C-041, in K.A. Fields and G.B. Wickramanayake (Chairs), *Remediation of Chlorinated and Recalcitrant Compounds—2010.* Seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2010). ISBN 978-0-9819730-2-9, Battelle Memorial Institute, Columbus, OH, **www.battelle.org/chlorcon**.

Green Remediation via an Enhanced In Situ Bioremediation Solar-Powered System

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Geosyntec Consultants identified and delineated a dissolved phase trichloroethene (TCE) plume during a RCRA Facility Investigation at a site located at the Kennedy Space Center in east central Florida. The corrective measures strategy implemented included: (i) enhanced bioremediation using biostimulation and bioaugmentation with aquifer buffering, and (ii) groundwater recirculation using a solar powered extraction system to mitigate the potential discharge of impacted groundwater to an adjoining surface water body and provide enhanced mixing within the dissolved plume.

The project initially relied on the injection of potassium lactate, sodium bicarbonate, and microbial culture into a network of injection wells. Following implementation, optimization of the system was performed that included modifying the electron donor and aquifer neutralization agent to EOS® and EOS® AquaBupH™, respectively, to eliminate the need for multiple injections. Additionally, the locations of the recirculation injection wells were modified to enhance electron donor distribution. An evaluation of groundwater performance monitoring data has revealed a significant and ongoing mass reduction of both TCE and its breakdown products, with a corresponding order of magnitude increase in *Dehalococcoides* and ethene concentrations. These reductions have resulted in TCE and cis-1,2-dichloroethene concentrations below their cleanup target levels in multiple performance monitoring wells.

The Corrective Measures Study for this site was prepared in 2004, with considerations given to the benefits to a "green" strategy, though the various tools to assist in implementing green remedial strategies were not formalized. Following implementation and the increased emphasis on utilizing green remedial approaches, the site was evaluated against the six EPA Core Elements of Green Remediation. Based upon the results of the evaluation, the corrective measures and associated system optimization strategy is effectively meeting the EPA Core Elements of Green Remediation. In addition, the CO_2 footprint for the implemented corrective measures was compared to other technologies evaluated in the Corrective Measures Study (pump and treat, air sparging, and multiphase extraction). The comparison revealed that the footprint for implementation and operation of the enhanced bioremediation strategy was notably smaller than the other technologies evaluated. These results suggest that the remedial strategy implemented at the site is a green remedial strategy, which is meeting corrective action objectives with a smaller carbon footprint relative to traditional remedial technologies.

Green Remediation via an Enhanced in situ Solar-Powered Bioremediation System

Rebecca C. Daprato, PhD, PE

The Seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds

May 2010

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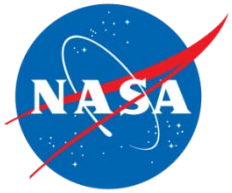


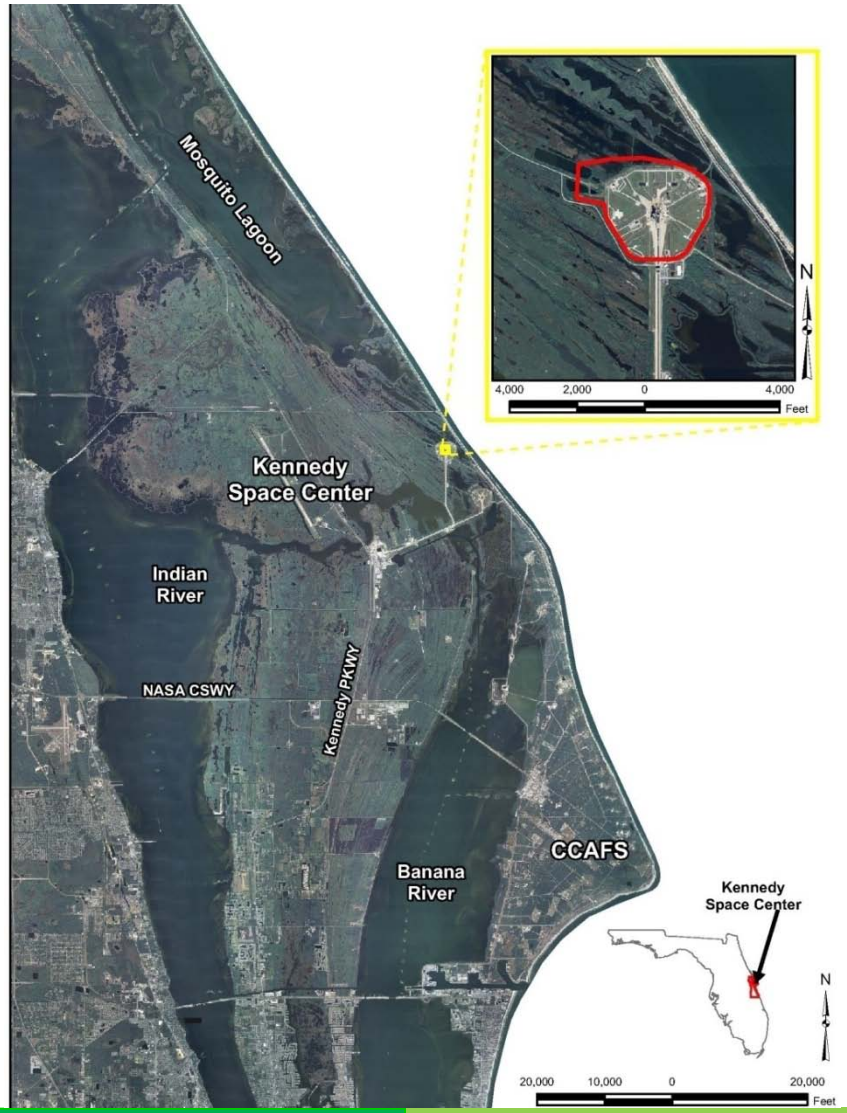
Presentation Outline

- Site history and background
- System design and implementation
- System optimization/results
- EPA Core Elements of Green Remediation
- Conclusions

Green Remediation: *The practice of considering all environmental effects of remedy implementation and incorporating options to maximize net environmental benefit of cleanup actions.*

Site Background and History

- LC39B is a 170 acre launch pad facility
- Constructed in 1960's for Apollo/Saturn V rocket and retrofitted for shuttle
- Pad is surrounded by wetland areas and Merritt Island National Wildlife Refuge



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Site Background and History

- RFI completed in 2003 identified TCE, cDCE, and vinyl chloride (VC) in groundwater above MCLs
- Corrective Measures Study completed in 2004
- Corrective Measures Design completed in 2005
- Due to location, remedial approach required:
  - *Mobility*
  - *Self-contained power source*
  - *Mitigation of potential plume discharge to surface water*

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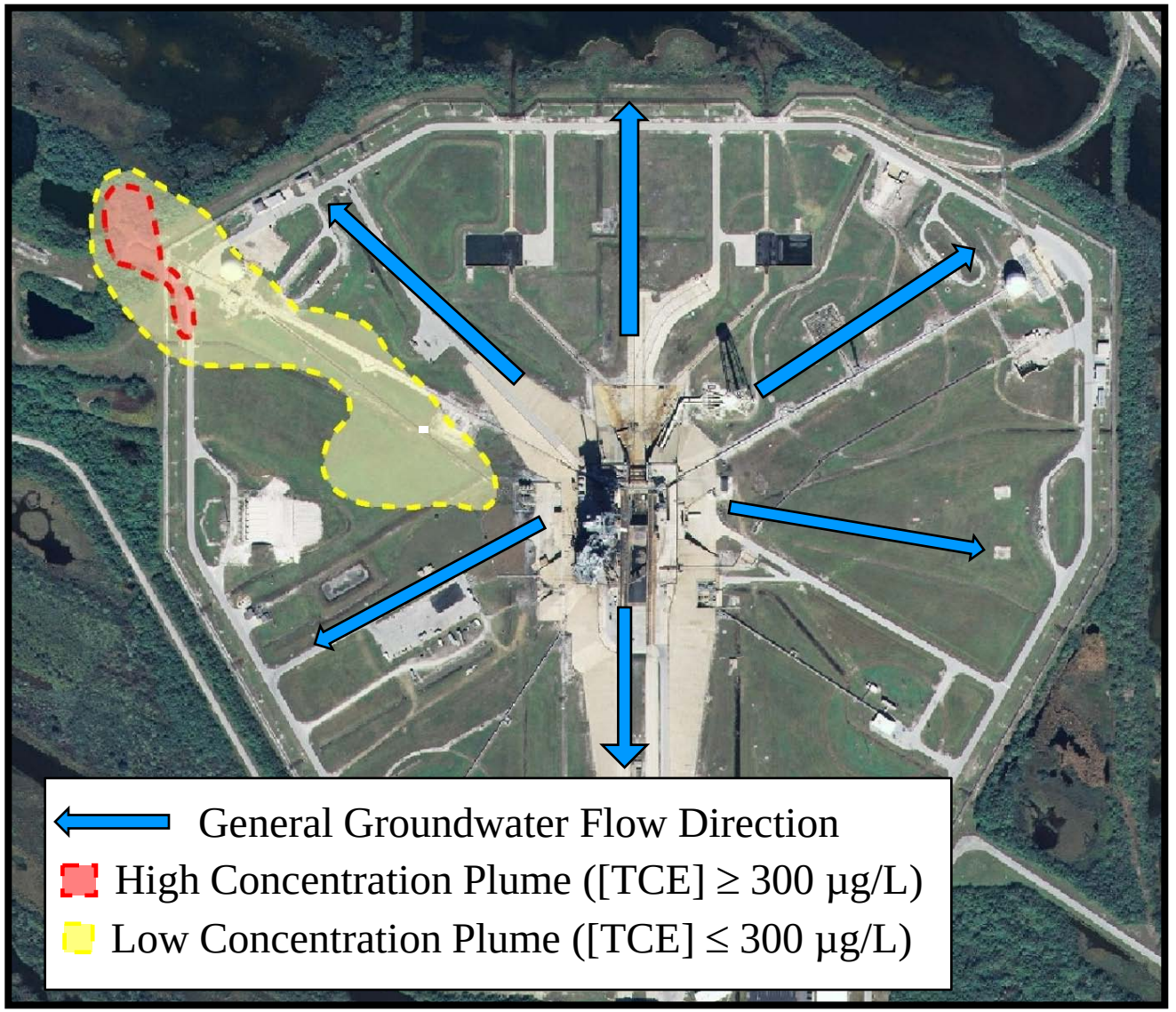
LC39B Groundwater Plumes



Site History and Background
Implementation
Results and Optimization
2010 Results

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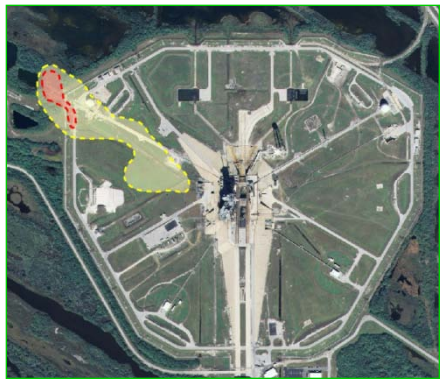
Remedy Selection

- Bioremediation selected for 1.2 acre high concentration plume (HCP)
  - *Biostimulation and bioaugmentation*
  - *Aquifer buffering*
  - *Recirculation*



- Monitored natural attenuation (MNA) selected for low concentration plume (LCP)
  - *Plume area within pad perimeter fence*

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LOX Area

- Site History and Background
- Implementation
- Results and Optimization
- 2010 Results

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Implementation

- Initial 2005 implementation based upon laboratory treatability testing:
  - *Electron donor: potassium lactate*
  - *Aquifer buffering: sodium bicarbonate*
  - *Microbial Culture: KB-1®*
- Implementation:
  - *107 injection wells*
  - *23,000 gallons of 3.5% potassium lactate solution*
  - *3,160 pounds of sodium bicarbonate*
  - *490 liters of KB-1®*
  - *Two extraction wells powered by mobile solar system*
  - *Two injection wells for recirculation system*

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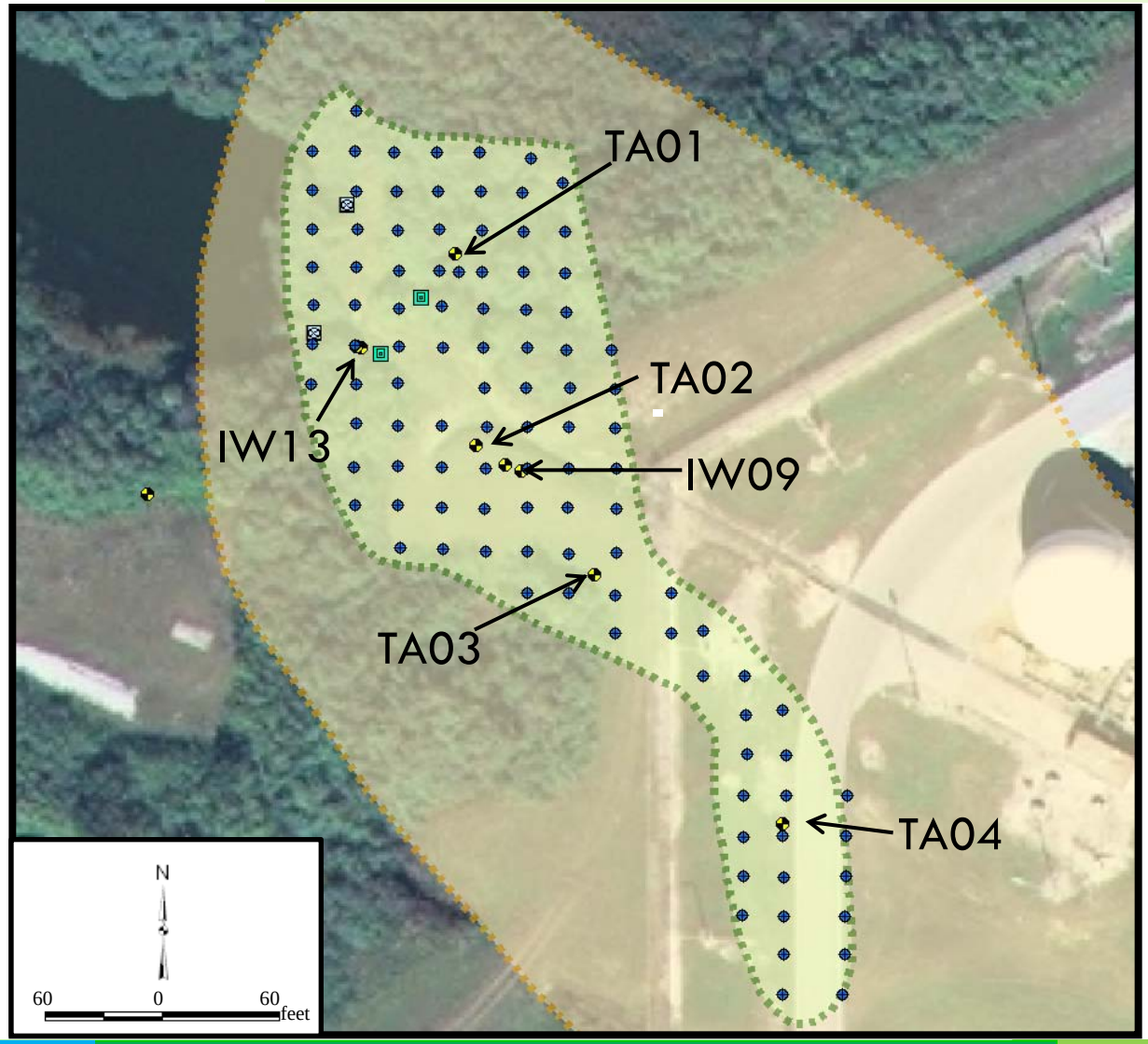
Implementation



Legend

- Injection Well
- Monitoring Well
- Extraction Well
- Injection Well (recirculation system)
- HCP
- LCP

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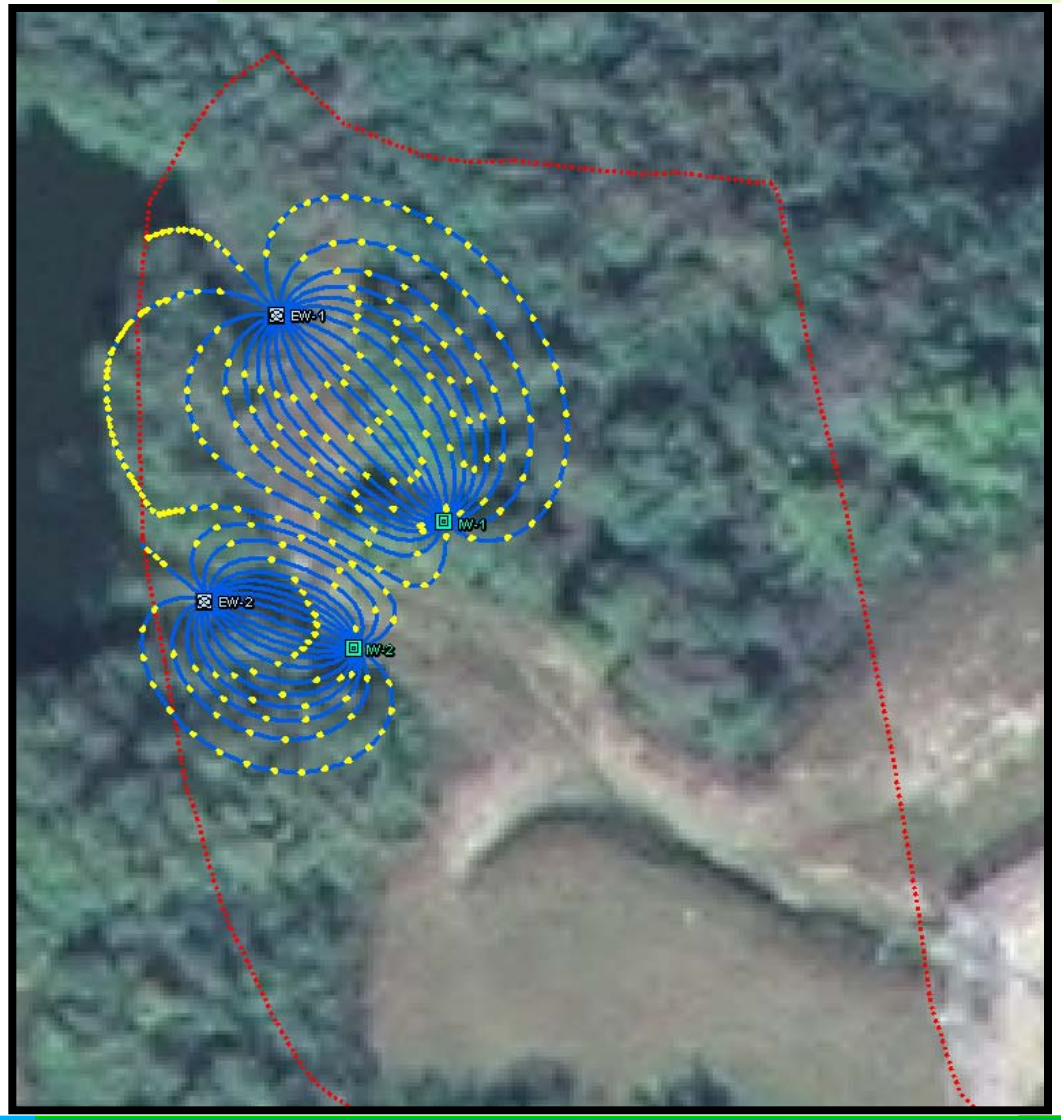
Recirculation System Layout



Legend

- Flow Path
- Extraction Well
- Injection Well
- HCP

Site History and Background

Implementation

Results and Optimization

2010 Results

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Solar System

- Solar system design considerations:
  - Continuous operation and low maintenance
  - Reserve power in batteries for 2 cloudy days (0 sun hours)
  - Sun hours = 4.5 hrs/day (annual average)
  - Mobile
- Components:
  - Four, Sharp 123 Watt, 17.2V, 7.16 amp photovoltaic modules
  - Charge controller (prevents battery overcharging)
  - Batteries: two, 12V, 265 Amp-hrs each
  - Hour meter
  - Two, 12V centrifugal pumps
  - Flow meters
  - Enclosed trailer

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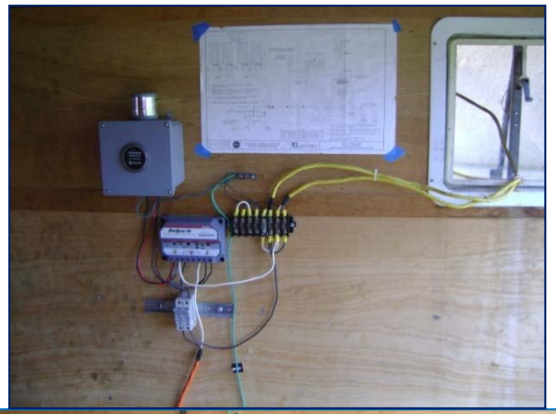
Solar System and Trailer

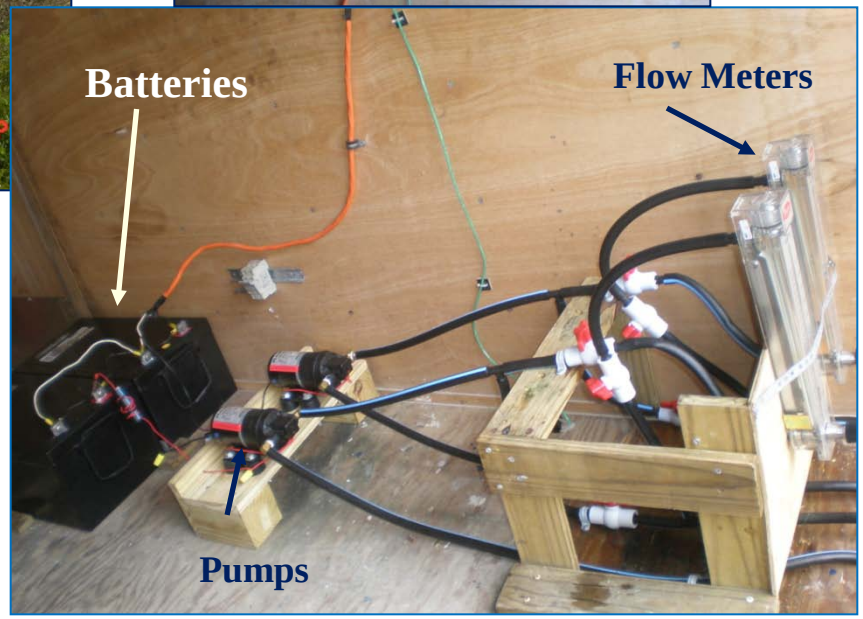
Site History and Background

Implementation

Results and Optimization

2010 Results





- Solar system operates at ~2 - 4 gpm (24/7)
- Typically recirculating ~30,000 gallons per week

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Optimization

- After ~2 years of operation re-evaluated site conditions
  - *Gain a better understanding of site conditions*
  - *Data to aid in optimization*
- Performed "snap shot" sampling
  - *CVOC distribution*
  - *pH distribution*
- Represents a Best Management Plan (BMP)

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Optimization Strategy

- Changed electron donor to EOS®
  - *Slow release electron donor*
  - *Injected 54 drums of EOS®*
    - Tailored injection based upon analytical results
- Changed buffering agent to EOS® AquaBupH™
  - *Injected 17 drums of EOS® AquaBupH™*
    - Tailored injection with higher volumes in areas with pH ≤ 6.3

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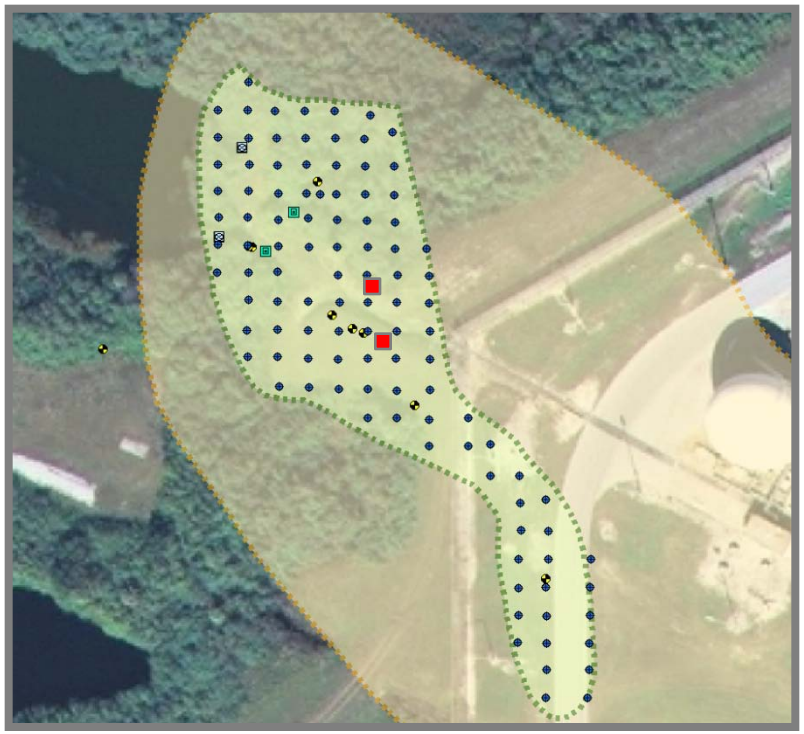
Additional Optimization

- After ~ 1 year of operation with new electron donor and buffering agent
  - *CVOC reduction in one site monitoring well lagging*
  - *Installed two additional recirculation injection wells*



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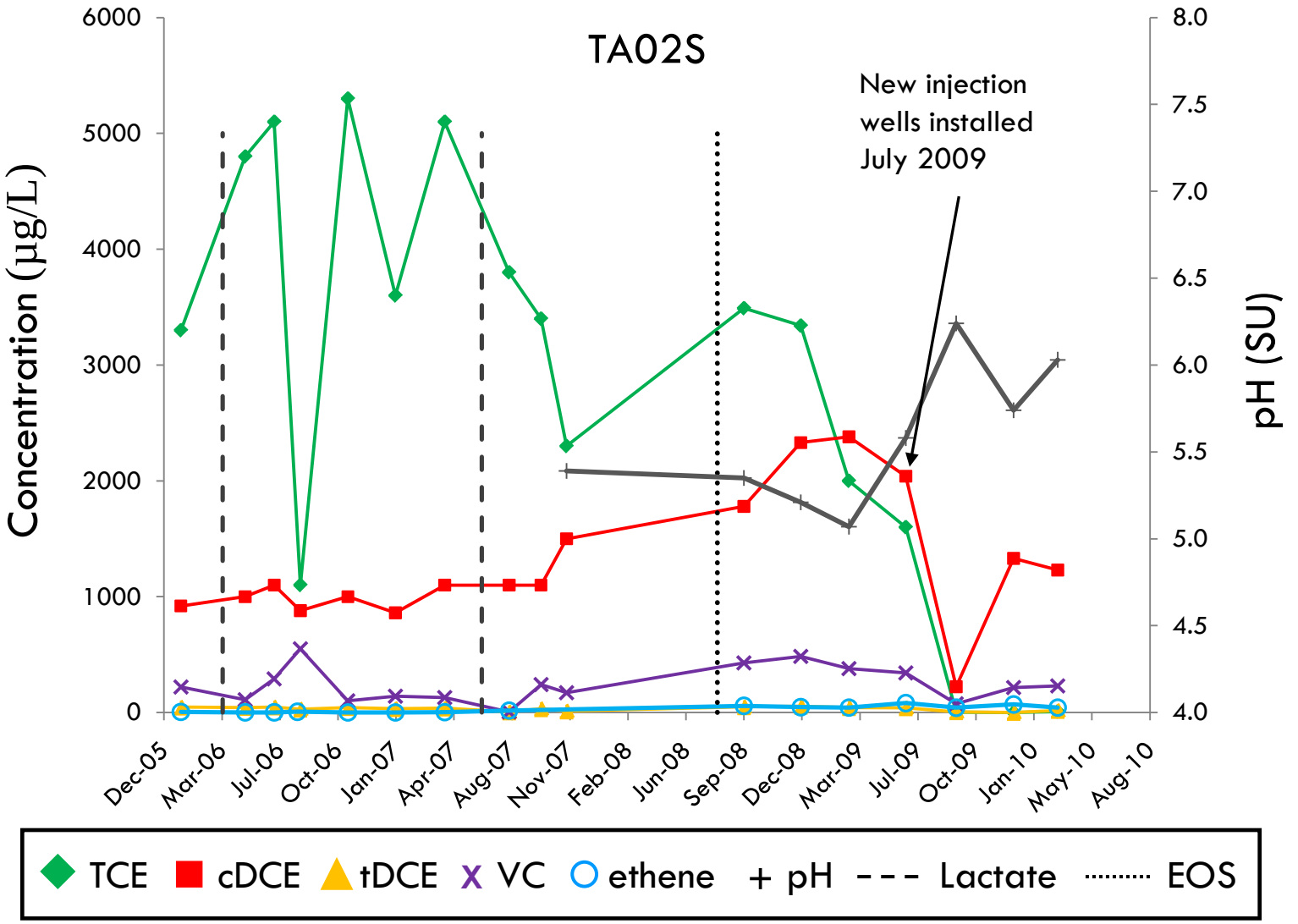
Groundwater Sampling Results
TCE Mass Removal

Site History and Background

Implementation

Results and Optimization

2010 Results



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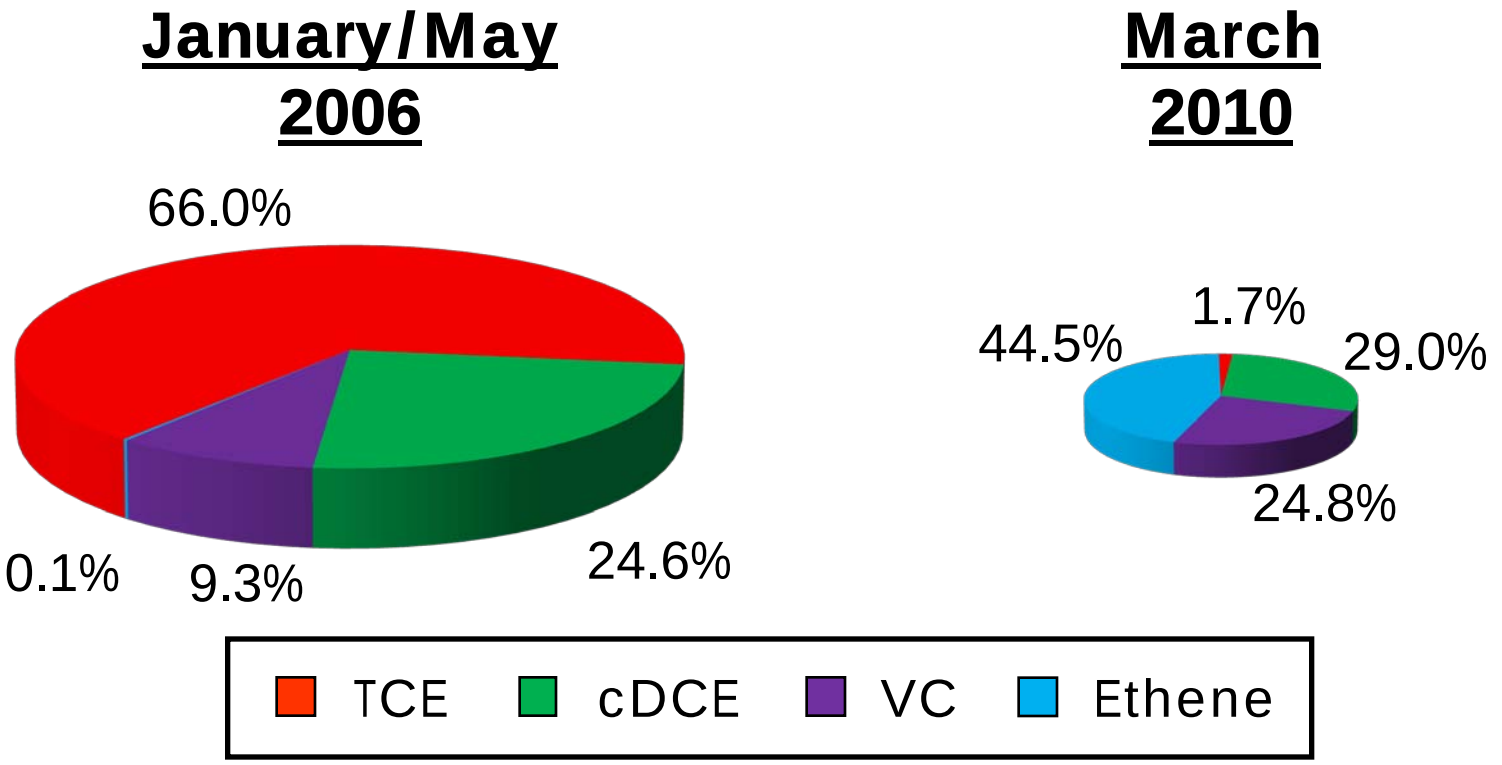
Groundwater Sampling Results
TCE Mass Removal

	January-May 2006	March 2010	
Well ID	TCE (µg/L)	TCE (µg/L)	% TCE Reduction
TA01S	6,400	81.9	98.7
TA02S	4,800	7.7	99.8
TA03S	120	36.0	70.0
TA04S	15	1.7	88.7
TA09S	470	0.1	99.9
TA13S	2,900	18.0	99.4
TA13I	2,200	2.2	99.9

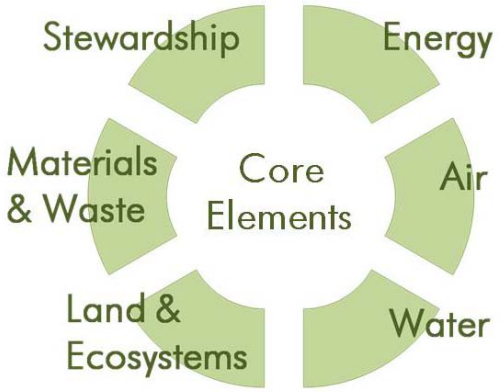
Groundwater Sampling Results
Mass Removal

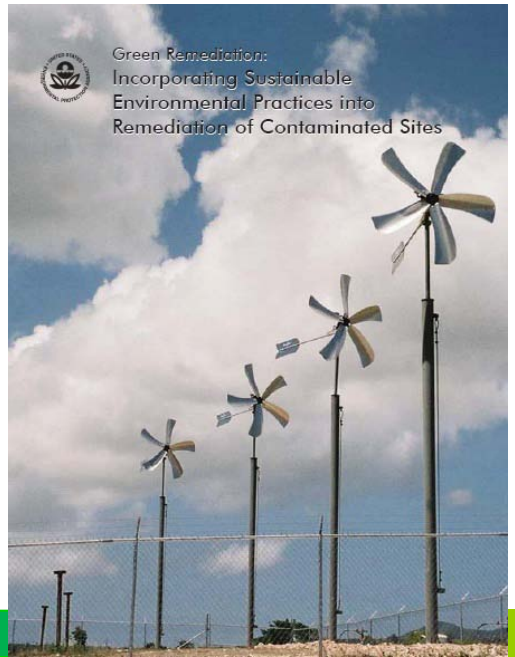


- 82% CVOC mass reduction since 2006
- *Dhc* increase from $<10^4$ to $>10^8$ gene copies/L

Remedy Approach Compared to Core Elements of Green Remediation

- Energy
  - *Solar system*
  - *No demand for external power*
- Air
  - *In situ remediation minimizes emissions*
  - *Minimal construction equipment/dust*
- Water
  - *Extracted groundwater recirculated*
  - *Mitigates potential plume discharge to surface waters*





Remedy Approach Compared to Core Elements of Green Remediation

- Land & Ecosystem
  - *Minimal habitat disturbance (minimal equipment), soil erosion, etc.*
  - *No damage to habitat*
- Materials & Waste
  - *Mobile solar system can be reused at other sites*
  - *DPT drilling (minimal waste)*
  - *Minimal investigation derived waste*
- Stewardship
  - *Passive remedy*
  - *System optimized to enhance performance*

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Are We Green? Technologies Evaluated/CO_2 Footprint

Bioremediation	Pump & Treat (10 hp)	Air Sparge (15 hp)	Multi-Phase Extraction (25 hp)
CO_2 Equivalents [Metric Tons/Year]			
5 to 15	40	30 to 60	50 to 100

Notes:

- Electricity Emission Factors Source: U.S. EPA eGRID2006 Version 2.1 – Sub-region FRCC (Florida)
- Bioremediation: Based upon ranges of CH_4, biomass, and CO_2 production. Does not include potential CO_2 tied up in carbonate cycle
- Pump and Treat included 3 recovery wells
- Air Sparge (45 air sparge wells) & Multi-Phase Extraction (15 extraction wells): Range represents 50 to 100% operational cycle

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Conclusion

- Pumping using solar powered system is meeting project objectives:
  - *Solar panels provide adequate power*
  - *Quick installation/mobilization and demobilization*
  - *Reusable system/components*
- Operational CO_2 footprint less than traditional air sparge, P&T, or MPE systems
- Optimization of system (ongoing process) has had a positive impact on site cleanup
- Good positive publicity!

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QUESTIONS?

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