**RISKeLearning**

# Nanotechnology – Applications and Implications for Superfund

April 19, 2007
Session 4:
"Nanotechnology – Superfund Site Remediation
Marti Otto, EPA OSRTI
Mary Logan, RPM, EPA Region 5

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# Nanoscale Zero-Valent Iron
# Field-Scale and Full-Scale Studies

Risk e-Learning Internet Seminar Series
"Nanotechnology: Applications and
Implications
for Superfund."

**April 19, 2007**

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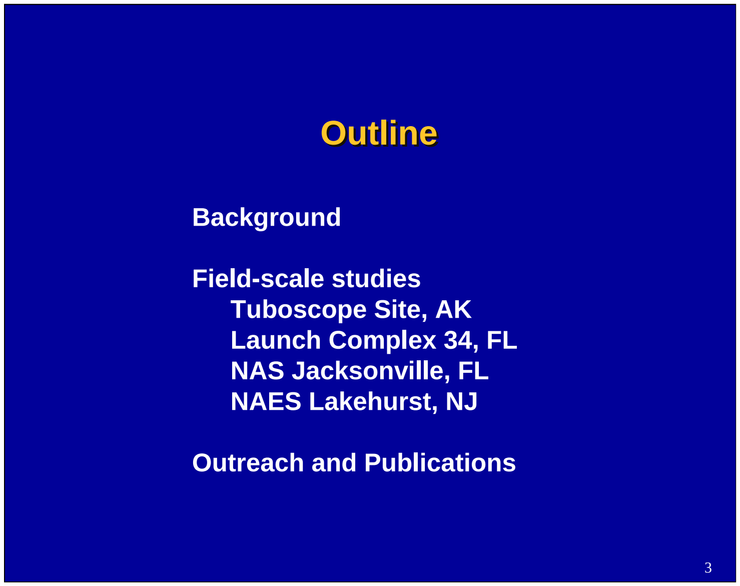



Nanotechnology shows great promise for improved sensors.  The sensors can lead to improved monitoring and detection capabilities that allow for real-time, accurate sensing of many compounds simultaneously at extremely low concentrations frequently in hostile environments[BK1].

Treatment involves cleaning up waste streams of contaminants, particularly those substances that are highly toxic, persistent within the environment, or difficult to treat.  Nanotechnology holds promise for cost-effective, specific, and rapid solutions for treatment of contaminants[BK2].

Remediation addresses problems brought about by prior technologies and past practices.  Cleanup of contaminated sites using nanotechnology is one of the initial successes in nano tech applications to the environment. Researchers are developing cost-effective technologies that enable both rapid and effective cleanup of recalcitrant compounds, particularly those located in inaccessible areas[BK3].

There are two aspects of nanotechnology applications in green manufacturing.  The first involves using nanotechnology itself to eliminate the generation of waste products and streams by designing in pollution prevention at the source.  The second aspect involves the manufacture of nano materials themselves in a benign manner.  Both of these involve use of environmentally friendly starting materials and solvents, improved catalysts, and significantly reduced consumption of energy in the manufacturing process[BK4].

## Background:  OSWER and TIFSD

## Office of Solid Waste and Emergency Response

http://yosemite.epa.gov/r10/cleanup.nsf/sites/CleanCare?OpenDocument

Develops hazardous waste standards and regulations (RCRA)

Regulates land disposal and waste (RCRA)

Cleans up contaminated property and prepares it for reuse (Brownfields, RCRA, Superfund)

Helps to prevent, plans for, and responds to emergencies (Oil spills, Chemical releases, Decontamination)

Promotes innovative technologies to assess and clean up contaminated waste sites, soil, and groundwater (Technology Innovation)

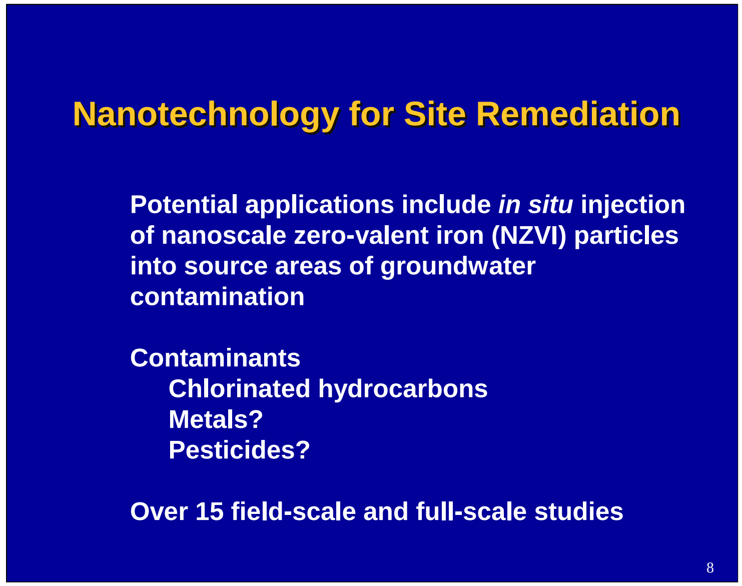
## Technology Innovation and Field Services Division

- Provides information about characterization and treatment technologies (Clu-in, TechDirect, TechTrends, Case Studies, Technical Overviews)
- Advocates more effective, less costly technologies

http://www.epa.gov

- Provides national leadership for the delivery of analytical chemistry services for regional and state decision makers to use at Superfund and Brownfield sites
- Environmental Response Team (ERT) provides technical assistance and science support to environmental emergencies

# Background:
# Nanotechnology for Site Remediation

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# Field Scale Studies

**2 EPA sites with field studies in 2006**
- Tuboscope site, Alaska
- Nease Chemical, Ohio

**2 field studies with emulsified nanoscale zero-valent iron (EZVI)**
- NASA's Launch Complex 34, FL
- Parris Island, SC

**Majority of field studies**
- Trichloroethene (TCE), trichloroethane (TCA), degradation products
- Gravity-feed or low pressure injection
- Source zone remediation

Tuboscope Site
BP/Prudhoe Bay,
Alaska

# Tuboscope Site
# BP/Prudhoe Bay
**North Slope, Alaska**

## Tuboscope Site
## BP/Prudhoe Bay
**North Slope, Alaska**

**Cleaned pipes used in oil well construction from 1978 to 1982**

**Contaminants**

- **Trichloroethane (TCA)**
- **Diesel fuel**
- **Lead**

## Tuboscope Site

**North Slope, Alaska**

- Pilot test: injection of NZVI
- Objectives/Goals
  - Reduce the concentrations of TCA and diesel fuel contaminants
  - Reduce the mobility of lead at the site
- Field Test conducted August 2006
- First round of sampling: September 2006
- More information: hedeen.roberta@epa.gov

# Launch Complex 34, FL

# Launch Complex 34

- Used as launch site for Saturn rockets from 1960 to 1968
- Rocket engines cleaned on launch pad using chlorinated VOCs, including TCE
- DNAPL (primarily TCE) present in subsurface
- EZVI demonstration conducted beneath the Engineering Support Building

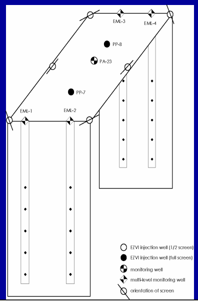
# Properties of Emulsified Zero-Valent Iron


Jacqueline Quinn, NASA

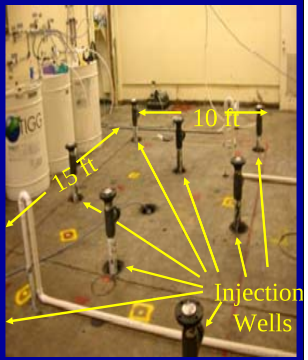
- Oil membrane is hydrophobic and miscible with DNAPL
- Abiotic degradation by ZVI
- Biodegradation enhanced by vegetable oil and surfactant components of EZVI

# EZVI Injection Set-Up

- EZVI injected in 8 injection wells
- Injection wells along edge of plot directed inwards
- Injection wells in center were fully screened
- Injection at 2 discrete depth intervals in each well

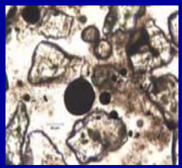


Slide: Jacqueline Quinn, NASA



# Soil Core Samples

EZVI in 1- to 3-inch thick stringer



Soil core sample

Jacqueline Quinn, NASA

## Results

- Significant reduction (57 to 100%) of TCE in target depths within 5 months
- Significant additional reduction of TCE in groundwater samples collected 18 months after injection
- Data suggest longer-term TCE reduction due to biodegradation
- Subsequent fieldwork indicates that better distribution of EZVI may be achieved using pneumatic fracturing or direct push rather than pressure pulse injection method

# NAS Jacksonville, FL

# NAS Jacksonville

Former underground storage tanks

Source area contaminants: TCE, PCE, 1,1,1-TCA, and 1,2-DCE

CERCLA cleanup

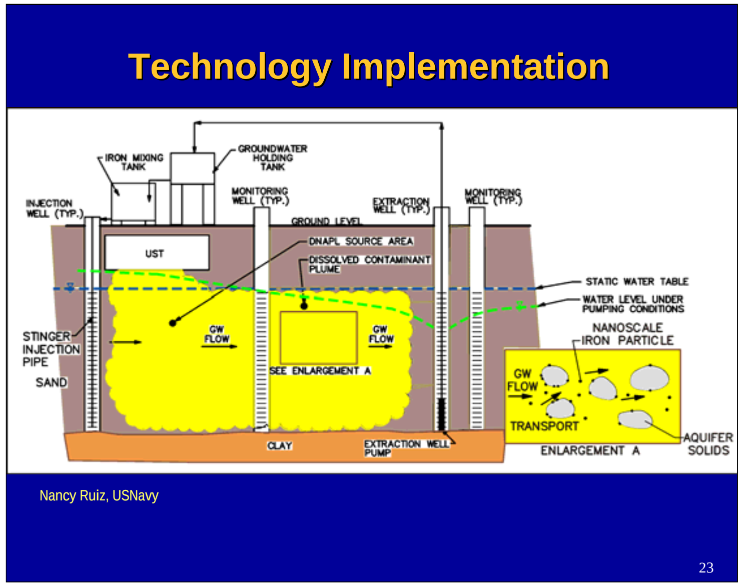
Groundwater monitoring under RCRA

# NZVI Injection

**Gravity Feed**

**10 injection points**

**300 lb bimetallic nanoparticles (BNP)**
**(99.9 % Fe, 0.1 % Pd and polymer support)**




300 lb BNP (99.9 % Fe, 0.1 % Pd and polymer support)

Initial direct-push technology injection (40 lb)

1st recirculation event (110 lb) – 2 to 4.5 g/L

2nd recirculation event (150 lb) – 4.5 g/L

Injection at 10 locations; known hot spots

Recirculation system – downgradient groundwater

NZVI continuously added to recirculation water

Gravity flow injection

## Results/Conclusions

NZVI significantly reduced dissolved TCE levels in several source zone wells

Some increases in cis-1,2 DCE and 1,1-DCA

Did not achieve strong reducing conditions to generate substantial abiotic degradation of TCE

- Potentially deactivated NZVI due to mixing with oxygenated water, or
- Insufficient iron may have been injected

# NAES Lakehurst, NJ

# NAES Lakehurst, NJ

- Pilot-scale study in 2003
- Full-scale work in 2005 and 2006
- PCE, TCE, TCA, *cis*-DCE, VC
- Largest amount of contamination 45 to 60 ft below groundwater table

# NAES Lakehurst, NJ

Full-Scale Project

- November 2005: Phase I (2300 lb nanoscale bimetallic particles)
- January 2006: Phase II (500 lb nanoscale bimetallic particles)
- Injection method: direct push wells
- Remedial objective: to attain NJ groundwater quality standards using a combination of NZVI and monitored natural attenuation

# Full-Scale Project

- Media treated
  - Groundwater
  - Soil
- Initial concentrations up to 360 ppb chlorinated VOCs
- Final concentrations:  TBD
- Groundwater quality standards have been obtained for some monitoring wells
- Monitoring continues.

# Summary of Navy's Conclusions

- NZVI is a promising technology for source zone treatment
- Inject sufficient iron to create strongly reducing environment, which is essential for success
- Take care to not deactivate NZVI during storage or mixing
- Short-term performance monitoring can be misleading. Long term monitoring of treatment zone until ORP levels have returned to pre-treatment levels is essential.
- Cost and Performance Report: Nanoscale Zero Valent Iron Technologies for Source Remediation available on http://www.clu-in.org
- More information: Project Manager at (805) 982-1155

## Outreach and Publications

October 2005 Workshop on Nanotechnology for Site Remediation

- Held October 20-21, 2005, in Washington, D.C.
- Proceedings and presentations:
  - http://www.frtr.gov/nano

Nanotechnology and OSWER: New Opportunities and Challenges

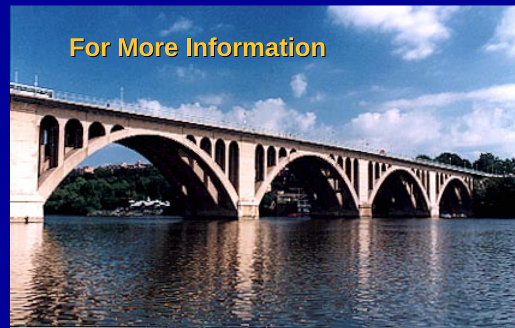
- Held July 12-13, 2006, in Washington, D.C.
- Presentations:
  - http://esc.syrres.com/nanotech/

## Outreach and Publications, Cont.

- Issues area on CLU-IN website
  - http://clu-in.org/nano

- Upcoming TIFSD products on nanotechnology
  - Spreadsheet of field tests
    - Cost and performance
    - Media/contaminants
    - Technology/vendor information
    - Points of contact
  - Fact sheet on nanotechnology for site remediation

# For More Information



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# Nease Chemical Site Nanotechnology Update

Risk e-Learning Internet Seminar Series
"Nanotechnology: Applications and Implications for Superfund"

Mary Logan
U.S. EPA, Region 5
April 19, 2007

# Objectives

- Provide brief site description
- Brief overview of selected remedy for soil, source areas and groundwater
  - Considerations that led to selection of nanotechnology for groundwater clean up
- Discuss status of groundwater remediation by nanotechnology at the Nease site
  - Preliminary pilot study results

# Acknowledgements

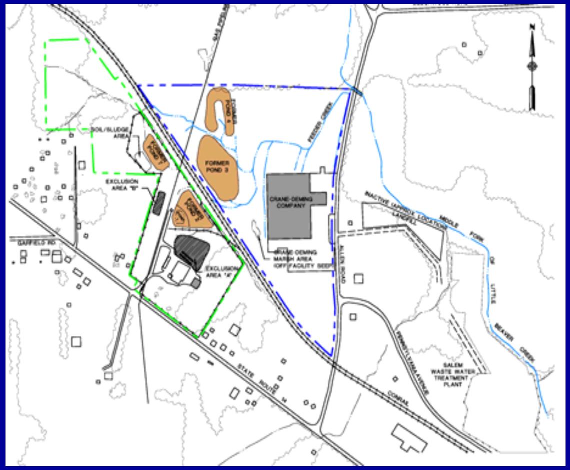
- Rutgers Organics Corporation – current site owner, has agreed to conduct work
- Golder Associates – primary contractor for Rutgers, is performing and/or overseeing the work
  - Special thanks for use of figures and pictures
- Ohio EPA – partner oversight agency and technical support
- EPA's technical support – Region 5 and ORD

# Nease Chemical Superfund Site Overview

# Site Background

- Nease facility
  - Former chemical manufacturing plant
  - Operated from 1961    1973
  - Spills and on-site waste disposal
- The remedy for soil, source areas and groundwater was selected by EPA in 2005
  - More than 150 contaminants identified
  - Primary site contaminants include:
    - Mirex in soil up to 2,080 ppm
    - VOCs in groundwater over 100 ppm
- A future remedy will address mirex in sediment and floodplains

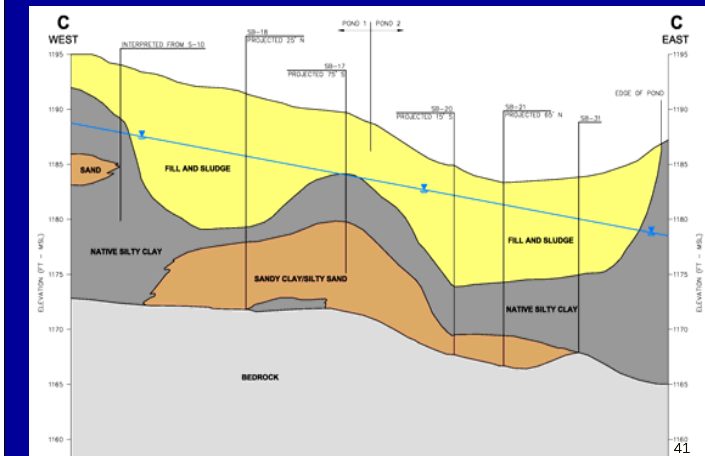
# Nease Chemical Superfund Site



## Summary of Source Area and Groundwater Contamination

- Hydrogeologic units:  overburden; transition bedrock; Middle Kittanning Sandstone bedrock
  - Units are hydraulically connected
  - Depth to groundwater – a few feet to ~ 9 ft.
- Former Ponds 1 & 2 → primary source of contamination to groundwater
  - 50,000 CY waste/fill and underlying soil
  - Waste/fill in ponds is generally below the water table
  - Maximum pond waste concentration:  VOCs > 50,000 ppm; SVOCs ~ 11,000 ppm; pesticides 1,000 ppm; NAPL is found in waste and till
- Primary groundwater contaminants chlorinated ethanes and ethenes, benzene, chlorobenzene

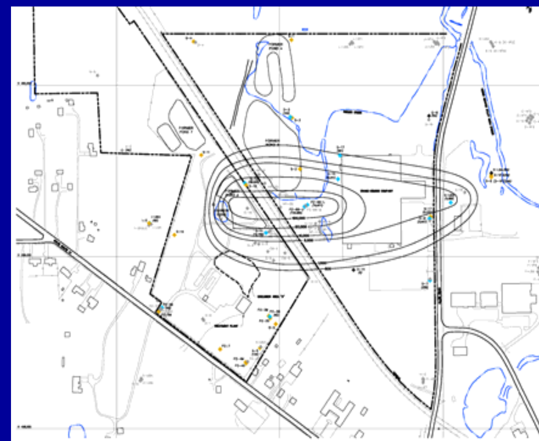
# Cross Section – Former Ponds 1 and 2



# Bedrock Groundwater

- Middle Kittanning Sandstone
  - Thickness 21 to 53 ft.
  - Velocity ~ 65 to 160 ft/yr
- Bedrock is fractured
  - Flow primarily through bedding plane partings
- DNAPL is present
- Plume length ~ 1650 ft.
- Max. total VOCs > 100 ppm
- Natural attenuation seems to be occurring

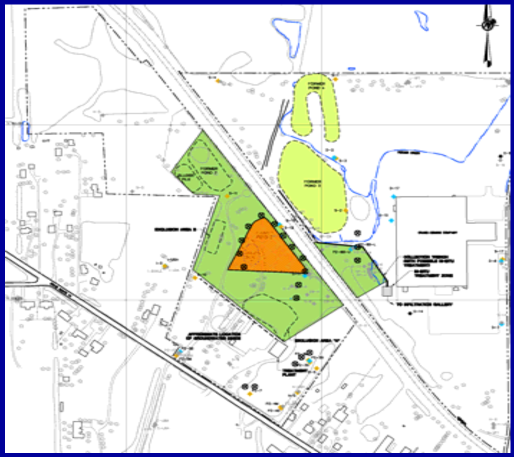
Groundwater Contaminant Contours
Total VOCs Bedrock July 2003



# Operable Unit 2 Selected Remedy

- Former Ponds 1 and 2 → in-situ treatment by soil mixing/air stripping, stabilization and solidification.
- Ponds and soil → covered/capped.
  - Includes Ponds 1 & 2 after treatment
- Shallow eastern groundwater → captured in a trench, pumped above ground, treated on site.
- Bedrock groundwater → treated by injection of nanoscale zero-valent iron (NZVI).
  - Treatment of plume core, MNA downgradient
  - NZVI treatment may be coupled with enhanced biological treatment
  - Pre-design data suggests that the approach for the southern area groundwater must be reconsidered
- Long-term O&M, institutional controls.

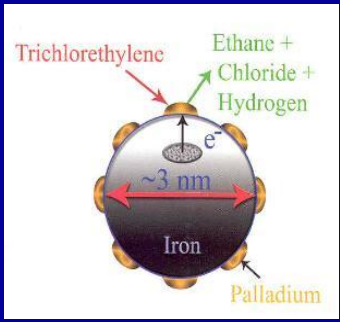
# Conceptual Layout of Remedy



# NZVI – Remedy Evaluation Considerations

# What is NZVI?

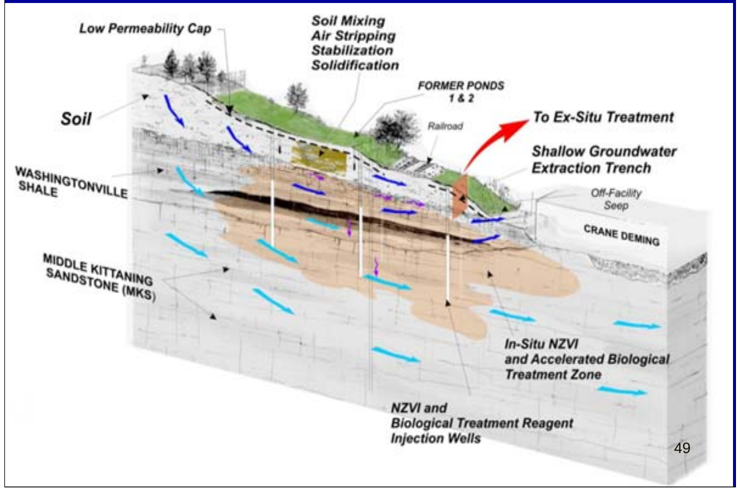
- 1 100 nanometer sized iron particles
  - A human hair is 500 to 5000 times wider
  - Large surface area compared to volume
- NZVI is very reactive
  - Contaminants are destroyed by a reaction similar to rusting
  - Non-toxic by-products are formed
- Iron can be enhanced
  - Reactive catalyst
  - Coatings



# How Does NZVI Work?

- An iron-water slurry is injected through wells into the contaminated aquifer.
  - Intended to diffuse/flow with groundwater
    - Need to spread the iron
  - Goal → in-situ treatment of contaminants
- Contaminants are rapidly destroyed by oxidation-reduction reactions.
- With time, iron particles partially settle out and reactivity declines.

# Conceptual Diagram of Nease Site Remedy



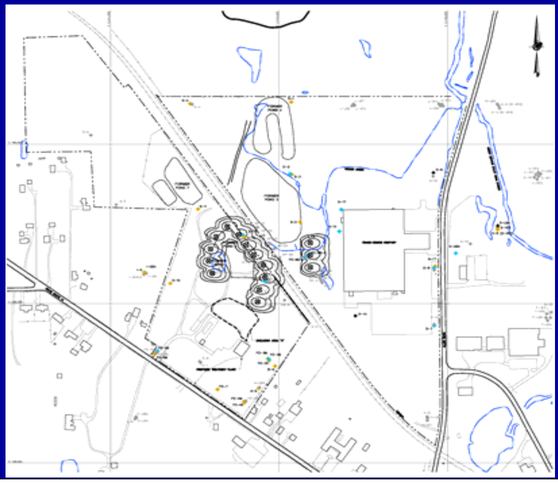
# FS Analysis - Considerations

- Types of contaminants and the ability of NZVI to treat the contaminants of concern
  - Ability to combine NZVI with other approaches for recalcitrant contaminants
- Existing conditions
  - Site hydrogeology
  - Groundwater geochemistry
- Source control
- Underground injection requirements
  - Likely to be ARARs
- Cost

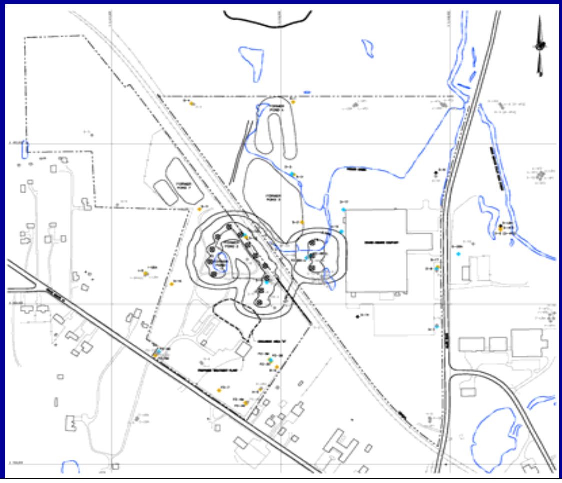
# FS Analysis – Considerations (cont.)

- Estimate number of injection wells
  - Radius of influence of treatment zone to determine injection well spacing
    - Simple 2D modeling
- Estimate frequency and timing of injections
  - Calculate NZVI mass requirements
    - Simple stoichiometric calculations
    - Additional iron to account for waste
  - Rebound can occur as NZVI is used up
    - Addressed by multiple injections

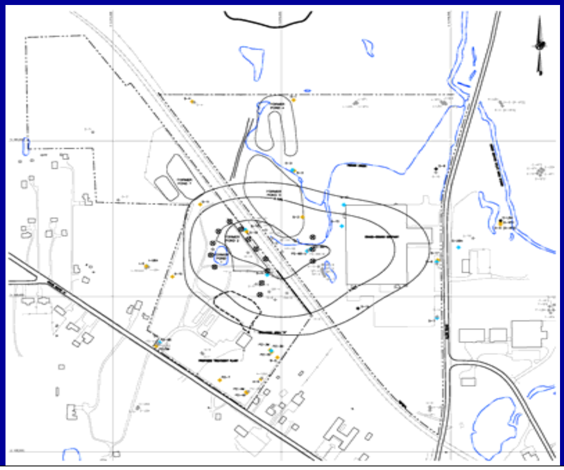
## FS Projections - NZVI Area of Influence After a Few Days



## FS Projections - NZVI Area of Influence After a Few Weeks



## FS Projections - NZVI Area of Influence After a Few Months



# Why NZVI at the Nease Site?

- Contaminants – generally treatable
  - Chlorinated ethenes, ethanes
- Favorable geochemical conditions
  - Low dissolved oxygen concentrations
  - Relatively low nitrate/nitrite and sulfate
- Unfavorable conditions for other options
  - Fractured bedrock (favorable for NZVI)
  - DNAPL
- Desire to maintain/enhance existing site conditions that support natural attenuation
  - Strongly reducing conditions created by NZVI
    - Favorable for anaerobic bacteria that may help degrade chemicals not treated by the iron
- Relatively low cost

# Nease Chemical Site
# NZVI Treatability Study

# NZVI Treatability Study

- NZVI treatability study is being conducted as part of the pre-design investigation
- NZVI study has two phases
  - Bench scale study
  - Field pilot test
- Final Remedial Design will be based on results
- Bench study started in July 2006
- Field pilot started in November 2006

# Bench Scale Study

## Bench Study - Objectives

- Assess effectiveness of NZVI for treatment of chlorinated VOCs
- Determine effects (if any) of NZVI on non-chlorinated VOCs
- Evaluate by-product generation
- Determine optimal formulation and dosage
- Evaluate site-specific geochemical influences on treatment effectiveness
- Determine the longevity of NZVI

# Bench Study - Approach

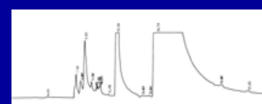
- Highly contaminated groundwater collected
  - Baseline analysis
- Four different iron materials tested
  - Mechanically produced or chemically precipitated
  - With and without palladium catalyst
- Jar tests for rate and effectiveness of a range of NZVI concentrations/formulations
  - 0, 0.05, 0.1, 0.5, 1, 2, 5, and 10 g/L
- Jar tests to assess the influence of site soils
- Capacity tests → effectiveness of iron to treat re-contaminated samples

# Bench Test Procedures

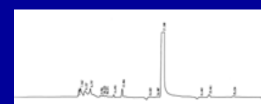
Water Samples from the Site

Batch Reactors

Gas Chromatograph



Before



After

# Baseline Contaminant Levels

| Contaminant | Result (ug/L) |
|---|---|
| Benzene | 7,000 |
| 1,2-Dichlorobenzene | 15,000 |
| cis-1,2-Dichloroethene | 11,000 |
| trans-1,2-Dichloroethene | 2,200 J |
| Methylene chloride | 2,100 J |
| 1,1,2,2-Tetrachloroethane | 2,300 J |
| Tetrachloroethene (PCE) | 82,000 |
| Toluene | 1,500 J |
| Trichloroethene (TCE) | 21,000 |

## Bench Study - Primary Results

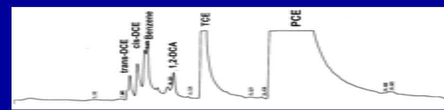
- Mechanically produced NZVI with 1% palladium at 2 g/L recommended formulation
- Chemically produced iron showed slightly better performance than mechanically produced, but both were adequate
- NZVI without palladium showed only partial treatment within 2 weeks
- No chlorinated by-products were detected
- Benzene was not adequately treated and was produced as a by-product by reduction of 1,2-dichlorobenzene
- Site soils did not seem to inhibit treatment

**Bench test reductions within 2 weeks using mechanically produced NZVI with 1% palladium at 2 g/L.**

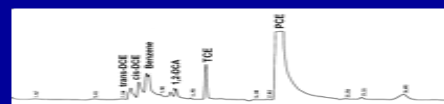
| Contaminant | Reduction |
|---|---|
| PCE | 98% |
| TCE | 99% |
| cis-1,2-DCE | 97% |
| trans-1,2-DCE | >99.9% |
| 1,2-DCA | 99% |
| 1,2-Dichlorobenzene | “complete” |

# Nease Bench Test - GC Spectra

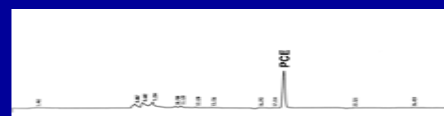
T = 0




T = 2 days

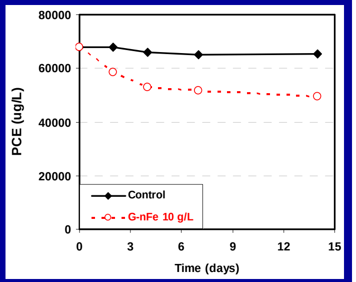


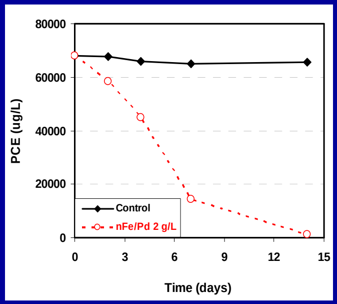

T = 14 days




**2 g NanoFe/Pd per liter groundwater**

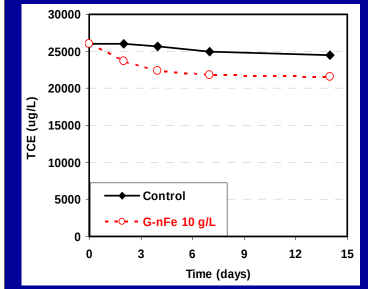
# Nease Bench Test - PCE Degradation

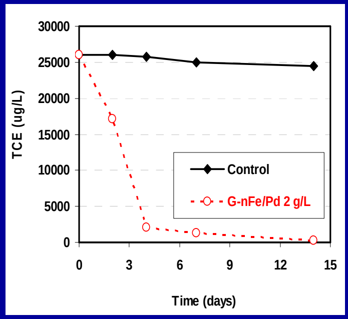



**10 g NanoFe or 2 g NanoFe/Pd per liter groundwater**
**Pd concentration was 1%wt**
**PCE initial concentration 68000 ug/L**

# Nease Bench Test - TCE Degradation



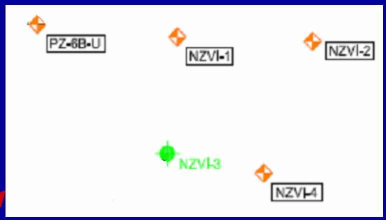

**10 g NanoFe or 2 g NanoFe/Pd per liter groundwater**
**Pd concentration was 1%wt**
**TCE initial concentration 26000 ug/L**

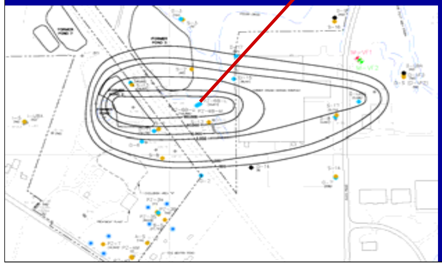
# Field Pilot Test

# Field Pilot Test - Objectives

- Verify laboratory results
- Evaluate treatment under field conditions
  - Confirm in-situ treatment effectiveness
  - Evaluate geochemical changes in the aquifer
- Support the remedial design
  - Evaluate rate of transport/dispersion of NZVI
  - Assess size of effective treatment zone

# Study Area and Pilot Study Wells



# Field Pilot Well Array

# Additional Aquifer Testing

- Slug tests performed on wells
  - Some wells in zones of lower hydraulic conductivity
- Tracer testing was conducted using saline
  - Demonstrated interconnection of wells
  - Provided data on time for saline to reach wells and time for peak concentrations to be seen
- Tests provided estimates of potential injection rates and volume
- Resulted in a new well and the planned injection well was changed

# Field Pilot Test – Approach

- NZVI brought to site as parent slurry, mixed in batches
- Parent slurry mixed with potable water to provide injected slurry
  - Injected concentration 10 g/L
  - Contained powdered soy (patent pending) as an organic dispersant
    - 20% by weight of NZVI
  - Most batches contained palladium
    - 1% by weight of NZVI
  - Last few injections were iron without palladium

# Mixing NZVI Injection Slurry

# Field Pilot Test – Approach (cont.)

Injection of NZVI slurry

- Injection well
  - Work plan: Planned to use PZ-6B-U
  - Actual: Used well NZVI-3
- Injection rate
  - Work plan: Planned at 2 gpm or higher
  - Actual: 0.15 – 1.54 gpm
- Injection time
  - Work plan: Planned over 3 – 4 days
  - Actual: Took about 22 days
- NZVI mass
  - Work plan: Planned to inject 100 kg (75% with palladium)
  - Actual: Injected 100 kg (~87% with palladium)
- Injection volume
  - Work plan: Planned on 2,600 to 3,500 gallons of slurry
  - Actual: 2,665 gallons

# Summary of NZVI Injections

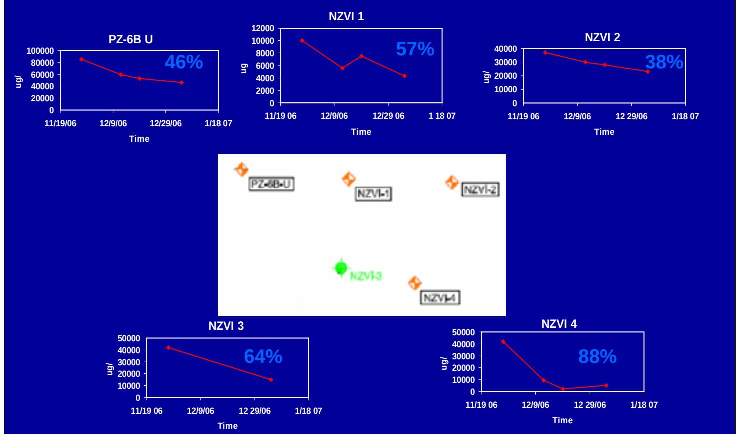
| Date | Injection Method | Injection Pressure (psi) | Average Injection Rate (gallons per minute (GPM) | NZVI/Pd (KG) | NZVI (KG) | NZVI Slurry (gallons) |
|---|---|---|---|---|---|---|
| 11/28/2006 | Gravity w/ pumping - open system | NA | 0.6 | 5 | | 132 |
| 11/29/2006 | Gravity w/ pumping - open system[1] | NA | 0.9 | 6 | | 159 |
| 11/30/2006 | Gravity w/ pumping - open system[2] | NA | 0.5 | 1.5 | | 40 |
| 12/1/2006 | Gravity w/ pumping - open system | NA | <0.5 | 3 | | 79 |
| 12/4/2006 | Gravity - open system[3] | NA | 1.25 | 1.9 | | 50 |
| 12/5/2006 | Gravity - open system[3] | NA | 0.3 | 3.4 | | 90 |
| 12/6/2006 | Gravity - closed system[4] | 4 | 1 | 1.9 | | 50 |
| 12/7/2006 | Gravity - closed system[5] | NA | 0.46 | 2.6 | | 70 |
| 12/8/2006 | Pressure Injection - closed system | 11 | 2 | 4.5 | | 120 |
| 12/9/2006 | Pressure Injection - closed system[6] | 8 | 1.54 | 6.4 | | 170 |
| 12/10/2006 | Pressure Injection - closed system[6] | 8 | 1.5 | 1.1 | | 30 |
| 12/11/2006 | Pressure Injection - closed system[6] | 6 | 0.77 | 6.4 | | 170 |
| 12/12/2006 | Pressure Injection - closed system[7] | 5 to 19 | 0.6 | 4.3 | | 115 |
| 12/13/2006 | Pressure Injection - closed system | 5 to 25 | 0.7 | 5.5 | | 145 |
| 12/14/2006 | Pressure Injection - closed system[8] | 17 | 0.36 | 4.9 | | 130 |
| 12/15/2006 | Gravity - closed system[4] (over night) | NA | 0.07 | 2.07 | | 55 |
| 12/15/2006 | Pressure Injection - closed system[8] | 17 | 0.44 | 4.54 | | 120 |
| 12/16/2006 | Pressure Injection - closed system[9] | 17-10 | 0.15 | 1.89 | | 50 |
| 12/18/2006 | Pressure Injection - closed system[9] | 3-10 | 1.3 | 3 | | 80 |
| 12/19/2006 | Pressure Injection - closed system[10] | 7-12 | 0.95 | 11.72 | | 310 |
| 12/20/2006 | Pressure Injection - closed system | 10 | 0.73 | 5.67 | | 150 |
| | | 14 | 0.60 | | 2.27 | 60 |
| 12/21/2006 | Pressure Injection - closed system | 14 | 0.69 | | 10.96 | 290 |
| | | | TOTAL | 87.4 | 13.2 | 2,665 |

# NZVI Injection

Pressure injection system allows for injection under pressure in a closed system.

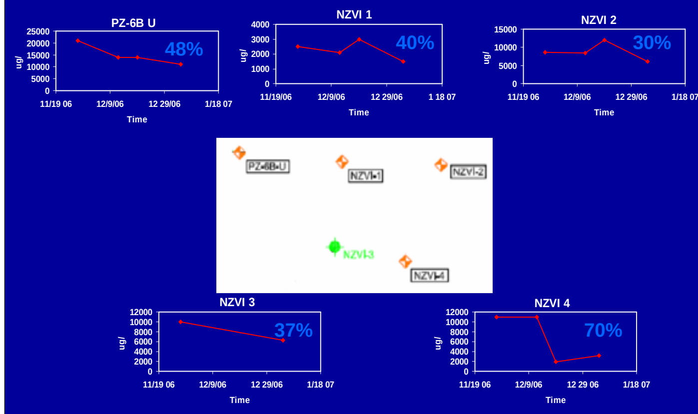
# Field Pilot Test – Monitoring

- Downhole electronic dataloggers
  - Continuously
  - Geochemical parameters – conductivity, pH, ORP, DO, temperature, potentiometric head
- Baseline chemical monitoring
- Post-injection chemical monitoring
  - 1, 2, 4, 8, and 12 weeks post-injection planned
    - 1 week" sample taken about 14 days after injections started
  - VOCs all sample events
  - SVOCs and natural attenuation parameters – select sample events



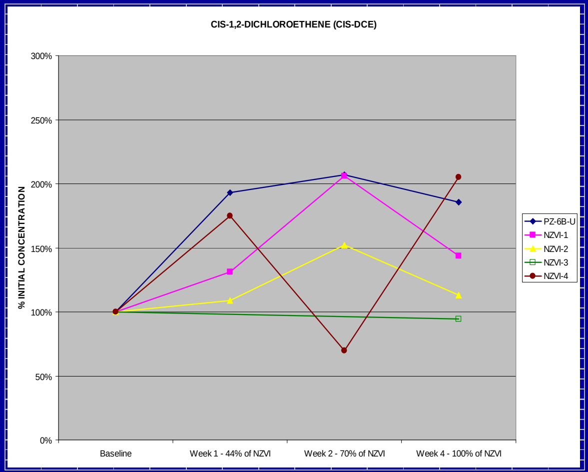

**PCE Reduction Over Time**

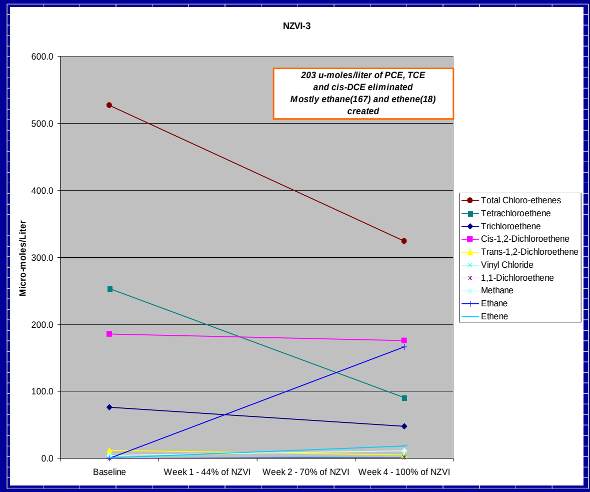
**WEEK 4**

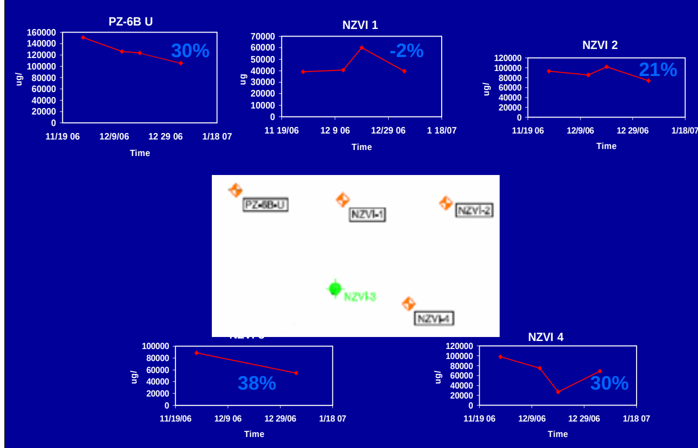



**TCE Reduction Over Time**

**WEEK 4**


CIS-1,2-DICHLOROETHENE (CIS-DCE)
% INITIAL CONCENTRATION
300%
250%
200%
150%
100%
50%
0%
Baseline
Week 1 - 44% of NZVI
Week 2 - 70% of NZVI
Week 4 - 100% of NZVI
PZ-6B-U
NZVI-1
NZVI-2
NZVI-3
NZVI-4


NZVI-3
203 u-moles/liter of PCE, TCE
and cis-DCE eliminated
Mostly ethane(167) and ethene(18)
created
Micro-moles/Liter
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Baseline
Week 1 - 44% of NZVI
Week 2 - 70% of NZVI
Week 4 - 100% of NZVI
Total Chloro-ethenes
Tetrachloroethene
Trichloroethene
Cis-1,2-Dichloroethene
Trans-1,2-Dichloroethene
Vinyl Chloride
1,1-Dichloroethene
Methane
Ethane
Ethene




**VOC Reduction Over Time**

**WEEK 4**

# Field Pilot - Preliminary Results

DISCLAIMER: All data is not available and results are just being assessed

- Promising results!
- Downhole dataloggers showed that all wells were being influenced
- Injection well “best” for overall VOC reduction
- NZVI-4 “best” for PCE and TCE reduction
  - Closest downgradient
- cis-DCE produced
  - Need to track breakdown over time
- End breakdown products observed

# Next Steps

- Complete analysis of monitoring data
- Work on enhanced biological treatment
- Remedial design
  - Number of injection wells?
  - Well placement?
  - Frequency and timing of injections?
  - NZVI mass requirements?
    - With or without palladium?
  - Use of organic dispersant?
- Construct and implement full-scale system

# Nease Site - NZVI Information

- Technical memorandum – later in 2007
  - Results of all tests
  - Recommendations for full scale use
  - Lessons learned
- On the internet
  - http://www.epa.gov/region5/sites/nease/
- Contact me:
  - (312) 886-4699
  - logan.mary@epa.gov

# Questions/Comments

# Thank You

After viewing the links to additional resources, please complete our online feedback form.

**Thank You**

Links to Additional Resources