Anaerobic Chlorinated Hydrocarbon Remediation

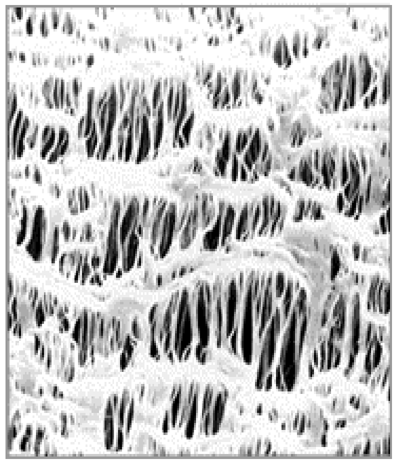
HiSOC® Hydrogen inFusion System

What is HiSOC®?

- Based on iSOC® Gas inFusion Technology
- Hydrogen gas is used to enhance anaerobic reducing conditions
- System powered by compressed gas in cylinder
- Mass transfer device delivers dissolved hydrogen to treatment zone
- No moving parts; Installs in 2” well or larger
- Measures 1.62” in diameter by 12.65” long

How Does HiSOC® Work?

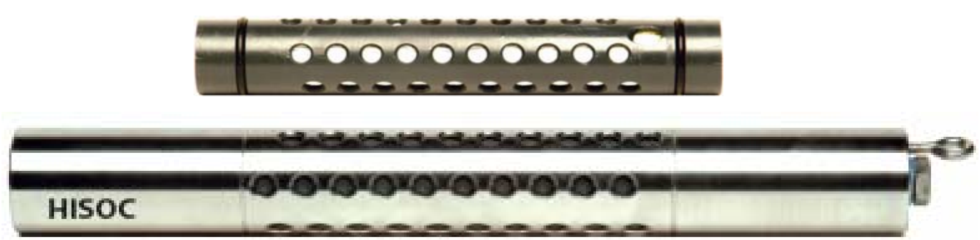
Cross Section 200 µm



Inner Surface 1 µm

- Over 700 Hollow fibers
- Creates large surface area for mass transfer
  (7000 sq ft per cu ft)
- 1-HiSOC® Delivers approx. 3.6 grams H_2 per day

Mass Transfer Device



Hydrogen Cylinder Life and Production Rate

HiSOC Depth		**15**	**ft**
Number of of iSOCs		**6**	
Regulator Setting (psi)		**50**	**psi**
	Hydrogen Flow	**28**	standard cc/min
Hydrogen Cylinder Volume (ft^3)	**Hydrogen (pounds)**	**Actual Cylinder Life for Y HiSOCs**	
250	1.4	**24**	
220	1.2	**21**	
125	0.7	**12**	
	Max Dissolved Hydrogen @ Y depth (ppb)	**2337**	
	Hydrogen Production Rate (Grams / Day)	**21.600**	
	(mg / Day)	**21600**	
	(ug / Day)	**21600000**	

*Caution: Pressure guages are often inaccurate after a period of use particularly at low pressures

*Temperature variations can effect the pressure reading by as much as 15%

Why Use HiSOC®?

- Effective remediation in any lithology
- Eliminates need to inject organic substrates for production of H_2 by fermentation
- No excessive biomass produced that can foul the aquifer or treatment wells
- Minimizes secondary water quality issues

Why Use HiSOC®?

- Can be used for source attenuation or dissolved plume treatment
- Small and simple with very low O&M
- Unlike oils, direct H_2 will not reduce pH in the aquifer and will not inhibit the growth or kill the dechlorinating microbes

HiSOC® and Dissolved Hydrogen

- H_2 is quickly used by dechlorinating bacteria (no fermentation time)
- H_2 gas is very inexpensive
- H_2 does not leave any environmentally unfriendly residue
- Much more flexible system than other chlorinated solvent remediation techniques

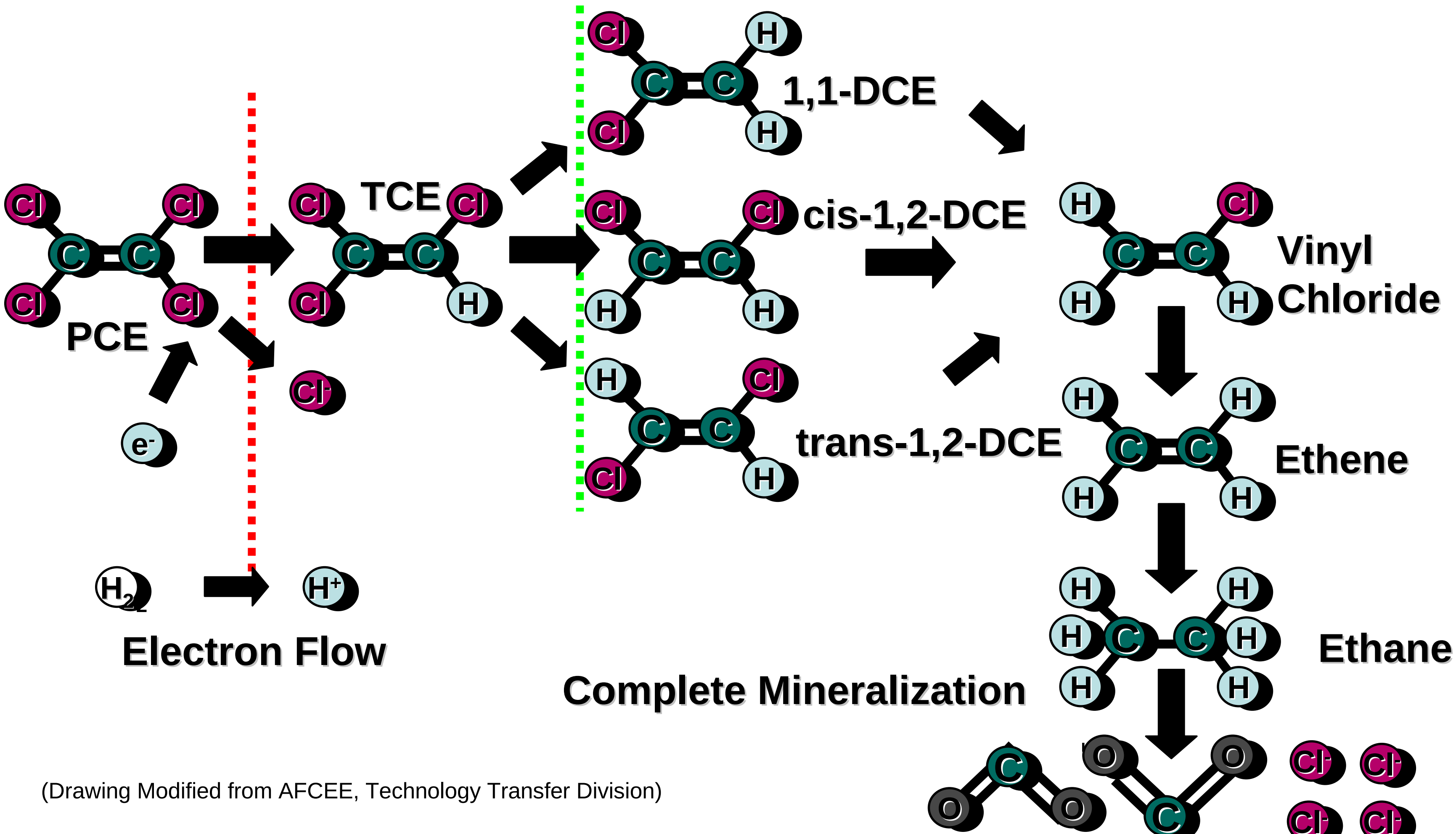
HiSOC® and Dissolved Hydrogen

- When coupled with lactate, direct H_2 addition has been observed to significantly lower dissolved iron concentrations; reducing iron fouling issues
- H_2 addition with lactate significantly increases the rate of complete degradation of PCE AND TCE to ethene over lactate alone.
- Hydrogen is safe and utilized in many industrial processes

H_2 Applications as an Electron Donor

- Reductive dechlorination of CAHs (PCE, TCE, DCE, VC etc)
- Denitrification of nitrate
- Perchlorate Degradation

Anaerobic Reductive Dechlorination of Chlorinated Ethenes



(Drawing Modified from AFCEE, Technology Transfer Division)

Typical HiSOC® Setup

- Engineered using National Fire Protection Association 50A Standards
- Place HiSOC® at bottom of treatment zone to maximize head pressure
- Screen treatment well over vertical thickness of contaminant plume
- Stainless steel tubing and fittings in conduit and Parflex hose in well

Hydrogen is Safe

- H_2 is a flammable gas used in numerous industrial applications
- Store gas cylinders in well ventilated cage or open shelter
- H_2 is 18 times lighter than air and will dissipate, not collect
- Use stainless steel tubing, fittings and required OSHA signage
- Use H_2 gas sensors in storage areas and well vaults

In-Situ Bioremediation of TCE-Contaminated Groundwater using Hydrogen Gas inFusion

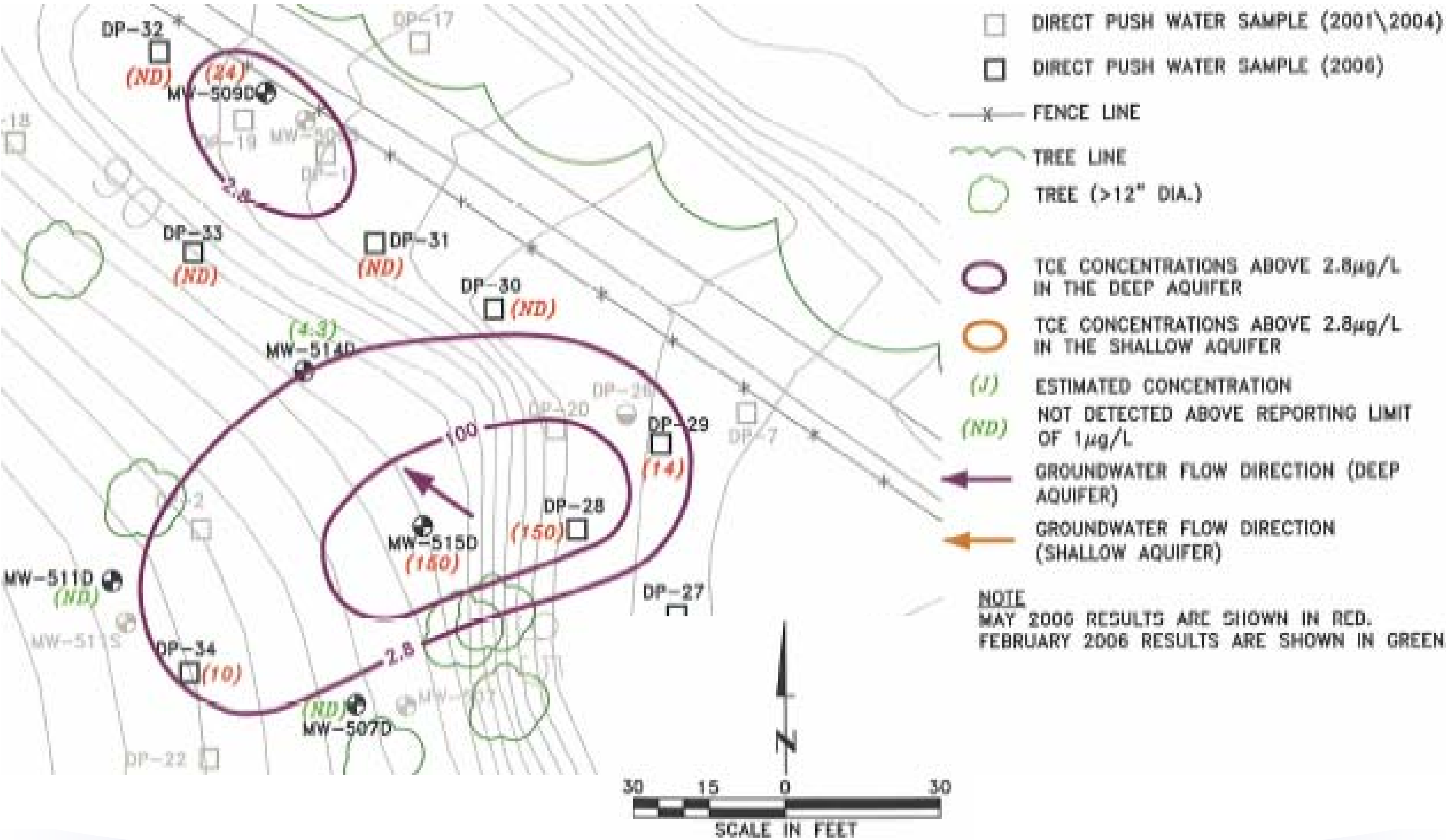
Seymour-Johnson Air Force Base

Goldsboro, NC

Site Background

- Former Air Force base drum storage area
- TCE release to groundwater
- Shallow groundwater table with layers of alluvial sands and clays with varying amounts of silt and gravel content
- Hydraulic conductivity
  - shallow aquifer (10 to 20 ft bls)-0.16 ft/day to 32 ft/day
  - deep aquifer (20-30 ft bls) -1.3 ft/day to 17 ft/day
- Overall site remediation approach was developed by URS Corporation

Site Plan TCE Plume Area



Site Background

- 2004 - HRC used to stimulate anaerobic reductive dechlorination in the shallow and deep aquifer – Unable to close site
- Shallow aquifer maximum concentrations of 6 ppb TCE were reduced to less than 2 ppb at most monitoring points by HRC
- Shallow aquifer target redox conditions developed after 3 months and were maintained for only 6 months by HRC

Site Background

- HRC treatment in the deep aquifer with initial concentrations of up to 140 ppb TCE were reduced at some monitoring points and were increased at others up to 230 ppb
- In Deep Aquifer Target redox conditions developed after 6 months and were maintained for only 3 months by HRC
- Site was not closed by HRC

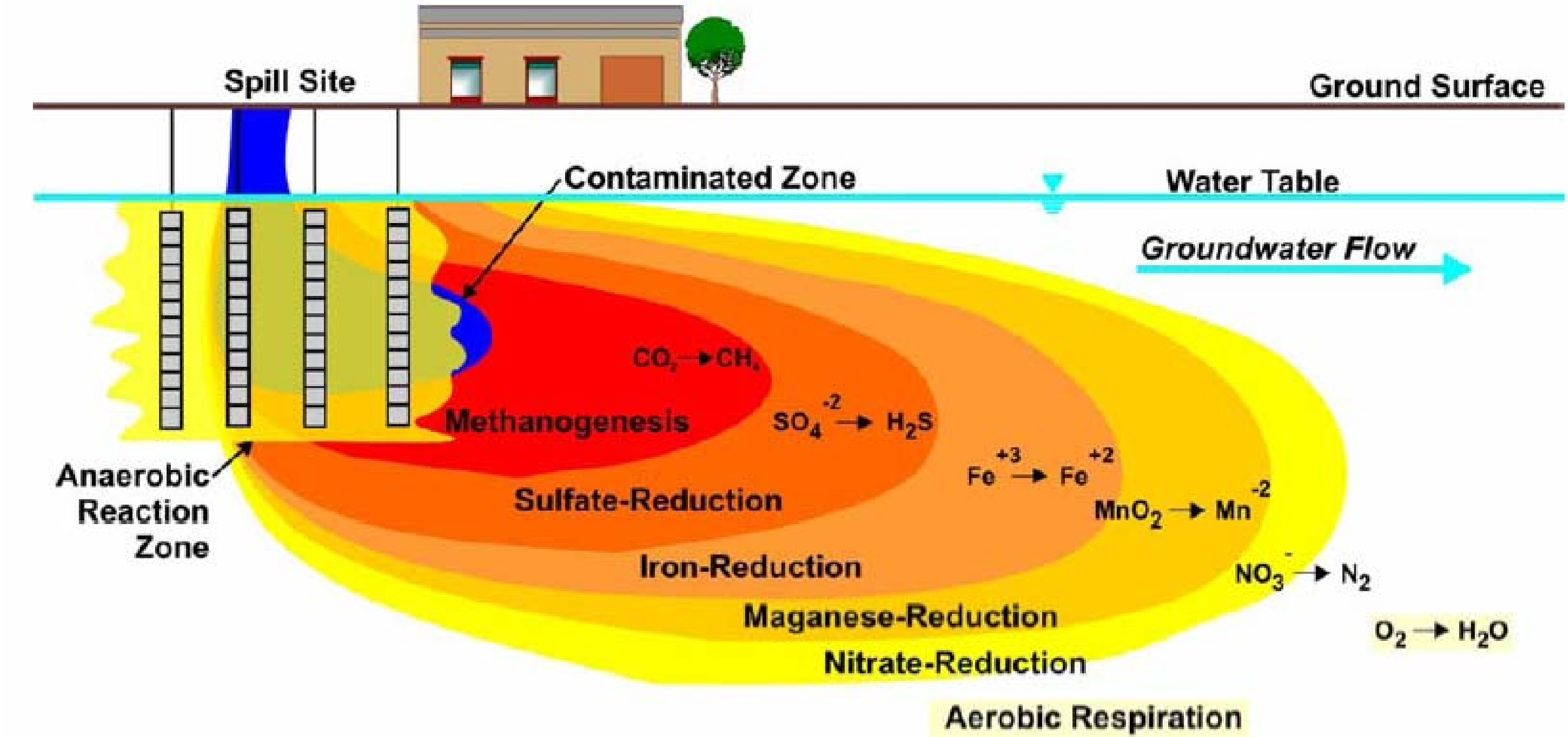
Consultant's Basis for Selecting HiSOC® System

- H_2 infusion was selected over HRC re-injection because it is expected to be more effective at maintaining reductive conditions in the aquifer until the remedial objectives are achieved
- Pilot studies conducted at sites with similar characteristics to the site indicated that direct H_2 addition is effective at degrading chlorinated solvents

Target Redox Conditions

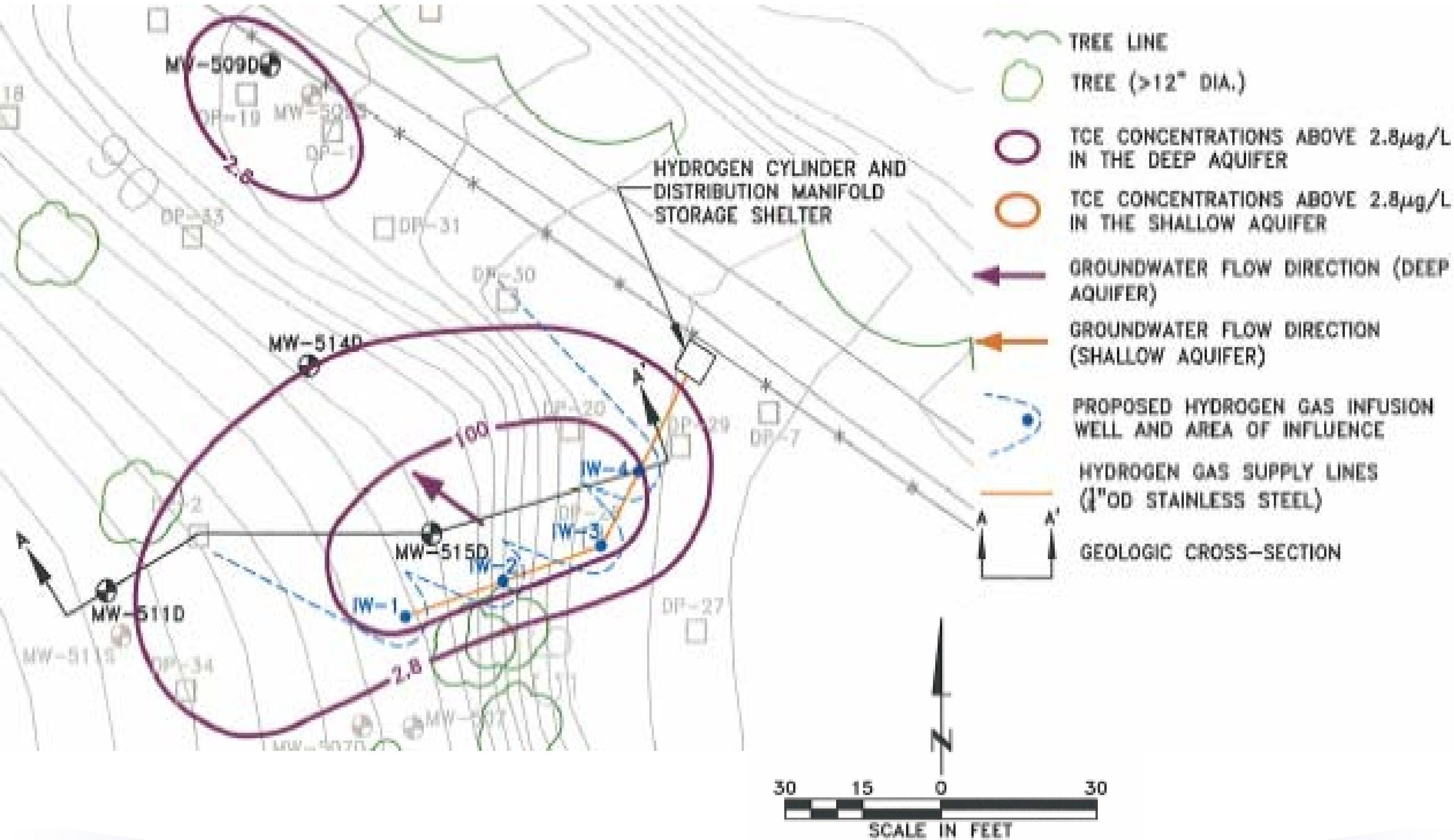
Anaerobic dechlorination has been demonstrated under a range of reducing conditions including nitrate, iron, and sulfate reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, at near methanogenic conditions (AFCEE 2004).

Reducing Zones Downgradient of H_2 inFusion



(AFCEE 2004)

HiSOC® Treatment Well Layout

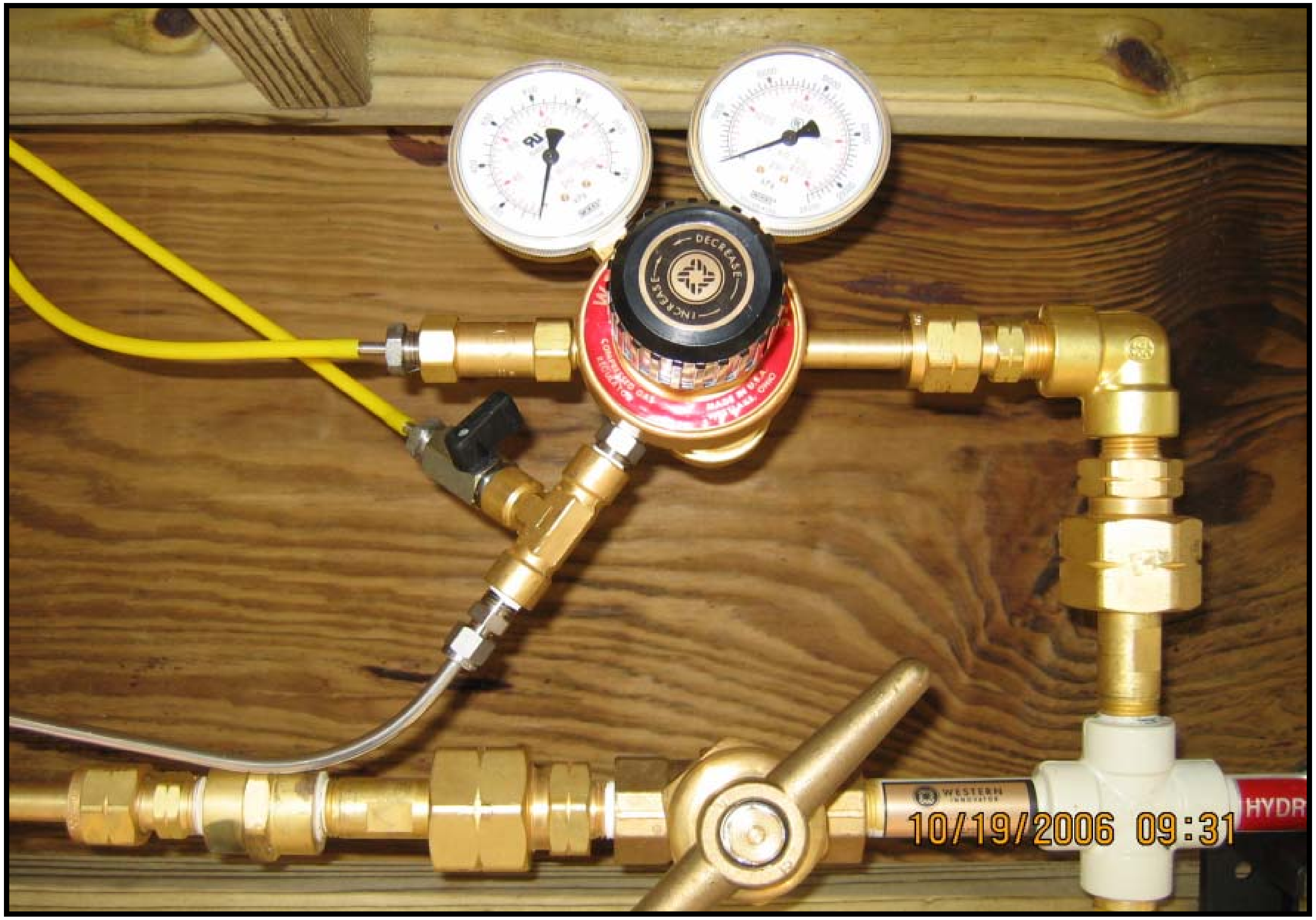


Installation of the 4-HiSOC® System

- **Day One**: Purchase supplies and build shelter
- **Day Two**: Install gas delivery system inside shelter, conduit, tubing, passive vents and install HiSOC®. Start system up with nitrogen.
- **Day Three**: Check for leaks, compete shelter, ground H_2 system, switch to hydrogen gas, install fence compound, remove debris and affix OSHA signage

Gas Supply Inside Shelter

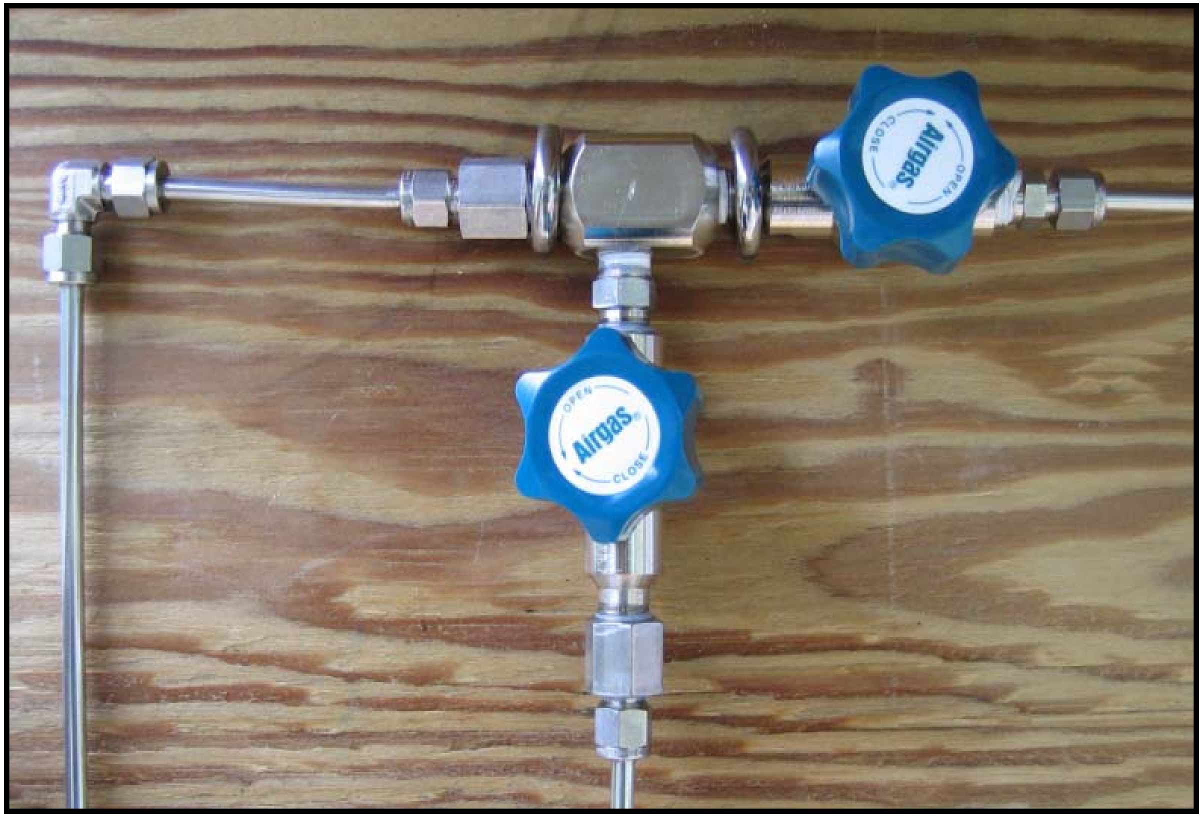
Hydrogen Regulator



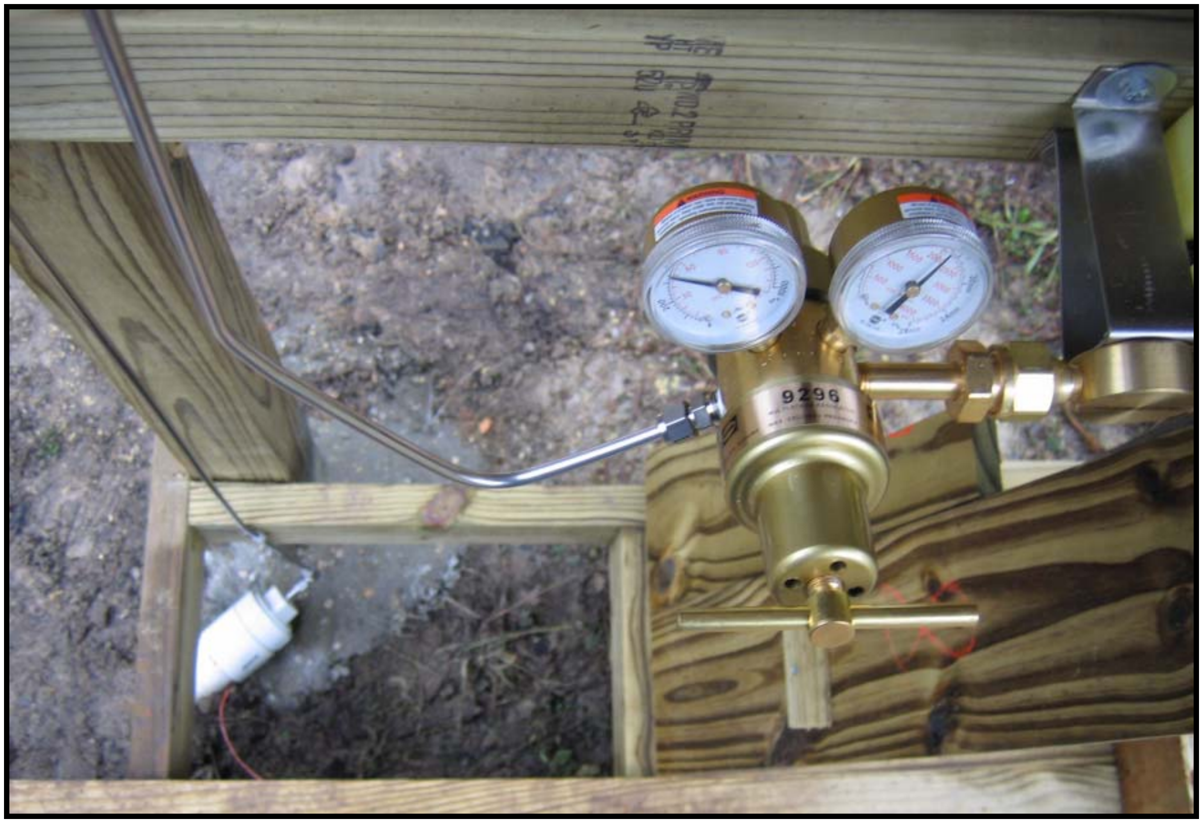
Nitrogen Purge Cylinder and Regulator

Gas Switching Assembly

(H_2 valve at top / N_2 valve below-used for startup, leak testing and purging)



Routing Valex Stainless Steel Tubing to Wellheads



SS Tubing in PVC conduit to Injection Wells

HiSOC® and Paflex Hose Connection

HiSOC® installed at IW-1

(Paflex hose grounded)

Operational HiSOC® Treatment Well H_2 Concentrations

Sample ID			IW2-1	IW4-1
Date Sampled			1/11/2007	1/11/2007
Dissolved H2, water matrix				
Sample Result	H^2	nmol/L	570,000	200,000

- H_2 amended water moves into the groundwater system forming a treatment zone
- Target H_2 concentrations in the treatment zone are 1 to 11 nmol/L for effective reductive dechlorination (AFCEE 2004)

Site Status

- First quarter HiSOC® treatment results show declining TCE concentrations 35% decline in concentration at the nearest downgradient monitoring well (MW-515D)
- Additional data will be collected during quarterly monitoring events