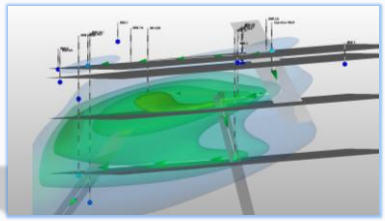
# In Situ Bioremediation Optimization in Fractured Bedrock using 3D Visualization and Analysis



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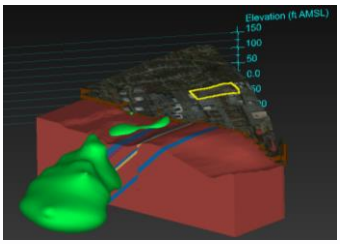
# Presentation Outline

- Project Background
- Geologic/Hydrogeologic Setting
- Contaminant Mass Distribution and Injection Areas
- Tracer Test & 3D Visualization of Dye Migration
- Enhanced Bioremediation Pilot Study
- Evolving Redox Conditions
- Volumetric Contaminant Plumes Over Time
- Future Work



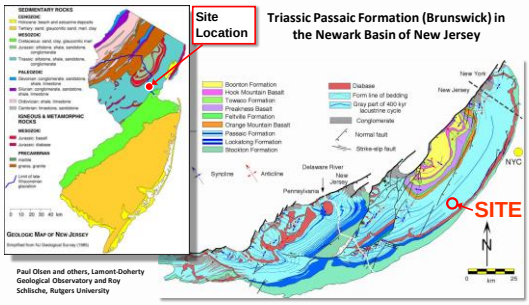
# Project Background




- NJDEP ISRA Compliance
- Former Industrial Site, 1947-2002
- GW Plumes: Chlorinated Volatile Organic Compounds (CVOCs)
- Co-mingled Sources
- 115-acre/5,000 ft Plume Located in a Densely Populated Area
- Plumes in Overburden and Bedrock Aquifers
- Fractured and Faulted Bedrock Aquifer System



# Geologic Setting – Newark Basin






# Summary Geology/Hydrogeology

## Overburden

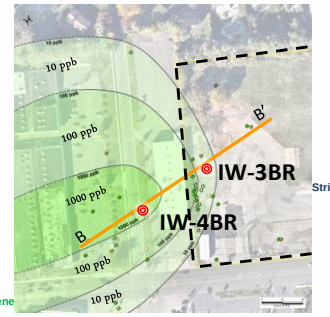
- O – 40 Feet Thick Rahway Glacial Till & Terminal Moraine (Clay, Silt, Sand, Gravel, Cobbles

## Bedrock

- Fractured Interbedded Shales, Siltstones, and Mudstones
- Homoclinal Structure, Strike NE-SW, Dip 7° – 16° NW
- Aquifer Use – Residential Drinking Water, Golf Course Irrigation



# TCE Isoconcentration Map

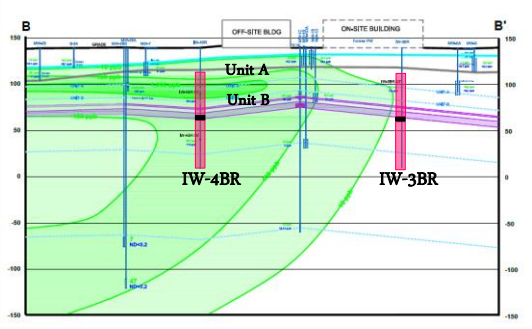



Strike of Bedding

Strike of Tectonic Fractures

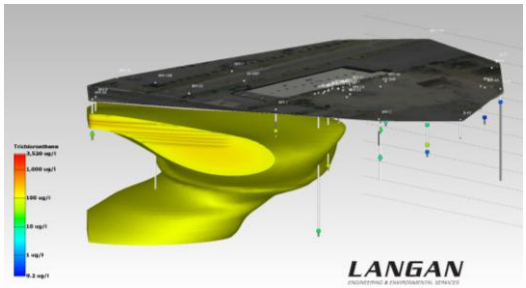
TCE = Trichloroethene

## TCE Isoconcentration Map



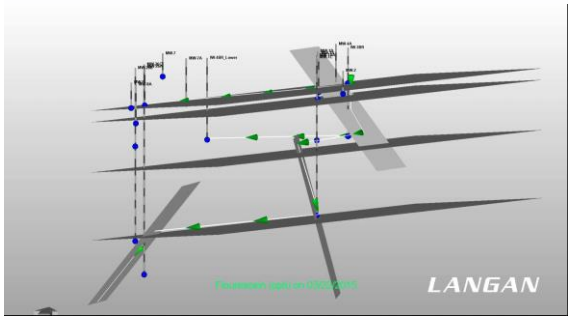



## TCE Plume 100 ppb Along Strike





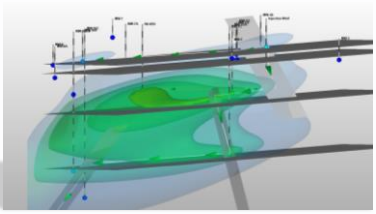

## Fluorescein Injection





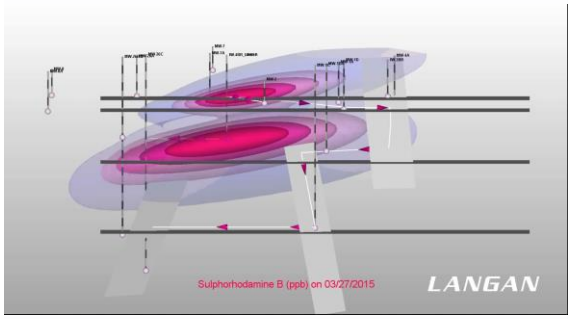

## Fluorescein Results

- Followed Conceptual Flow Paths
- Fast Migration Along A/B Zone (> 9 ft/day)
- Follows Tectonic Fractures Vertically into C and D Zone
- Vertical Groundwater Velocity Up to 2 ft/day (first arrival MW-1C)
- Slower Migration Along C-Zone (approx. 3 ft/day)
- Estimated Groundwater Velocity of Up to 3.8 ft/day in D-Zone
- Similar Distribution to TCE Plume





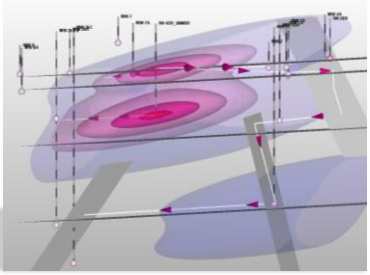
## Sulphorhodamine B Injection





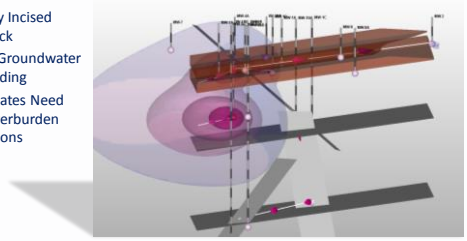

## Sulphorhodamine B Results

- Does Not Follow Conceptual Flow Paths
- "Backward" Migration
- Estimated Groundwater Velocity in A/B Zone of approx. 4 ft/day
- Follows Tectonic Fractures Vertically into C and D Zone
- Possible Up-dip Migration to MW-8A and MW-2



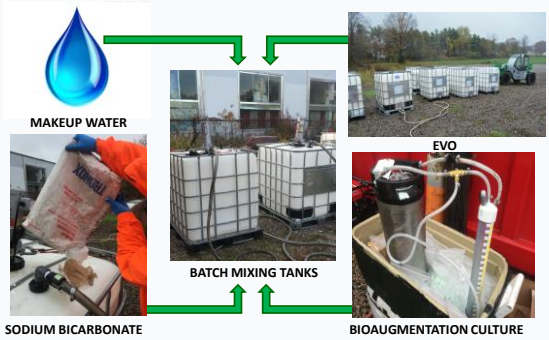
## Sulphorhodamine B Results

- Locally Incised Bedrock
- Local Groundwater Mounding
- Eliminates Need for Overburden Injections



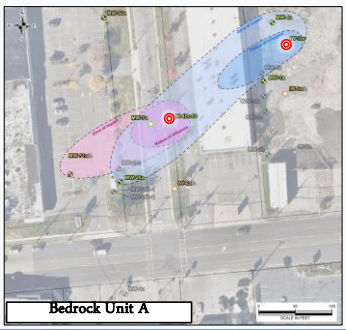


## Bioremediation Pilot Study






## Area Affected by Injections



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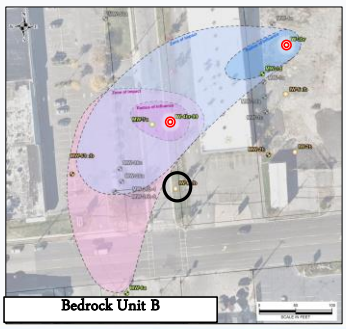
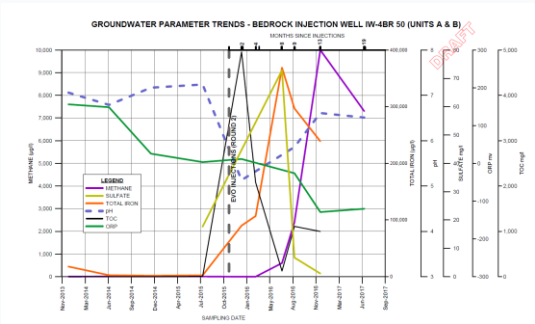


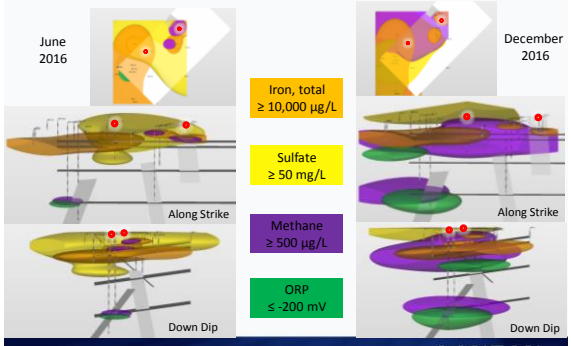



## Bioremediation Progress – IW-4BR 50






## 3D Visualization of Redox Parameters



## Redox Assignment

**Redox Assignment**

| Sample ID | Dissolved $O_2$ | $NO_3^-$ (as Nitrogen) | $Mn^{2+}$ | $Fe^{2+}$ | $SO_4^{2-}$ | Sulfide (sum of $H_2S$, $HS^-$, $S^{2-}$) | $Fe^{2+}$ / Sulfide, ratio | Num of Params | General Redox Category | Redox Process |
|---|---|---|---|---|---|---|---|---|---|---|
| Units | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | | | | |
| Threshold values | 0.5 | 0.5 | 0.05 | 0.1 | 0.5 | none | | | | |
| Clear Redox Assignments | | | | | | | | | | |
| MW-4br-50 | 2.17 | 0.97 | 3.56 | 239 | 1.1 | | | 5 | Mixed(oxic–anoxic) | O2-Fe(II)/SO4 |
| MW-1d | 1.49 | 0.32 | 0.0049 | 0.0392 | 18.6 | | | 5 | Oxic | O2 |
| MW-1da | 1.02 | 0.9 | 0.103 | 0.0392 | 21.6 | | | 5 | Mixed(oxic–anoxic) | O2-Mn(IV) |
| MW-1r | 0.26 | 0.4 | 1.26 | 38 | 16.5 | | | 5 | Anoxic | Fe(III)/SO4 |
| MW-25 | 1.89 | 0.4 | 2.86 | 58.8 | 40.3 | | | 5 | Mixed(oxic–anoxic) | O2-Fe(II)/SO4 |
| MW-26a | 6.95 | 0.15 | 0.698 | 26.1 | 21.1 | | | 5 | Mixed(oxic–anoxic) | O2-Fe(II)/SO4 |
| MW-4a | 0.15 | 2.1 | 0.265 | 3.06 | 9.09 | | | 5 | Mixed(anoxic) | NO3-Fe(II)/SO4 |
| MW-7a | 4.4 | 1 | 6.13 | 339 | 1.15 | | | 5 | Mixed(oxic–anoxic) | O2-Fe(II)/SO4 |
| Assign Redox Categories and Processes | | | | | | | | | | |

**Table 1. Criteria and threshold concentrations for identifying redox processes in ground water.**

[Table was modified from McMahon and Chapelle, 2008. Redox process: O2, oxygen reduction; NO3, nitrate reduction; Mn(IV), manganese reduction; Fe(III), iron reduction; SO4, sulfate reduction; CH4gen, methanogenesis. Chemical species: O2, dissolved oxygen; NO3-, dissolved nitrate; MnO2(s), manganese oxide with manganese in 4+ oxidation state; Fe(OH)3(s), iron hydroxide with iron in 3+ oxidation state; FeOOH(s), iron oxyhydroxide with iron in 3+ oxidation state; SO42-, dissolved sulfate; CO2(g), carbon dioxide gas; CH4(g), methane gas. Abbreviations: mg/L, milligram per liter; –, criteria do not apply because the species concentration is not affected by the redox process; ≤, less than or equal to; <, less than; >, greater than]

| Redox category | Redox process | Electron acceptor (reduction) half-reaction | Criteria for inferring process from water-quality data: Dissolved oxygen (mg/L) | Nitrate, as Nitrogen (mg/L) | Manganese (mg/L) | Iron (mg/L) | Sulfate (mg/L) | Iron/sulfide (mass ratio) |
|---|---|---|---|---|---|---|---|---|
| Oxic | O2 | $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ | ≥0.5 | — | <0.05 | <0.1 | — | |
| Suboxic | Suboxic | Low O2; additional data needed to define redox process | <0.5 | <0.5 | <0.05 | <0.1 | — | |
| Anoxic | NO3 | $2NO_3^- + 12H^+ + 10e^- \rightarrow N_{2(g)} + 6H_2O$; $NO_3^- + 10H^+ + 8e^- \rightarrow NH_4^+ + 3H_2O$ | <0.5 | ≤0.5 | <0.05 | <0.1 | — | |
| Anoxic | Mn(IV) | $MnO_{2(s)} + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$ | <0.5 | <0.5 | ≥0.05 | <0.1 | — | |
| Anoxic | Fe(III)/SO4 | Fe(III) and (or) $SO_4^{2-}$ reactions as described in individual element half reactions | <0.5 | <0.5 | — | ≥0.1 | ≥0.5 | no data |
| Anoxic | Fe(III) | $FeOOH_{(s)} + H^+ + e^- \rightarrow Fe^{2+} + H_2O$; $FeOOH_{(s)} + 3H^+ + e^- \rightarrow Fe^{2+} + 2H_2O$ | <0.5 | <0.5 | — | ≥0.1 | ≥0.5 | >10 |
| Mixed(anoxic) | Fe(III)-SO4 | Fe(III) and $SO_4^{2-}$ reactions as described in individual element half reactions | <0.5 | <0.5 | — | ≥0.1 | ≥0.5 | ≥0.3, ≤10 |
| Anoxic | SO4 | $SO_4^{2-} + 9H^+ + 8e^- \rightarrow HS^- + 4H_2O$ | <0.5 | <0.5 | — | ≥0.1 | ≥0.5 | <0.3 |
| Anoxic | CH4gen | $CO_{2(g)} + 8H^+ + 8e^- \rightarrow CH_{4(g)} + 2H_2O$ | <0.5 | <0.5 | — | ≥0.1 | <0.5 | |

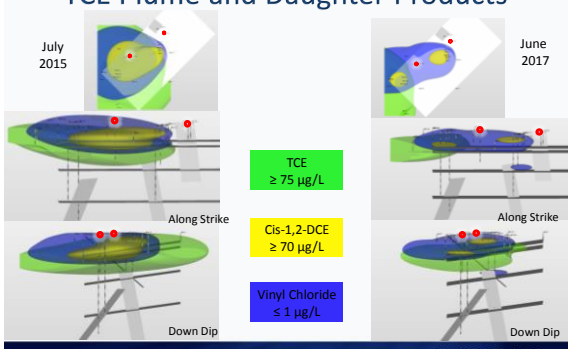
**An Excel Workbook for Identifying Redox Processes in Ground Water**

by Bryant C. Jurgens, Peter B. McMahon, Francis H. Chapelle, and Sandra M. Eberts

U.S. Geological Survey Open-File Report 2009-1004.



## TCE Plume and Daughter Products






## Future Work

- Continue to monitor and visualize evolving redox conditions
- Visualize contaminant volumes and estimate mass reduction
- Refine CSM with additional downhole geophysical data and incorporate into 3D model
- Full-scale enhanced bioremediation