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PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES FOR SOIL AND GROUNDWATER AT STUDY AREAS 8 AND 9 WITH TRANSMITTAL LETTER NTC ORLANDO FL
7/21/1998
HARDING LAWSON ASSOCIATES

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Harding Lawson Associates

July 21, 1998

Commanding Officer
Southern Division
Naval Facilities Engineering Command
2155 Eagle Drive
North Charleston, SC 24919-9010

ATTN: **Ms. Barbara Nwokike, Code 187300**

SUBJECT: **Preliminary Screening of Remedial Technologies**
Soil and Groundwater at Study Areas (SAs) 8 and 9, Operable Unit (OU) 3
Naval Training Center (NTC), Orlando, Florida
Contract No. N62467-89-D-0317/CTO 136

Dear Barbara:

As requested during the June 1998 Orlando Partnering Team (OPT) meeting, Harding Lawson Associates (HLA, formerly ABB Environmental Services, Inc.) is pleased to provide this preliminary screening of remedial technologies for contaminated soil and groundwater at SAs 8 and 9 (OU3) located on the main base of NTC, Orlando. This information is provided to the OPT for informational purposes, and to initiate conversation and feedback regarding possible technologies for remedial action at the OU. A discussion of these technologies with the CURTT team is planned for August 1998.

The information provided in this letter will be used in the development of the Feasibility Study (FS) for the OU. In the FS, the first step will be to develop remedial action objectives (RAOs). Then, remedial technologies that address the RAOs will be identified. The technologies described in this letter report are the most likely technologies that will be identified in this step of the FS. After identifying remedial technologies in the FS, the technologies are screened against cost, implementability, and effectiveness factors. Those technologies that pass the screening step will be developed into remedial alternatives. Remedial alternatives will then be analyzed in detail.

The list of technologies described in this letter report are potentially applicable to contaminated soil and groundwater at SAs 8 and 9, as described in the recently published final draft Remedial Investigation (RI) report (HLA, 1998). This list should be considered "preliminary" until the development of the FS has begun (scheduled to begin after receipt of comments on the final draft RI Report).

Several resources were used to identify technologies appropriate for contaminants at the two study areas. The following paragraphs provide a brief summary of the contaminants of concern at the two SAs and provide a summary of the resources used to develop the list of potential remedial technologies for OU3.

Contaminants of Concern at OU3

Study Area 8

Contaminants detected in soil and groundwater at SA 8 during the RI and previous investigations can be attributed to former site activities. The contaminants detected in surface soil at SA 8 were primarily

pesticides, herbicides, and related inorganics (arsenic) and PAHs. Inorganics, primarily arsenic, is the contaminant of concern in groundwater.

Contamination in soil and groundwater at Study Area 8 poses unacceptable cancer and noncancer risks to human receptors, including the potential future resident, the recreational user, and the commercial worker. The contaminants contributing to these risk estimates include arsenic, benzo(a)pyrene equivalents, beryllium, iron, MCPA, and MCPP in surface soil, and arsenic, dieldrin, iron, MCPA, and MCPP in groundwater.

Risks to terrestrial plants, terrestrial invertebrates, wildlife, and aquatic receptors based on exposure to contaminants in surface soil and/or groundwater at OU3 were evaluated in the ecological risk assessment. Potential risks were identified for terrestrial wildlife exposed to surface soil and terrestrial plants exposed to groundwater. The contaminants contributing to these risk estimates include arsenic and cadmium in surface soil, and arsenic in groundwater.

Concentrations of the chemicals of concern identified in the risk assessment were compared to screening values. The following chemicals exceed screening values and contribute to the potential risk identified at the SA:

- arsenic, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, and MCPP in surface soil, and
- arsenic, MCPA, and MCPP in groundwater.

Study Area 9

Contaminants detected in soil and groundwater at SA 9 during the RI and previous investigations can be attributed to former site activities. The contaminants detected in surface soil at SA 9 were primarily pesticides, herbicides, and related inorganics (arsenic). Herbicides and inorganics, primarily arsenic, are the contaminant of concern in groundwater.

Contamination in soil and groundwater at SA 9 poses unacceptable cancer and noncancer risks to human receptors, including the potential future resident, the recreational user, and the commercial worker. The contaminants contributing to these risk estimates include alpha- and gamma-chlordane, 4,4'-DDD, MCPA, MCPP, and arsenic in surface soil, and 2,4-dichlorophenol, alpha- and gamma-BHC, aldrin, dieldrin, heptachlor epoxide, MCPA, MCPP, arsenic, and iron in groundwater.

Risks to terrestrial plants, terrestrial invertebrates, wildlife, and aquatic receptors based on exposure to contaminants in surface soil and/or groundwater at SA 9 were evaluated in the ecological risk assessment. Potential risks were identified for terrestrial wildlife exposed to surface soil and terrestrial plants exposed to groundwater. The contaminants contributing to these risk estimates include arsenic and 4,4'-DDD in surface soil.

Concentrations of the chemicals of concern identified in the risk assessment were compared to screening values. The following chemicals exceed screening values and contribute to the potential risk identified at the SA:

- arsenic, alpha- and gamma-chlordane, 4,4'-DDD, and MCPA in surface soil, and
- arsenic, alpha- and gamma-BHC, MCPA, and MCPP in groundwater.

Resources Used to Develop List of Potential Remedial Technologies

The following resources were used to develop the list of potential remedial technologies presented in this letter report:

- Remedial Information Management System (RIMS) database, developed by Research Triangle Park,
- USEPA's Vendor Information System for Innovative Treatment Technologies (VISITT),
- USEPA's Remediation Technologies Screening Matrix and Reference Guide,
- USEPA's Engineering Bulletin, Technology Alternatives for the Remediation of Soils Contaminated with As, Cd, Cr, Hg, and Pb
- articles from the Ground-Water Remediation Technologies Analysis Center, Pittsburgh, PA, including:
    - *Phytoremediation*, October 1996
    - *Remediation of Metals Contaminated Soils and Groundwater*, October 1997
- several literature articles, including
    - *Arsenic: Chemical Behavior and Treatment*, National Environmental Journal, May/June, 1995
    - *Recent Developments for Insitu Treatment of Metal Contaminated Soils*, prepared for USEPA by PRC Environmental Management, Inc., March 1997
    - *In Situ Remediation of Contaminated Ground Water: The Funnel-and-Gate System*, Ground Water Journal, May/June 1994
    - *Spodic Material for In Situ Treatment of Arsenic in Ground Water*, Ground Water Monitoring and Remediation Journal, Fall 1997
- various internet searches for current literature on specific technologies or general arsenic treatment information.

Potential Remedial Technologies for OU3

Potential remedial technologies for contaminated soil and groundwater at OU3 were identified based on a literature and database searches, as discussed in the previous section. Technology descriptions are provided in Attachment A to this letter. Please note that technology descriptions are not included for the excavation and offsite disposal and extraction and treatment technologies.

The following technologies may be applicable to remediation of contaminated soil at OU3:

- Phytoremediation
- Soil Washing
- Soil Flushing
- Stabilization
- Electrokinetics
- Excavation and offsite disposal (i.e., "Dig-and-Haul")

The following technologies may be applicable to remediation of contaminated groundwater at OU3:

- Phytoremediation
- Permeable Reactive Wall
- In-situ Reactive Zones
- Extraction and Treatment (i.e., "Pump-and-Treat")
    - Precipitation
    - Ion Exchange

HLA welcomes your input regarding this preliminary screening of remedial technologies for OU3. If you have any questions or comments regarding this letter, please call me at (703) 769-8145.

Very Truly Yours,
HARDING LAWSON ASSOCIATES
(formerly ABB Environmental Services, Inc.)

Shannon B. Gleason, P.E.
Task Order Manager

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Attachments

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ATTACHMENT A
DESCRIPTION OF POTENTIAL REMEDIAL TECHNOLOGIES FOR OU3

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

PHYTOREMEDIATION

Phytoremediation is the use of naturally-occurring and genetically-engineered vegetation to clean up or contain contaminated environmental media. It is considered an innovative technology at this time because, although the technology has shown to be very effective in specific situations, the processes are not well understood and they have been applied (full-scale) to a relatively small, but growing number of remediation sites.

There are several mechanisms involving plants that accomplish removal, degradation, or stabilization of contaminated soil and water. These mechanisms include:

- Phytoextraction - process involving direct uptake and translocation of contaminants into the plant tissues; effective for contaminants in soil and water; effective removal mechanism for moderately hydrophobic organics (log K_{ow} = 0.5-3)
- Phytodegradation/Phytotransformation - process effective on contaminants in soil and groundwater involving the breakdown and or transformation of contaminants (by enzymes and exudates) into other chemicals (usually harmless)
- Phytostabilization - this process is the use of plants to reduce the migration potential of contaminated soil (reduced wind or water erosion)
- Rhizofiltration - process involving uptake of contaminants by root systems; contaminants often remain fixed to roots; effective for water contaminants
- Phytostimulation/Assisted Bioremediation - this process involves selective stimulation of microbial action in the root zone that results in enhanced biodegradation; effective for contaminants in soil and groundwater

ADVANTAGES TO PHYTOREMEDIATION OVER OTHER ALTERNATIVES:

- in situ process; low impact
- passive; solar-driven
- high public acceptance
- generally very cost-competitive with alternatives (10-20% of mechanical alternatives)
- plants can generally tolerate higher contaminant concentrations than microorganisms (bioremediation)
- effective in series with other technologies (polishing step)
- waste disposal volumes (therefore costs) eliminated or significantly reduced
- applicable to a range of contaminants (organics, metals, explosives)
- double-duty effect of hydraulic control of contaminated plume migration along with uptake (trees)

LIMITATIONS:

- optimum effectiveness in settings where soil contamination is within three feet of the surface and depth to groundwater is less than ten feet below surface
- may require extended time to achieve cleanup goals (i.e., multiple growing seasons), particularly in cold weather climates
- may not be able to achieve required reductions in chemical concentrations
- unfamiliar technology to many regulators, therefore regulatory approval may require more effort (considered an innovative technology by USEPA; states may approve on a case-by-case basis)
- physical conditions may limit effectiveness (salt tolerance, weather conditions, animal and insect damage, blights/funguses)

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

SOIL WASHING

Soil Washing is the ex situ extraction of contaminants from soil using water or other suitable aqueous solutions. The technology transfers the contaminants from the soil matrix into the washing fluid or mechanically concentrates the contaminants into a much smaller soil mass for subsequent treatment. Soil washing is performed on excavated soil and may involve some or all of the following steps, depending upon soil matrix, waste characteristics, and cleanup goals:

- mechanical screening to remove oversize materials
- crushing to reduce oversize materials for treatment
- physical processes (soaking, scrubbing, etc.) to separate the fine-grained fraction ("fines") from the coarse-grained fraction
- treatment of the coarse-grain fraction
- treatment of the fines
- management of the generated residuals

Treatment of the coarse-grained fraction involves physical separation techniques and possibly aqueous-based leaching. The separation techniques (gravity separation, hydrocyclones, flotation) separate the contaminated particles from the coarse soil particles in order to produce a clean (or nearly clean) coarse fraction and one or more contaminant streams. Typically, water or an aqueous solution is used to separate the contaminants from the coarse grain fraction. If the metal or contaminants are still bound to the coarse fraction, solubility enhancement using oxidation/ reduction, leaching solutions, increased mixing, elevated temperatures, or higher solution/soil ratio may be required. Treatment of the fines is similar to the coarse fraction, but more iterations are typically required to achieve the smallest concentrated sludge volume. To determine the soil washing effectiveness, both pretreatment and post-treatment sampling of the soil must be measured. Finally, the concentrated sludge cake would be sent for offsite disposal.

ADVANTAGES TO SOIL WASHING OVER OTHER ALTERNATIVES:

- applicable to soils contaminated with metals and organics
- better control of treatment conditions than in-situ alternatives
- ensures thorough mixing and washing of contaminated soil
- effective when used in conjunction with other technologies to treat soil and/or groundwater
- waste disposal volumes significantly reduced
- treated soil reused onsite
- disposal costs reduced
- closed-loop or semi-closed loop process allows leachate to be recycled and reused

LIMITATIONS:

- ex situ process; high impact to environment; high costs
- high energy requirements needed (electricity, water, steam, compressed air)
- innovative technology with limited success on arsenic removal in soil
- soil with high fraction (>40%) of silts and clays ("fines") not effective for soil washing
- metal contaminants with very low solubility and stable forms require long contact times and excessive amounts of reagents to solubilize
- wide range and types of contaminants may require multiple washing solutions
- high clay content, cation exchange capacity, or humic acid content may interfere with contaminant desorption

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
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SOIL FLUSHING

Soil Flushing is the in situ extraction of contaminants from soil using water or other suitable aqueous solution. The flushing solution is introduced to the soil by surface flooding, surface sprinklers, leach fields, vertical or horizontal injection wells, basin infiltration systems, or trench infiltration systems. The contaminants are mobilized by solubilization, formation of emulsions, or a chemical reaction with the flushing solution. After the flushing solution passes through the contaminated soil, the contaminant-bearing fluid is typically recovered from the groundwater by strategically placed wells or trenches. The fluid is brought to the surface for further treatment, disposal, or recirculation.

Soil flushing can solubilize contaminants in soil using either water as the flushing fluid or chemical additives to enhance the solubility of the contaminants. Water alone can be used to remove certain water-soluble contaminants. The use of soil flushing chemicals may involve adjusting the pH of the soil, chelating metal contaminants, or displacing toxic cations with nontoxic cations. For metals, soil flushing is most effective in removing water-soluble species.

Several soil factors affect the sorption of metals and their migration in the subsurface:

- pH of soil
- soil type (clays, silts, sands, etc.)
- cation exchange capacity (CEC)
- soil particle size
- soil permeability
- types and concentrations of metals in soil
- types and concentrations of organic and inorganic compounds in solutions

Once the infiltrated or percolated solution has flushed the contaminants to a certain location, the contaminated fluids must be extracted. Extraction techniques include vacuum extraction methods in the vadose zone and pump-and-treat systems in the saturated zone. Recovered groundwater and flushing fluids containing the desorbed contaminants may require treatment to meet appropriate discharge standards before such fluids are recycled or disposed.

In situ soil flushing has been used most often at sites contaminated with organics. For treatment of metals, soil flushing has been used at a limited number of projects. For example, soil flushing has been selected at 7 Superfund sites with metals present; however, organic contaminants are the primary targets at 6 of these sites. Site-specific conditions must be carefully considered to address the possible spread of contamination.

ADVANTAGES TO SOIL FLUSHING OVER OTHER ALTERNATIVES:

- in situ process; low impact to environment and human health exposure
- low energy requirements (ie., typically combined with groundwater treatment)
- generally cost-competitive with other alternatives
- soil disposal costs eliminated
- extracted fluid volume and cost reduced by treatment and recycling of the extraction fluid for further flushing

LIMITATIONS:

- innovative technology with limited data and success on metal removal in soil

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

STABILIZATION

Stabilization, also referred to as immobilization, changes the physical and chemical characteristics of the waste in order to immobilize the contaminants. This technology typically applies to ex situ treatment; however, in situ applications have been used through the use of proprietary augers and reagents.

Stabilization processes change the physical characteristics of the waste to improve its handling and to reduce the mobility of the contaminants by creating a physical barrier to leaching. Stabilization processes convert contaminants into their least soluble, mobile, and toxic forms through chemical or thermal interactions, thus minimizing the potential for offsite migration.

Stabilization technology is applied by mixing contaminated soil with a physical binding agent to form a crystalline, glassy, or polymeric framework surrounding the waste particles. Other forms of stabilization treatment rely on macroencapsulation, where the waste is unaltered but macroscopic particles are encased in a relatively impermeable coating, or on chemical fixation, where the contaminant is converted to a solid compound resistant to leaching. Stabilization treatment can be accomplished through the use of organic or inorganic binders. The final treated product from the stabilization treatment can range from a crumbly, soil-like mixture to a monolithic block. Depending on the binders used, the final product will be 5% to 50% larger in volume from the original volume of soil.

Reagent-based stabilization reduces the mobility of inorganic compounds from several processes:

- formation of insoluble hydroxides, carbonates, or silicates
- substitution of the metal into a mineral structure
- sorption
- physical encapsulation

Reagent-based stabilization consists of a reagent formulation and a delivery system. Most reagent formulations for in situ stabilization applications consist of ordinary pozzolanic reagents and/or proprietary reagents. Depending on the soil characteristics to be treated and the desired end product of the treated soil, additives such as bentonite or silicates may be added. Potential reagent binders include Portland cement, lime/calcium carbonate, thermoplastic binders, or sorbents such as activated carbon, clays, zeolites, and sodium silicate.

ADVANTAGES TO STABILIZATION OVER OTHER ALTERNATIVES:

- technology is proven effective in reducing leachable concentrations of metals to below regulatory levels
- various forms of stabilization systems available (reagent-based vs. thermal-based systems)
- in situ or ex situ treatment available
- treated soil would retain its soil-like consistency that may be beneficially reused onsite
- applicable to broad range of contaminants (metals, organics)

LIMITATIONS:

- high moisture content of soil will increase cost substantially for thermal-based system
- may require a 2-step process to stabilize both arsenic and organics in soil
- in situ thermal stabilization method is an innovative technology with limited data and success on metal stabilization in soil

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

ELECTROKINETICS

Electrokinetics is an in situ treatment process that applies low intensity direct current between electrodes placed in the soil. A direct current is applied across the electrodes. Under such conditions, moist soil acts as an aqueous electrolyte and ions and solution move toward the electrodes. Contaminants are immobilized in the form of charged species, particles, or ions. The experience with this technology is limited to bench scale and pilot scale tests in the U.S., with limited full scale applications in Europe. Performance data from full scale test indicated that the potential for achieving 90% removal is possible for some contaminants.

The principle of electrokinetic remediation relies upon application of a low-intensity direct current through soil between two or more electrodes. Most soils contain water in the pore space between soil particles and have an inherent electrical conductivity. Electrokinetics can be efficient in extracting contaminants from fine-grained, high-permeable soils. Water or other suitable salt solution may be added to the system to enhance the mobility of the contaminant and increase the effectiveness of the technology. Contaminants arriving at the electrodes may be removed by electroplating at the electrode, precipitation or coprecipitation at the electrode, pump and treat of groundwater near the electrode, or complexing with ion exchange resins.

The range of treatment for metals is broad. The electrode spacing and duration of treatment is site-specific. The process requires adequate soil moisture in the vadose zone, therefore, the addition of a conduction pore fluid may be required. Specifically designed pore fluids are added to enhance the migration of target contaminants. The pore fluids are added at either the anode or cathode, depending upon the desired effects.

Before electrokinetic remediation is implemented, a number of field and laboratory tests must be conducted to determine whether a particular site is amenable to treatment:

- field conductivity surveys
- chemical analysis of pore water for dissolved major anions and cations
- electrical conductivity and pH of the pore water
- bench-scale tests

One problem to overcome when applying electrokinetic remediation to the vadose zone is the drying of the soil near the anode. When an electric current is applied to soil, water will flow by electro-osmosis in the soil pores, usually toward the cathode. The movement of water will deplete soil moisture adjacent to the anode and moisture will collect near the cathode. However, processing fluids may be circulated at the electrodes. The fluids can serve as both a conducting medium and as a means to extract or exchange the chemical species. Another use of processing fluid is to control, depolarize, or modify electrode reactions.

ADVANTAGES TO ELECTROKINETICS OVER OTHER ALTERNATIVES:

- in situ process; low impact to environment and human health exposure
- applicable to a wide range of metals
- effective when used in conjunction with other technologies to treat groundwater because this technology involves extraction of groundwater near electrodes
- applies to saturated and partially saturated soil
- soil disposal costs eliminated

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

IN SITU PERMEABLE TREATMENT WALLS

In situ permeable treatment walls is an innovative technology employed to clean up organic and inorganic contamination in groundwater. The technology involves installation of a permeable wall containing a reactive material to intercept the groundwater contaminant plume. For example, the use of elemental iron walls has been proven effective at remediating both halogenated organics and hexavalent chromium in groundwater. The materials in the wall remove the targeted contaminants by degrading, transforming, precipitating, or adsorbing the target solutes as the groundwater flows through the wall. Chemical, physical, and biological processes have all been used within the reactive wall, alone or in combination. A design known as "Funnel and Gate" is commonly used to implement this technology because it allows narrower reactive walls by funneling the contaminated groundwater.

There are several classes of reactive materials used to construct the permeable wall. These include **pH or Eh modifiers**, that affect solubility, degradation rates, and aerobic conditions, thereby affecting the behavior of selected contaminants; **dissolution and precipitation minerals**, where the reactive material, such as calcium phosphate dissolves, increasing the phosphate concentration in the barrier, and causing the removal of inorganics such as lead through precipitation of lead phosphates; **sorptive media** (e.g., activated carbon, zeolites, ion exchange resins, peat), that remove and immobilize contaminants by sorption; and **nutrient supplies**, to enhance biodegradation processes that may be occurring naturally.

A recently published study from Sweden indicates that the use of spodic B-horizon soil material (subsurface, weathered soil with little organic material, and oxidized mineral grains) in the reactive wall provided a low cost, highly effective method of inducing sorption of arsenite (the dominant arsenic species at OU 3).

ADVANTAGES TO IN SITU PERMEABLE TREATMENT WALLS OVER OTHER ALTERNATIVES:

- in situ, passive process; relatively low impact to the environment and existing activities nearby
- low O&M costs; wall installation; periodic wall maintenance; and sampling and analysis of observation wells
- applicable to organic and inorganic contaminants
- waste disposal volumes (therefore costs) eliminated or significantly reduced
- particularly effective in tight soils
- operable for long periods of time
- extremely flexible; potential use of a series of funnels and gates with different reactive materials in different walls (gates) would allow treatment train to address wide range of contaminants
- disposal costs limited to reactive wall material; not water

LIMITATIONS:

- not practical for deep plume remediation; depth of reactive wall limited by installation equipment (e.g. backhoe reach) methods
- reactive barrier materials (e.g. elemental iron polymer resins) can be relatively expensive, so continuous walls are not practical; this can be overcome by incorporating funnel and gate design to reduce the required size of the reactive wall (gate)
- removal or replacement of the barrier may be difficult and/or costly

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

IN SITU REACTIVE ZONE

In situ reactive zone technology is an innovative technology employed to clean up inorganic contamination in groundwater. The technology involves creation of an anaerobic zone within the aquifer where microbial or chemical redox reactions can occur. This "reactive zone" is created by injecting a harmless reagent containing carbohydrates, such as corn syrup or molasses, into the contaminated portion of the aquifer by means of injection wells. The presence of carbohydrates stimulates existing microorganisms to deplete the dissolved oxygen as they consume the carbohydrates. This reaction yields carbon dioxide and water, thus creating anaerobic conditions. The presence of anaerobic conditions causes the sulfates naturally present in the aquifer or contained in the reagent (e.g. molasses) to be reduced to sulfide ions. These sulfide ions, in turn, react with the metals or other inorganic ions in groundwater to form solid, stable precipitates (metal sulfides). These solid phase precipitates can potentially be left in place to be filtered by the soil matrix.

ADVANTAGES TO IN SITU REACTIVE ZONES OVER OTHER ALTERNATIVES:

- in situ process; low impact to the environment and existing activities nearby
- low O&M costs; injection well installation; periodic nutrient injections; and sampling and analysis of observation wells
- applicable to inorganic contaminants only
- waste disposal volumes (therefore costs) eliminated or significantly reduced

LIMITATIONS:

- works only on inorganics; will not effect organic contaminants
- unfamiliar technology to many regulators, therefore regulatory approval may require more effort (considered an innovative technology by USEPA; states may approve on a case-by-case basis)
- presence of organic contaminants may affect reaction process
- may release other compounds during reactive process that were previously stable
- may require secondary treatment or removal of precipitates caught up in contaminated soil

Applicability to OU 3:

- Primary contaminant of concern in ground water is arsenic (in its more soluble form), which has shown to be treatable.
- Shallow aquifer appears to tend towards anaerobic conditions at both sites.
- Contaminant zone is relatively small and therefore more easily treated (and monitored).
- Relatively non-intrusive method involving installation of injection wells and periodic monitoring of observation wells (could potentially be implemented after site redevelopment has begun).
- Treatment may proceed relatively quickly, allowing redevelopment of the land to occur within a year or so.

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

PRECIPITATION (with pump-and-treat)

Precipitation of metals is commonly used to treat metal-laden wastewater. As a result of its success, precipitation is being used to treat groundwater containing heavy metals. In groundwater treatment applications, precipitation is often used as a pretreatment step for other treatment technologies (i.e., ion exchange, air stripping, carbon adsorption, etc.) where the treatment of metals would interfere with the other treatment processes. Precipitation is an ex situ treatment process.

Metals precipitation from contaminated groundwater involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water stream via clarification (settling) and/or filtration. This process transforms dissolved contaminants into an insoluble solid that is subsequently removed from the liquid phase by sedimentation and/or filtration. Typically, metals precipitate from the solution as hydroxides, sulfides, or carbonates. The type of reagents/chemicals used to maximize precipitation range from ferric iron salts, aluminum salts (alum), calcium carbonate (lime), or activated alumina. The solubility of the specific metal and the required cleanup standards will dictate the type or regents needed, process steps required, and number of iterations used.

The precipitation process usually consists of:

- groundwater pumped to surface
- oxidation/reduction (for hydroxide process)
- pH adjustment and reagent addition/mixing
- flocculation
- clarification
- sludge thickening
- sludge dewatering
- solids disposal

For arsenic in groundwater, the use of ferric iron and ferric iron salts is recognized as the most effective and most practical way of reduce arsenic concentrations. However, iron coprecipitation is more effective for arsenate (V) and only moderately effective for arsenite (III) speciation. For groundwater treatment, there is a limited range of values for pH and redox potential (Eh) for precipitation to be effective. The pH must be within 3 to 8 standard units and Eh within 400 to 800 millivolts (mV).

ADVANTAGES TO PRECIPITATION OVER OTHER ALTERNATIVES:

- technology is moderately effective in reducing arsenic concentrations to below the drinking water standard (50 ug/l)
- ex situ method has better control over system operation, efficiency, and effectiveness of COC removal
- cost-competitive to other ex situ treatment alternatives
- treated effluent may be suitable for discharge back into aquifer
- can be easily combined with other treatment technologies to address organic contaminants
- applicable to broad range of metals
- concentrates metals into small sludge cake/solids volume for disposal

REMEDIAL ALTERNATIVES EVALUATION - PRELIMINARY SCREENING
NTC, ORLANDO OU 3

ION EXCHANGE (with pump-and-treat)

Ion exchange is an ex situ treatment process that removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups where exchangeable ions are attached. Resins may also be inorganic and natural polymeric materials. After the resin capacity has been exhausted, the resins can be backwashed and regenerated for reuse.

Ion exchange has the potential for soluble arsenic removal. Anion exchange resins are available in 2 basic forms: weak-base and strong-base. Many weak-base anion exchangers are capable of significant adsorption due to ionic bonding and ion exchange, giving them a higher level of adsorptive capacity for nonionic arsenite. However, strong-base resins have higher removal efficiencies than the weak-base resins.

In groundwater treatment applications, ion exchange is often used in a treatment train with other treatment technologies (i.e., chemical precipitation, air stripping, carbon adsorption, etc.) to treat a variety of organic and inorganic contaminants. The process for treatment involves pumping groundwater to the surface and passing the water through a packed bed of ion exchange resin pellets or alumina granules in a downflow or upflow mode until the adsorbent is exhausted. The exhaustion or breakthrough point will be determined by checking the effluent concentrations of the contaminants from a grab sample. The concentration of the specific metal and the required cleanup standards will dictate the process steps used, resins quantities, and number of iterations used.

For arsenic in groundwater, ion exchange is an area of intense research where the development of anionic chelating exchange resins or ion exchange polymers may dramatically improve the technology for arsenic treatment.

ADVANTAGES TO ION EXCHANGE OVER OTHER ALTERNATIVES:

- technology is moderately effective in reducing arsenic concentrations
- ex situ method has better control over system operation, efficiency, and effectiveness of COC removal
- cost-competitive to other ex situ treatment alternatives
- system is relatively insensitive to feed water flow variations (i.e., water can be pumped on a timed cycle not continuous flow, which may cause excessive drawdown of the surficial aquifer)
- treated effluent may be suitable for discharge back into aquifer
- can be easily combined with other treatment technologies to address organic contaminants
- applicable to broad range of metals
- wide variety of resins available

LIMITATIONS:

- ineffective against VOCs, SVOCs (PAHs), pesticides, herbicides
- high costs due to high energy requirements, equipment costs, and reagents needed
- must control for pH and Eh in order to be effective
- disposal of the spent resins may be toxic (fail TCLP) based on metal concentrations
- capturing contaminated groundwater is dependent on placement of wells, effectiveness of pumping operation, solubility of metal, and ability of metal to be desorbed from soil