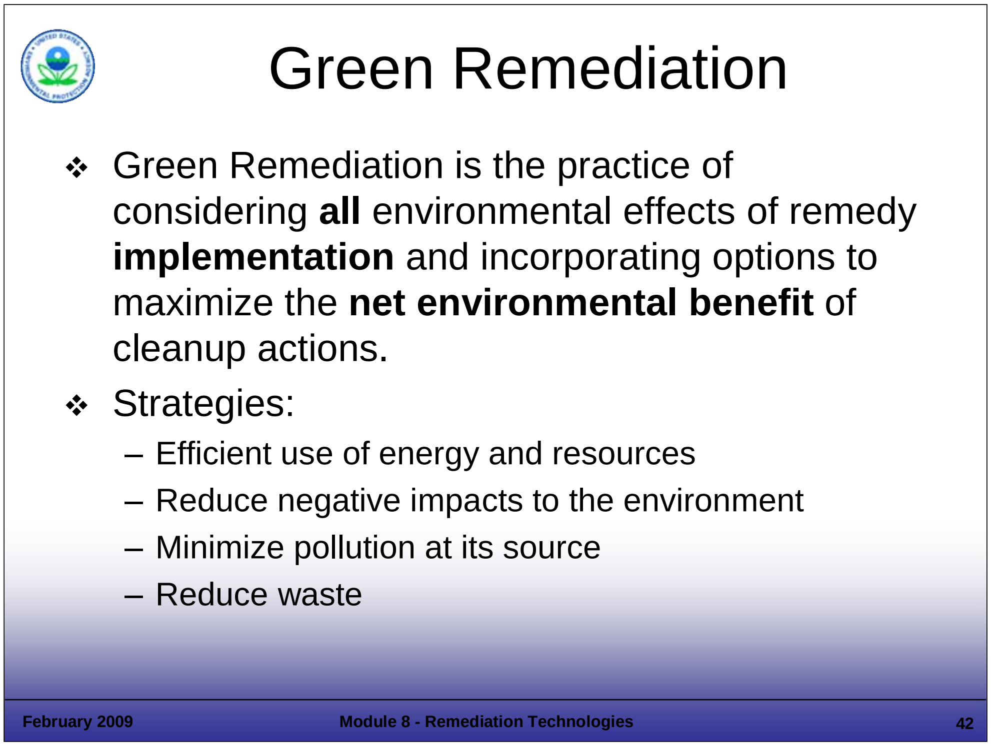
- Present and discuss a cross section of excavation at a DNAPL site.

Key Points

- As a result of a DNAPL investigation at the DOT site presented earlier, a former borrow pit and disposal site were excavated where there was evidence of DNAPL.
- The DNAPL source area was relatively large but other technologies could not remove 95% of the DNAPL – the amount necessary to justify the remedy in this case.
- The investigation focused on the area most likely to contain DNAPL. TCE and 1,1,1-TCA were the compounds sought.
- Excavation began by removing the clean backfill from the previous excavation; over 65,000 cubic yards of clean overburden were removed.
- Excavation of the suspected source areas revealed that the DNAPL was dispersed in very fine fissures within the soil as shown in the photograph on the left. Residual traces of the compounds were also found on top of the clay confining unit; over 75,000 cubic yards of additional contaminated soil were removed and treated.
- The resulting excavation is shown above (a former groundwater monitoring well is shown near the center). The excavated area was left as a pond.
- The source was successfully removed in two steps:
  - The original source was comprised of drums containing waste solvents that were removed.
  - The later source that was excavated was DNAPL, either residual from the buried drums or liquid that was released directly into the soil.

References

- None.



Notes:

Purpose of Slide

- Introduce the concept of green remediation and provide an overview

Key Points

- EPA defines green remediation as shown above. Green remediation reduces the environmental "footprint" of site remediation by reducing the negative impacts to the environment caused by remediation activities.
- Strategies for approaching green remediation and sustainable land use include:
  - Efficient use of energy and natural resources
  - Reducing the negative impacts of remediation activities to the environment[
  - Minimizing pollution at its source rather than exporting contamination off site.
  - Reducing the generation of waste through various means.
- EPA has articulated its thoughts and approaches to green remediation in an April 2008 Technology Primer on Green Remediation. Also, EPA and a number of other federal agencies (e.g., Army, Navy, Air Force and DOE) have green remediation websites which provide useful guidance and case studies, particularly EPA's CLU-IN web site.

References

- EPA. 2008. Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites. EPA542-R-08-002. April.
- EPA CLU-IN website (www.clu-in.org/greenremediation)

Green Remediation Practices

- Energy requirements
  - Use renewable energy
  - Maximize efficiency of remediation equipment
- Air emissions
  - Use clean fuels
  - Reduce releases of toxic pollutants, greenhouse gases, and dust
- Water requirements
  - Reduce fresh water consumption; maximize water reclamation/reuse
  - Reduce surface water quality impacts

(cont.)

February 2009 Module 8 - Remediation Technologies 43

Notes:

Purpose of Slide

- Introduce a number of green remediation practices

Key Points

- EPA has developed a number of strategies and best management practices for green remediation:
- **Energy requirements**:
  - Use renewable energy such as solar & wind to power equipment
  - Maximize efficiency of remediation equipment through system designs that minimize high energy demands & conducting RSE's
- **Air emissions**:
  - Use clean fuels (e.g., low sulfur, biofuels, hybrids) for excavation and transportation equipment
  - Reduce releases of toxic pollutants, greenhouse gases, and dust through efficient use and servicing of machinery and vehicles, dust suppression, and filters
- **Water requirements:**
  - Reduce fresh water consumption; maximize water reclamation/reuse through capturing and storage of rainfall & reusing treated wastewater
  - Reduce water quality impacts on nearby surface water by minimizing runoff

References

- EPA. 2008. Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites. EPA542-R-08-002. April.
- EPA. CLU-IN Web site (www.clu-in.org/greenremediation).

Green Remediation Practices

- Land & ecosystem impacts
  - Inventory ecological species, land contours, and drainage patterns
  - Relocate sensitive or threatened species
- Waste generation
  - Reuse uncontaminated excavated soil
  - Recycle waste & scrap materials
- Long-term stewardship
  - Install renewable or passive energy systems for long-term site controls
  - Construct remediation structures to complement site redevelopment

Notes:

<u>Purpose of Slide</u>

- Continue discussion of green remediation practices

<u>Key Points</u>

- EPA has developed a number of strategies and best management practices for green remediation:
- **Land & ecosystem impacts:**
  - Inventory ecological species, land contours, and drainage patterns prior to remediation to help recreate original conditions
  - Relocate sensitive or threatened species
- **Waste generation**:
  - Reuse uncontaminated excavated soil for onsite backfill or habitat creation
  - Recycle waste & scrap materials during construction & demolition
- **Long-term stewardship:**
  - Install renewable energy or passive energy systems for long-term site controls
  - Construct remediation structures (e.g., swales, ponds) that complement site redevelopment

<u>References</u>

- EPA. 2008. Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites. EPA542-R-08-002. April.
- EPA. CLU-IN Web site (www.clu-in.org/greenremediation).

Green Remediation Case Study

EXAMPLE

- Objective was to recover hydrocarbons from groundwater at RCRA site
- Strategy was to use renewable energy systems – solar & wind energy
- Use 6 wind turbines to operate compressors for hydraulic skimming pumps & to generate electricity to power 9 submersible pumps and fluid-gathering system
- Use 6 photovoltaic panels to power recovery wells & submersible pumps
- Recycle recovered petroleum product at adjacent oil refinery

February 2009 Module 8 - Remediation Technologies 45

Notes:

Purpose of Slide

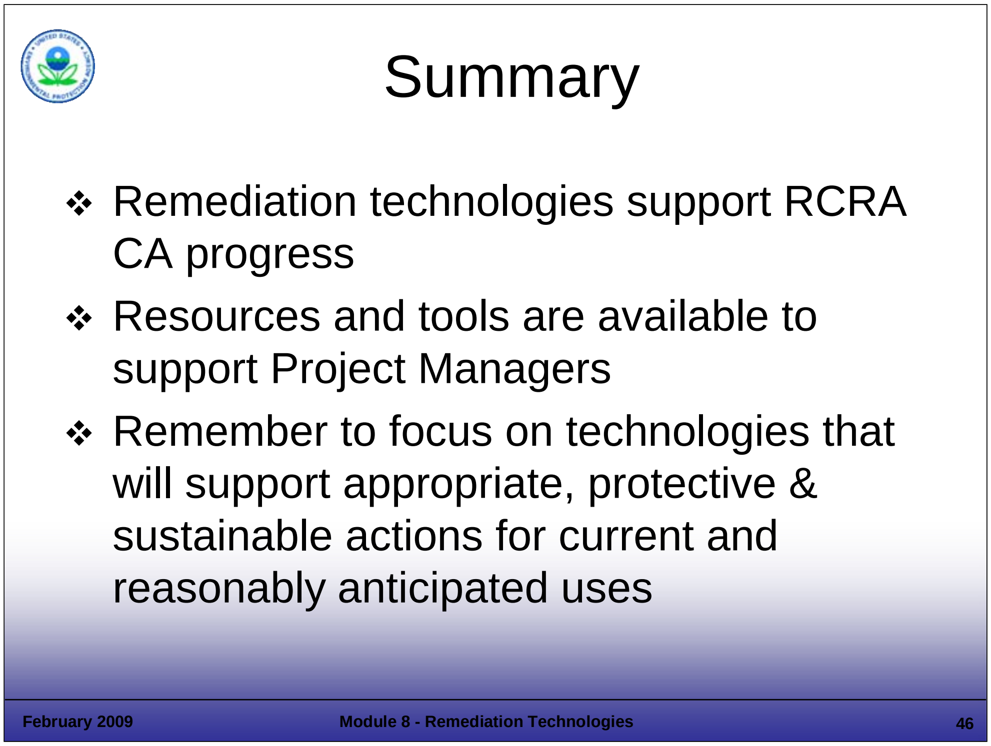
- Present green remediation case

Key Points

- This case study is for the St. Croix Alumina Plant in St. Croix, Virgin Islands
- This RCRA facility needed to remediate hydrocarbon contamination in groundwater as described in the slide.
- The results of the green remediation approaches used at the facility resulted in the following accomplishments:
  - Recovered over 200,000 gallons of free-product
  - Integrated renewable-energy sources to meet increasing portions of the recovery system's energy demand
  - Avoided air emissions associated with electricity consumption
  - Provided for beneficial use of recovered material
  - Avoided off-site transportation and disposal of free- product, along with the associated air emissions

References

- EPA. CLU-IN Green Remediation Web site (www.clu-in.org/greenremediation).



Notes:

Purpose of Slide

- Review key points included in Module 8, Remediation Technologies.

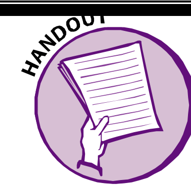
Key Points

- Review the key points of this module.

References

- None.

Green Remediation Resources



Green Remediation is evolving rapidly –resources below provide a starting point for exploration.

Web Sites:

EPA's Office of Solid Waste and Emergency Response (OSWER): Green Remediation Tool Box, Technical Information, Profiles & Case Studies of Green Remediation, Technical Assistance, and Additional Resources. www.cluin.org/greenremediation

Association of State and Territorial Solid Waste Management Officials (ASTSWMO): ASTSWMO Greener Cleanups Task Force. www.astswmo.org

California Environmental Protection Agency/Department of Toxic Substances Control: Green Remediation Initiative. www.dtsc.ca.gov/OMF/Grn_Remediation.cfm

Minnesota Pollution Control Agency: Green Practices for Business, Site Development, and Site Cleanups. www.pca.state.mn.us/programs/p2-s/toolkit/index.html

Wisconsin Department of Natural Resources: Remediation and Redevelopment Program/ Wisconsin Initiative on Sustainable Cleanups (WISC). http://ua.dnr.wi.gov/org/aw/rr/cleanup/wisc.htm

Illinois Environmental Protection Agency: Bureau of Land’s Greener Cleanup Initiative http://www.epa.state.il.us/land/greener-cleanups/

Presentations:

California Department of Toxic Substances Control Green Remediation Initiative: Presentation by John Scandura, CA DTSC. August 2008. ASTSWMO Federal Facilities Managers Symposium, San Diego, CA

Maximizing the Environmental Benefits of Site Remediation: Presentation by Gary King, Illinois Environmental Protection Agency. April 2008. ASTSWMO Mid-Year Meeting, Mobile, AL.

Wisconsin’s Approach to “Greener” Cleanups: Presentation by Mark F. Giesfeldt, WISC, remediation and Redevelopments Program. April 2008.ASTSWMO Mid-Year Meeting presentation, Mobile, AL.

Green Remediation: Opening the Door to Field Use: Presentation by Kira Lynch, EPA and Sandra Novotny, EMS. July 2008. National Association of Remedial Project Managers (NARPM) 2008 Training, Portland, OR.

Documents:

Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites: EPA Technology Primer. April 2008.

Introduction to Green Remediation: Incorporating Sustainable Practices into Site Remediation: EPA Quick Reference Fact Sheet. February 2008.

Guidelines for Making Environmentally-Sound Decisions in the Superfund Remedial Process: EPA. May 1993.

Incorporating Sustainable Environmental Practices into Site Remediation of Contaminated Sites: An Introduction. EPA Quick Reference Fact Sheet. April 2008.

Greener Cleanups – How to Maximize the Environmental Benefits of Site Remediation: Illinois Environmental Protection Agency, February 2008.