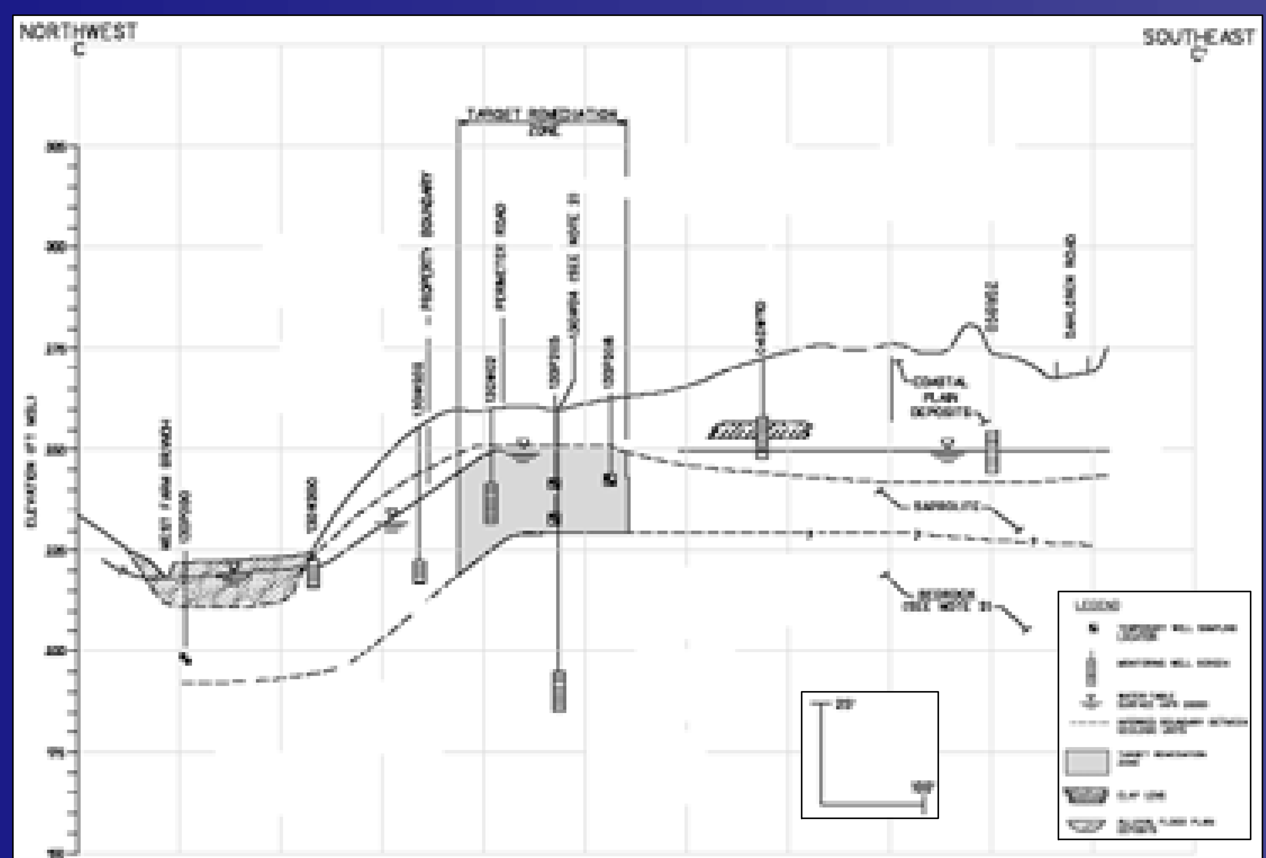
Enhanced *In Situ* Reduction of cVOCs using Zero-Valent Iron

Site Overview

- Former NSWC-White Oak, Silver Spring, MD. BRACed Navy Facility; currently owned by GSA.
- Site 13 source area is < 1 acre. Topography immediately adjacent to Site 13 drops steeply into the valley formed by West Farm Branch, such that Site 13 forms a hill.
- Groundwater flows toward creek.
- Former surface disposal area, but not well-documented. Therefore, exact source of cVOCs emanating from Site 13 is unknown.
- Groundwater impacted by cVOCs and moving offsite.
- ISCR selected remedy in ROD. ZVI injected using ARS's patented Ferox^{SM} technology in February 2005.

Site Geology

- Site 13 gently slopes to the west with a maximum elevation relief across the site of approximately 5 feet. Topography immediately adjacent to Site 13 to the northwest, west and southwest drops steeply at a grade of approximately 33% into the valley formed by West Farm Branch, such that Site 13 forms a hill.
- Site 13 geology consists of a layer of silty sand and gravel (Coastal Plain deposits) ranging in thickness from 10 feet in the TRZ to 0 foot near West Farm Branch. The Coastal Plain deposits are underlain by a 10 to 20-feet layer of decayed rock (saprolite). This grades from a micaceous silt or silty sand with varying amounts of clay and schist fragments to a severely weathered schist with relief texture. Fractured rock underlies the saprolite; the competent bedrock is primarily a garnet schist.
- Depth to the groundwater in TRZ is approximately 10 to 12 feet. Water table is present in low-permeability saprolite. Saturated thickness above the bedrock is approximately 20 to 25 feet.
- Groundwater flow beneath Site 13 is primarily to the west and northwest, toward and into West Farm Branch. Groundwater pH typically 5 to 7. Hydraulic gradient at the site is estimated to be 0.16. Hydraulic conductivity is estimated to be 0.15 feet/day. Using an effective porosity of 0.25, average groundwater velocity is 35 feet per year.
- Electron acceptors and geochemical conditions in TRZ before ZVI injection:
  - DO at 4 mg/L
  - Nitrate at 1 mg/L and Sulfate at 3 mg/L
  - COD at <10 mg/L (nondetect)
  - pH at 4.9
  - ORP at 294 mV
  - Iron II at <0.1 mg/L (nondetect)



Objectives

- Reduce target cVOC concentrations to below remediation goals.
- Obtain radius of influence for ZVI injection of at least 8 feet from each injection well for full coverage in the source area / TRZ using ARS's Ferox^{SM} method.
- Minimize timeframe of remediation to expedite site closure.

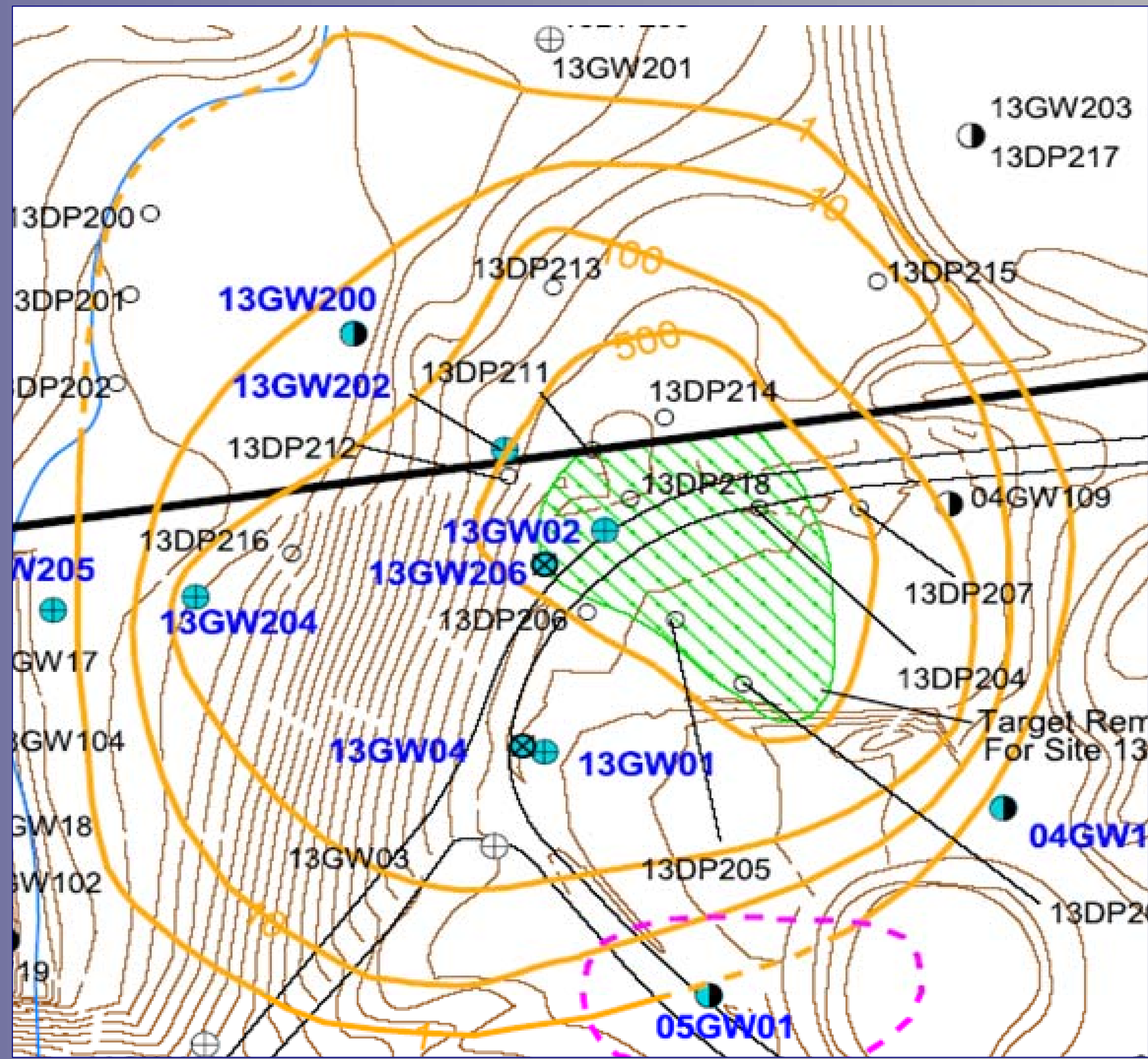
Nature and Extent of cVOCs

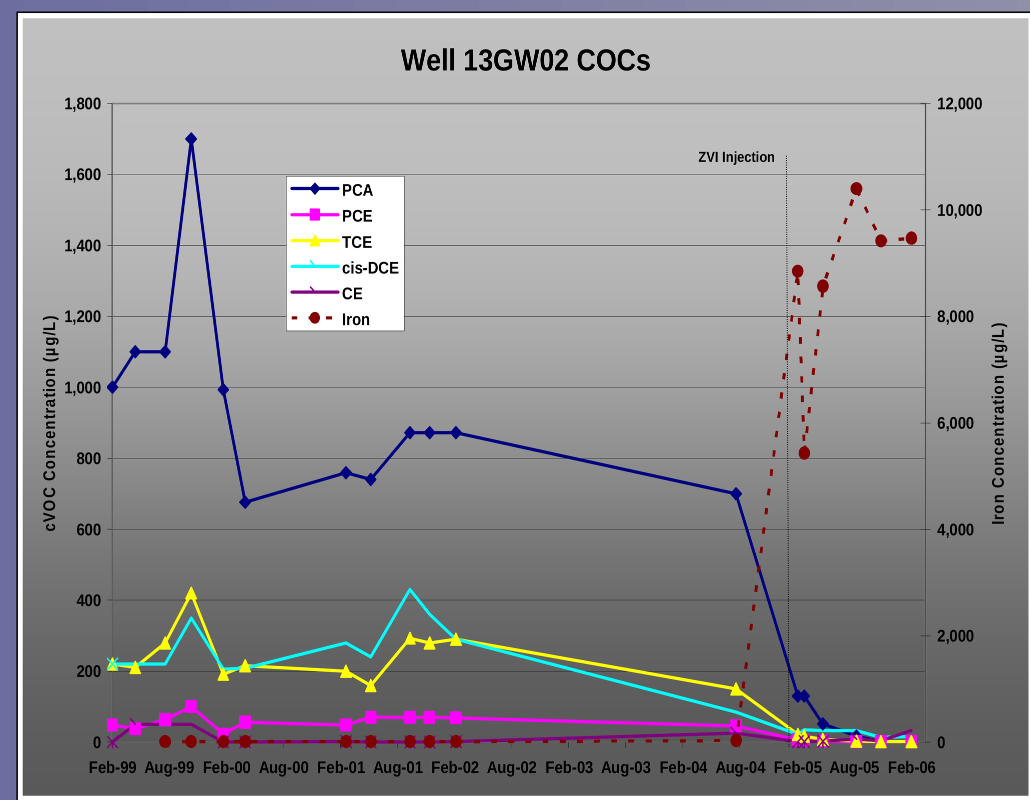
- The following cVOCs are present:
  - 1,1,2,2 tetrachloroethane (PCA) - max. 1,700 µg/L
  - tetrachloroethylene (PCE) - max. 150 µg/L
  - trichloroethylene (TCE) - max. 535 µg/L
  - cis-1,2-dichloroethylene (cis-1,2-DCE) - max. 794 µg/L
  - vinyl chloride [i.e., chloroethylene (CE)] - max. 26 µg/L
- Highest concentrations of cVOCs are in the TRZ at greater than 1,000 µg/L (total cVOCs), decreasing with direction of groundwater flow toward West Farm Branch.
- PCA most prevalent cVOC, followed by TCE and DCE.
- CVOCs detected in bedrock wells, but at lesser concentrations. Low vertical flow component. Only saprolite formation was targeted for remediation.

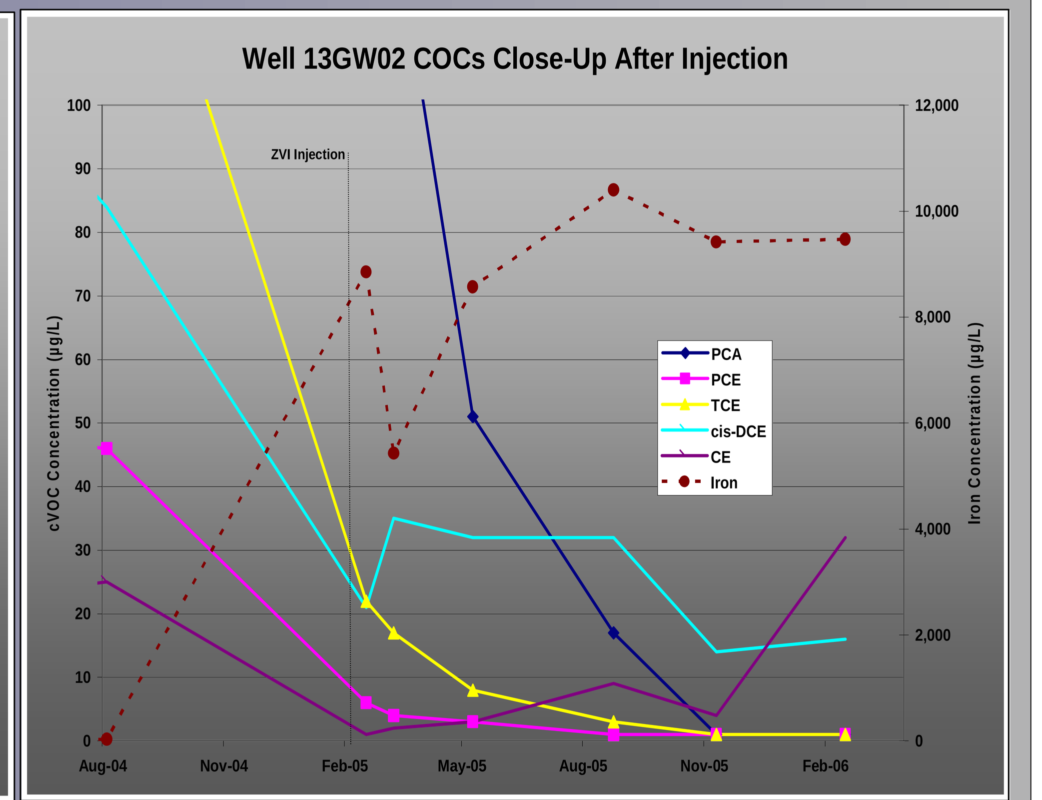
Remedial Action

- Reduce concentrations of cVOCs in source area / TRZ using ZVI.
- CH2M HILL designed the remedy, which was implemented by Shaw.
- Shaw installed 15 four-inch injection wells at 34-feet-spacing into the saprolite formation between 28 to 39 feet bgs. Three-inch PVC was used to keep holes open until the injection event. PVC was removed prior to injection.
- ARS Technologies used an integrated approach consisting of pneumatic fracturing (PF) and Ferox^{SM} injection. PF was first used to enhance the permeability of the saprolite formation and the ZVI was emplaced in the created fracture network. Discrete injection intervals ranging from 3 to 4 feet targeted depths ranging from 15.5 to 35 feet bgs.
- PF initiation pressures ranged from 50 to 400 psi and maintenance pressures ranged from 40 to 210 psi. PF occurred in 28 of the 48 injection intervals (determined bythe shape and magnitude of down-hole pressure-time history curves), most readily at greater depth.
- A total of 77,150 lbs of ZVI powder was mixed with approximately 23,506 gallons of water to form the activated slurry. Each borehole received approximately 5,100 pounds of ZVI. Dosages in each injection interval ranged from 900 to 5,200 pounds of ZVI (i.e., 150 to 1,600 gallons of ZVI slurry).
- ZVI emplacement was estimated to be at least 20 feet.

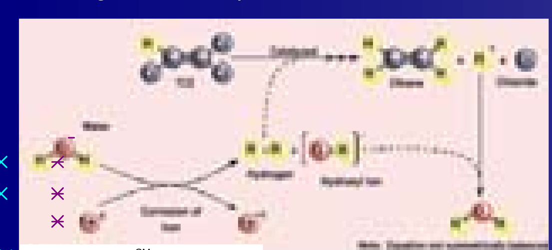
Baseline – August 2004







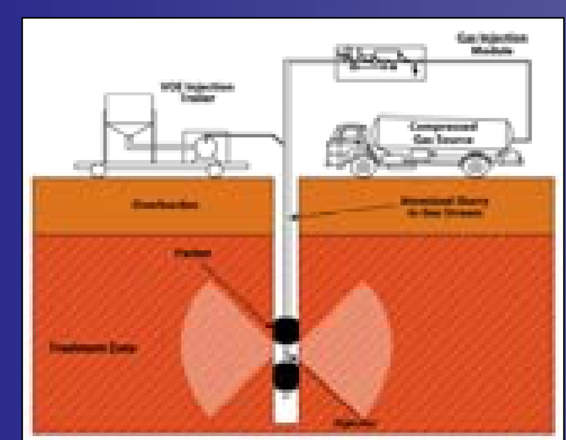
The FEROX^{SM} reaction mechanism begins with the corrosion of the ZVI powder as it comes into contact with a water molecule. The products of corrosion are ferrous iron (Fe^{+2}), hydrogen gas (H_2), and a hydroxyl ion (OH^-). The hydrogen gas then combines with the halogenated organic compound (e.g. TCE) on the surface of a catalyst (iron powder, naturally occurring electron mediator, or unidentified constituent in the soil organic matter) whereby the contaminant is dehalogenated. In addition to the dehalogenated compound, a proton (H^+) and chloride ion (Cl^-) are also produced. The proton then combines with the hydroxyl ion, formed during the corrosion reaction, to reform a water molecule. Accordingly, the end products of this reaction are ferrous iron, chloride ions, and the dehalogenated compound.



Simplified Ferox^{SM} Mechanism

The patented FEROX^{SM} technology consists of the integration of two commercially proven processes to provide a cost-effective *in situ* treatment method for groundwater and soils contaminated with halogenated organic compounds (and/or leachable heavy metals). FEROX^{SM} is applied in an open borehole or a direct-push injector assembly casing is used to position the down-hole apparatus into the subsurface. Once in place, ZVI powder is injected into the formation as slurry or as dry material. Nitrogen gas or compressed air is used as the carrier fluid.

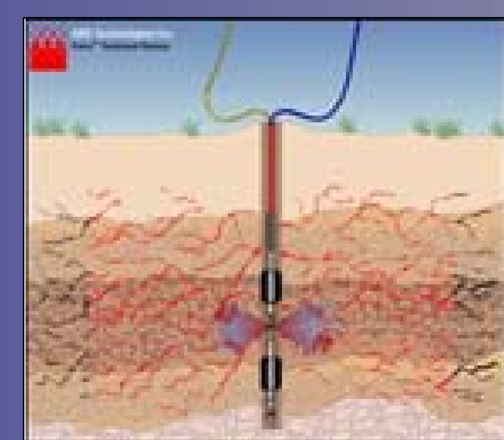
Liquid Atomization Injection (LAI) is a very effective method for injecting liquids uniformly within all types of geology. In addition, injection radii of influence are considerably greater than that achievable using conventional hydraulic injection. LAI relies upon the premise that it is more effective to inject gases or "aerosols" into the subsurface than it is to inject an incompressible liquid into the subsurface.



The atomized multi-phase injection approach provides several key benefits over conventional injection techniques. These include:

1. Aggressive mixing / recirculation maintains the iron powder in uniform suspension and allows for the reaction of the iron powder with water to be accelerated
2. Providing added moisture necessary for the reaction when applying in an unsaturated zone.
3. Allows the iron powder to be injected into the formation to significant radial distances using relatively low pressures (<150 psi).

This gas slurry injection technique has been shown to influence consolidated formations to distances of more than sixty feet from the injection well. In practice, the injections are applied across an 18-24 inch intervals of the subsurface using a straddle packer assembly.



Nitrogen