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Sustainable Remediation via Solar-Powered In Situ Bioremediation

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ENVIRONMENT, ENERGY & SUSTAINABILITY SYMPOSIUM & EXHIBITION

Presentation Outline

- Site history and background
- System design and implementation
- System optimization
- Results and conclusion

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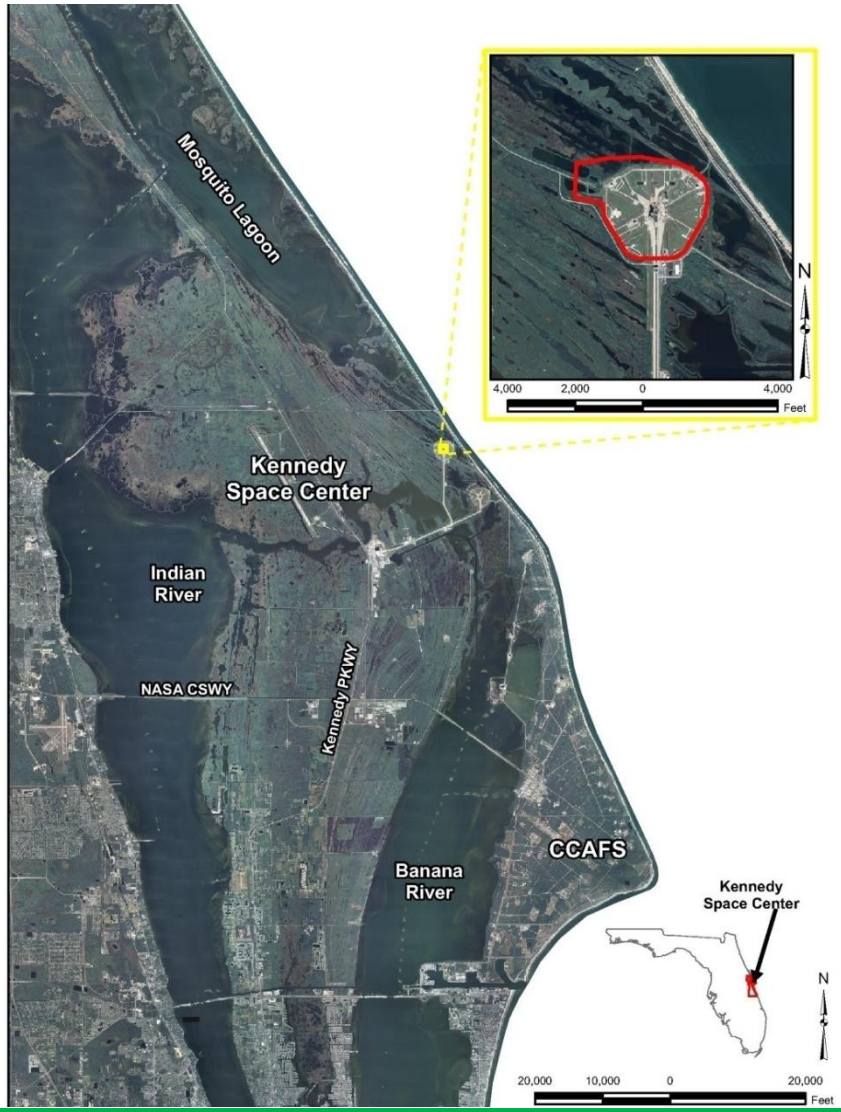
Site Background and History

- LC39B is a 170 acre active launch pad facility – Shuttle Launch Pad
- Constructed in 1960's for Apollo/Saturn V rocket and retrofitted for shuttle in 1970's
- Pad is surrounded by wetland areas and Merritt Island National Wildlife Refuge



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Site Background and History

- RCRA Facility Investigation completed in 2003 identified trichloroethene (TCE), cis-1,2-dischloroethene (cDCE), and vinyl chloride (VC) in groundwater at concentrations above maximum contaminant levels
- Corrective Measures Study completed in 2004 and Corrective Measure Design completed in 2005
- Due to location, remedial approach required:
  - *Mobility for any above-ground treatment systems*
  - *Preference for self-contained power source*
  - *Active treatment of plume outside pad perimeter fence and actions to mitigate potential plume discharge to surface water*

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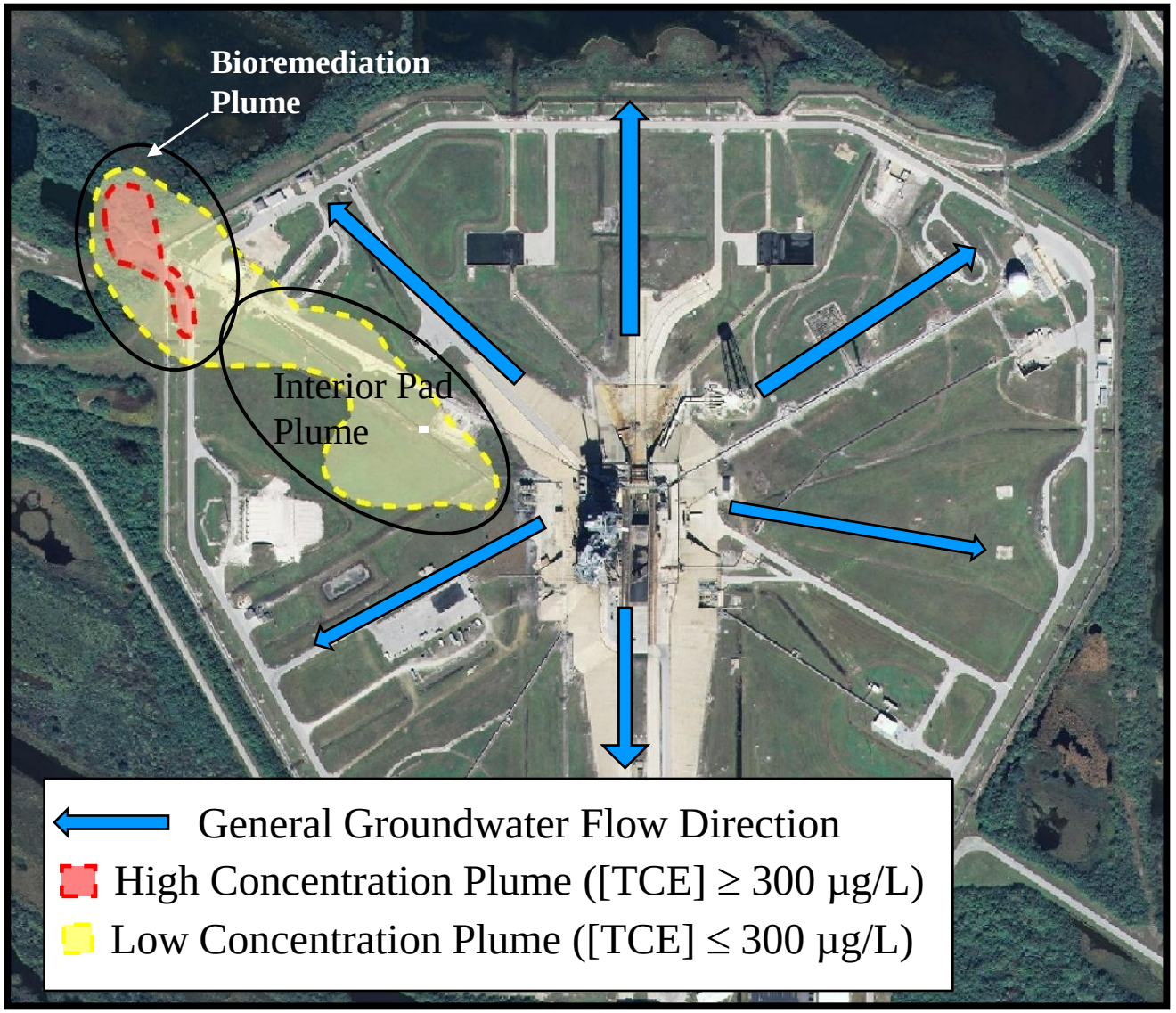
Site History and Background

Implementation

Results and Optimization

2009 Results

LC39B Groundwater Plumes



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Remedy Selection

- Bioremediation selected for high concentration plume (HCP)
  - *Biostimulation and bioaugmentation*
  - *Aquifer buffering*
  - *Recirculation*
    - Provide control of plume discharge
    - Enhance mixing/distribution of electron donor
- Monitored natural attenuation (MNA) selected for low concentration plume (LCP)
  - *Plume area within pad perimeter fence*

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LOX Area

LOX Discharge Pipes

Remedy Approach Compared to Core Elements of Green Remediation

- Energy
  - *Solar system*
  - *No demand for external power*
- Air
  - *In situ remediation minimizes emissions*
- Water
  - *Extracted groundwater recycled to enhance bioremediation*
  - *Mitigates potential plume discharge to surface waters*
- Land & Ecosystem
  - *Minimal habitat disturbance (minimal equipment)*
  - *No damage to mangroves*
- Materials & Waste
  - *Mobile solar system can be reused at other sites*
  - *DPT drilling (minimal waste)*
  - *Minimal investigation derived waste*
- Stewardship
  - *Passive remedy*

https://www.clu-in.org/greenremediation/subtab_b1.cfm

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Implementation

- Initial 2005 remedy implementation was based upon laboratory treatability testing:
  - *Electron donor: potassium lactate*
  - *Aquifer buffering: sodium bicarbonate*
  - *Microbial Culture: KB-1®*
- Implementation consisted of the following:
  - 107 injection wells
  - 23,135 gallons of 3.5% potassium lactate solution (~216 gallons per injection well)
  - 3,160 pounds of sodium bicarbonate (~15 gallons per injection well)
  - 490 liters of KB-1® (~4.5 liters per injection well)
  - Two extraction and two injection wells for recirculation and mixing powered via solar system

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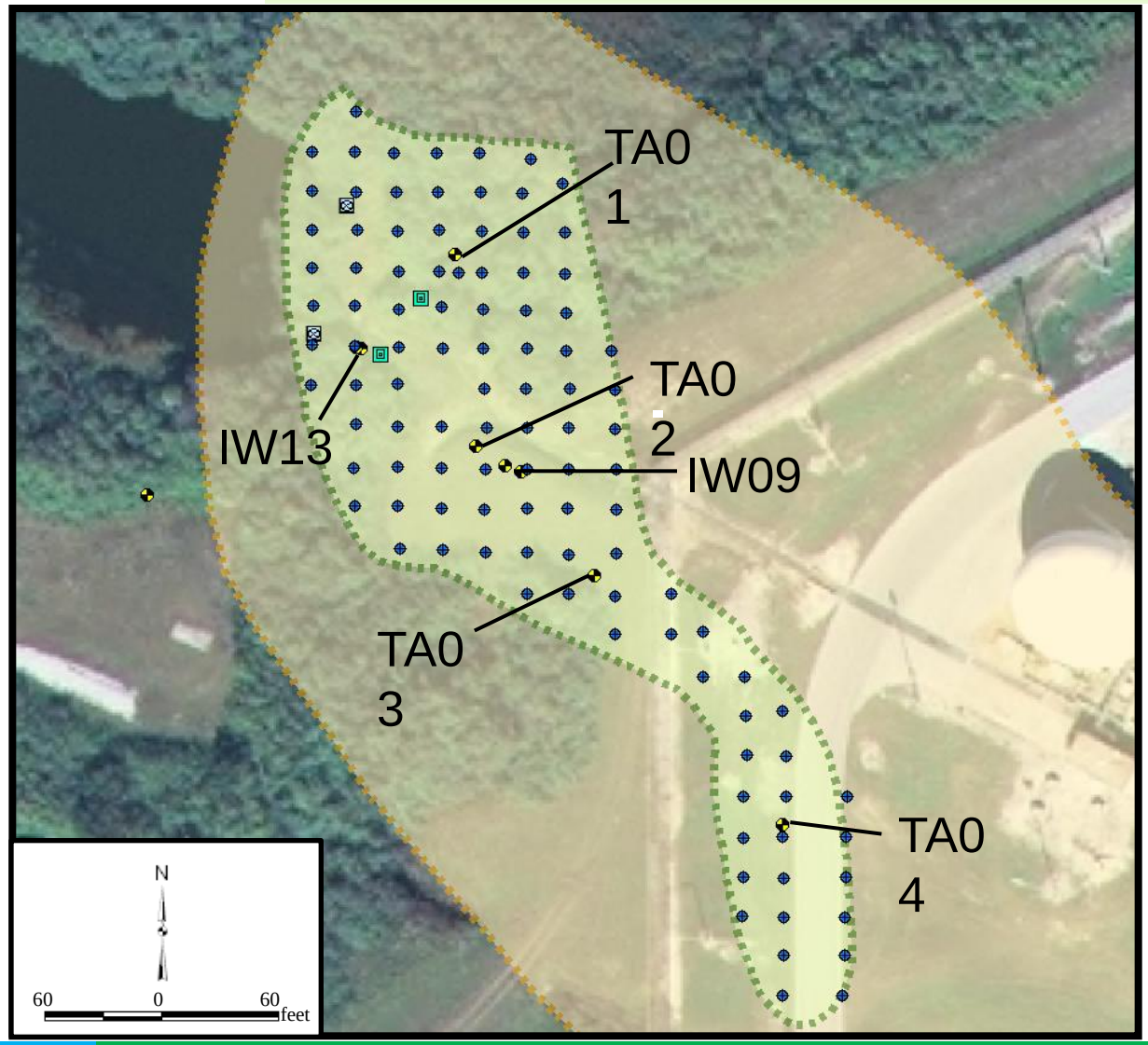
Implementation



Legend

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

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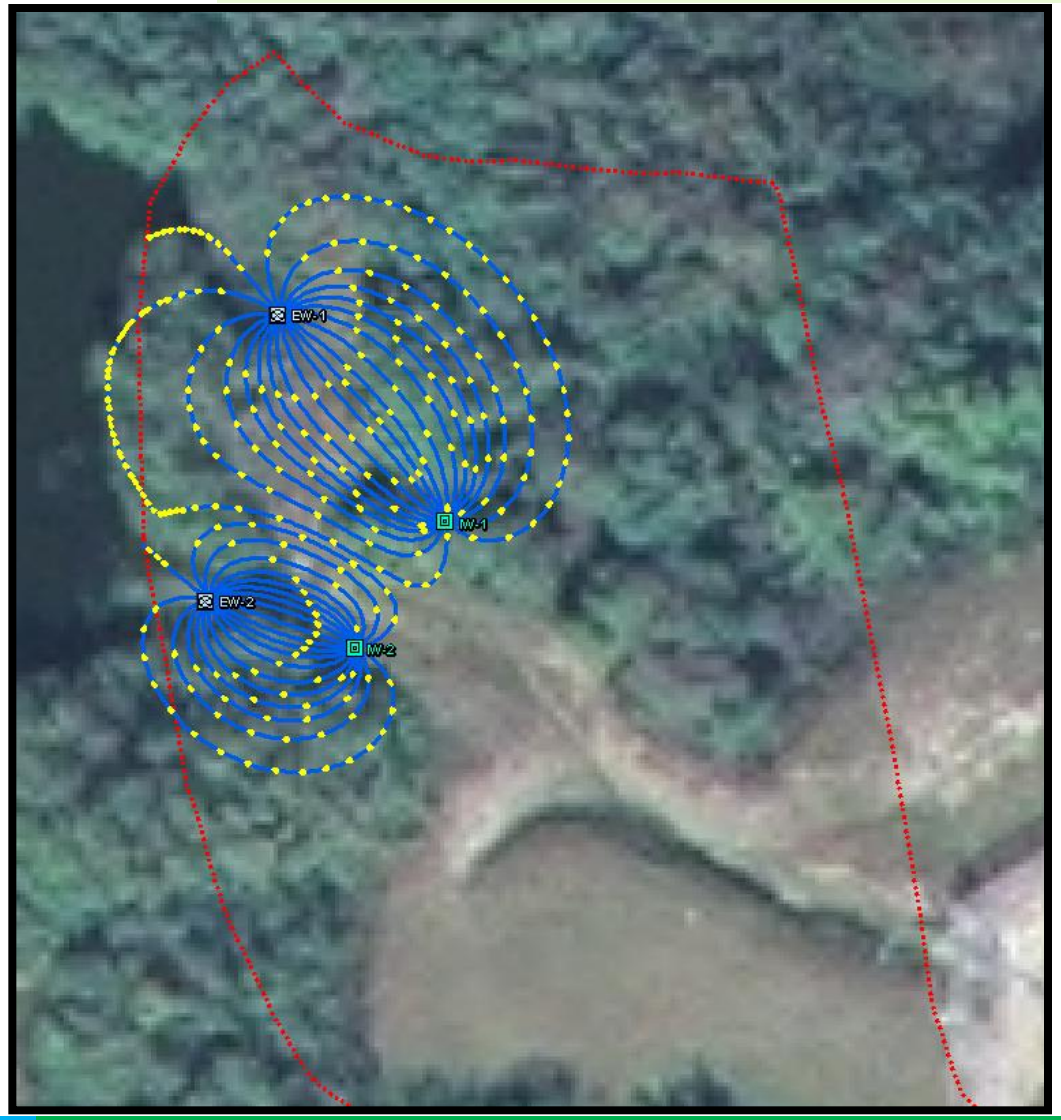
Recirculation System Layout



Legend

- Flow Path
- Extraction Well
- Injection Well
- HC
- P

Site History and Background

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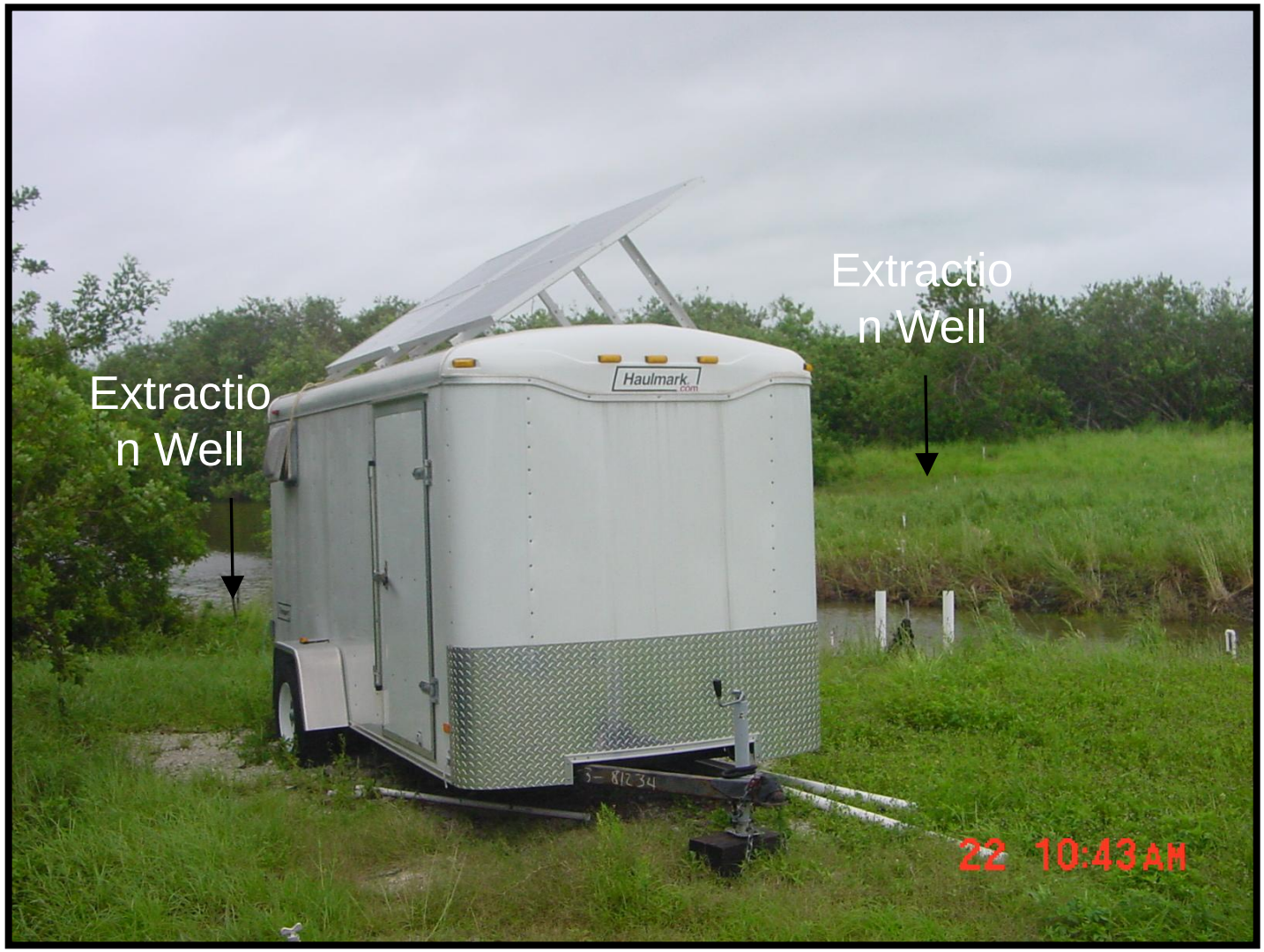
Solar System Layout



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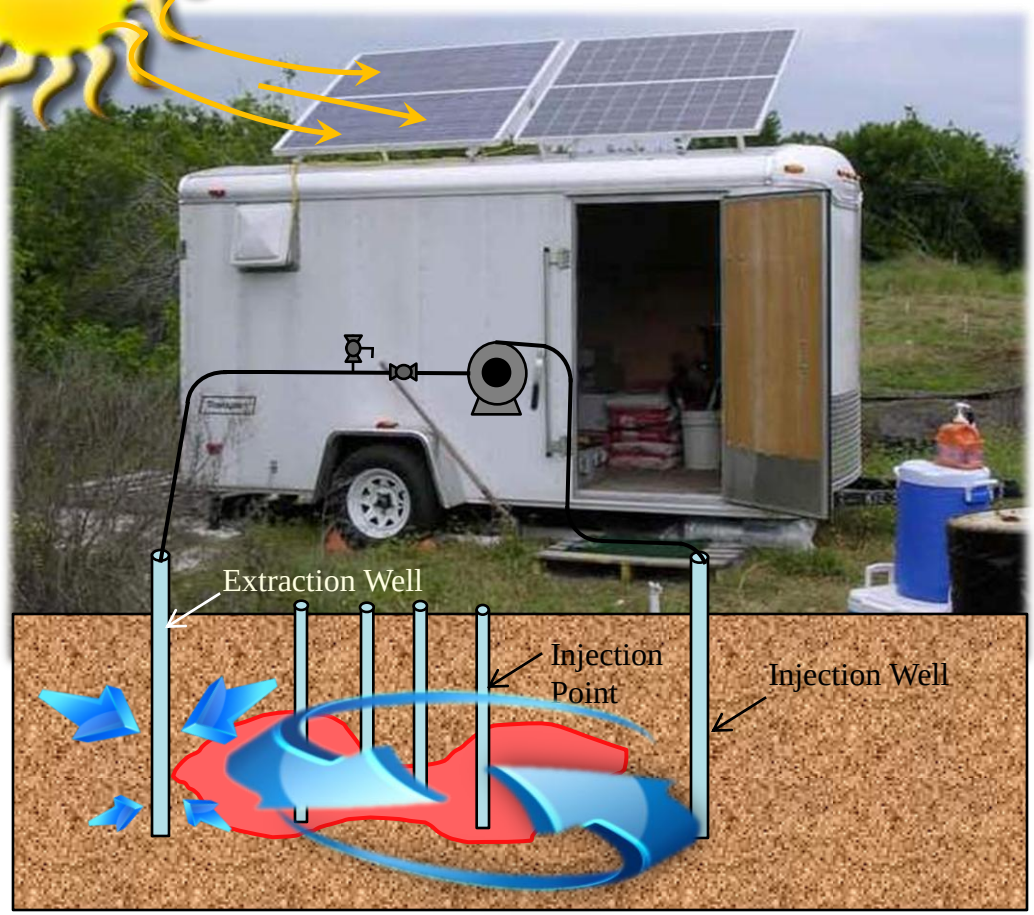
Solar System



- Solar system operates at ~1gpm (24/7)

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Solar System

- Solar system design considerations:
  - Continuous operation and low maintenance
  - Adequate reserve power in batteries to maintain pumping through 2 cloudy days (0 sun hours)
  - Sun hours = 4.5 hrs/day (annual average)
  - Portable: All components to be removed prior to shuttle launch, LOX area testing or tropical storms/hurricanes
  - Pumps capable of 0.5 to 1 gpm each
- 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
  - Enclosed trailer
  - Two, 12V centrifugal pumps

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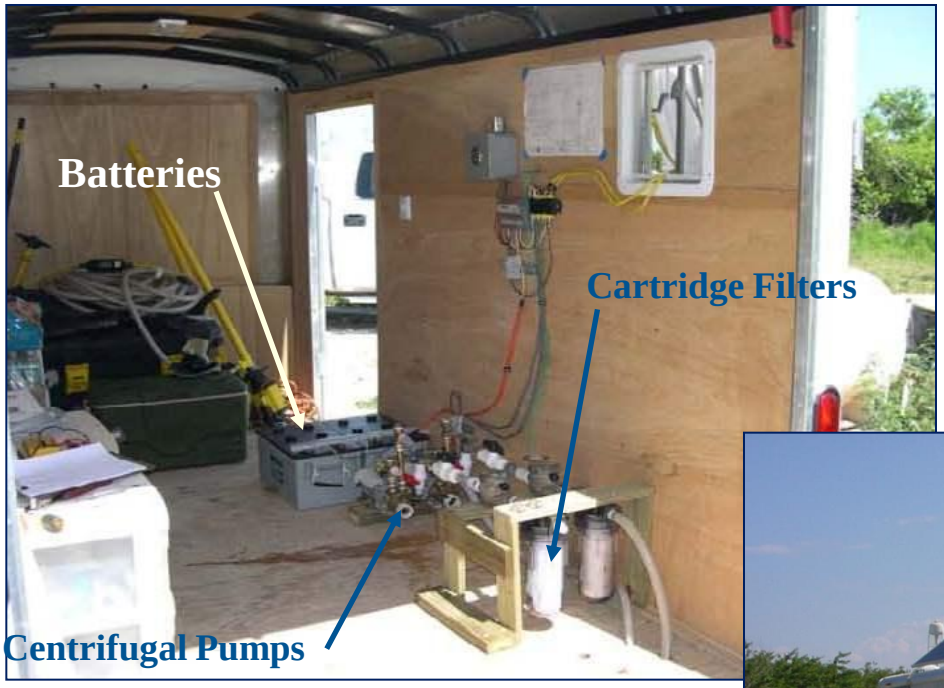
Solar System and Trailer



- Solar system operates at ~1gpm (24/7)

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Results and 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

Groundwater Sampling Results - TCE
Comparison of 2004 to 2007

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Site History and Background

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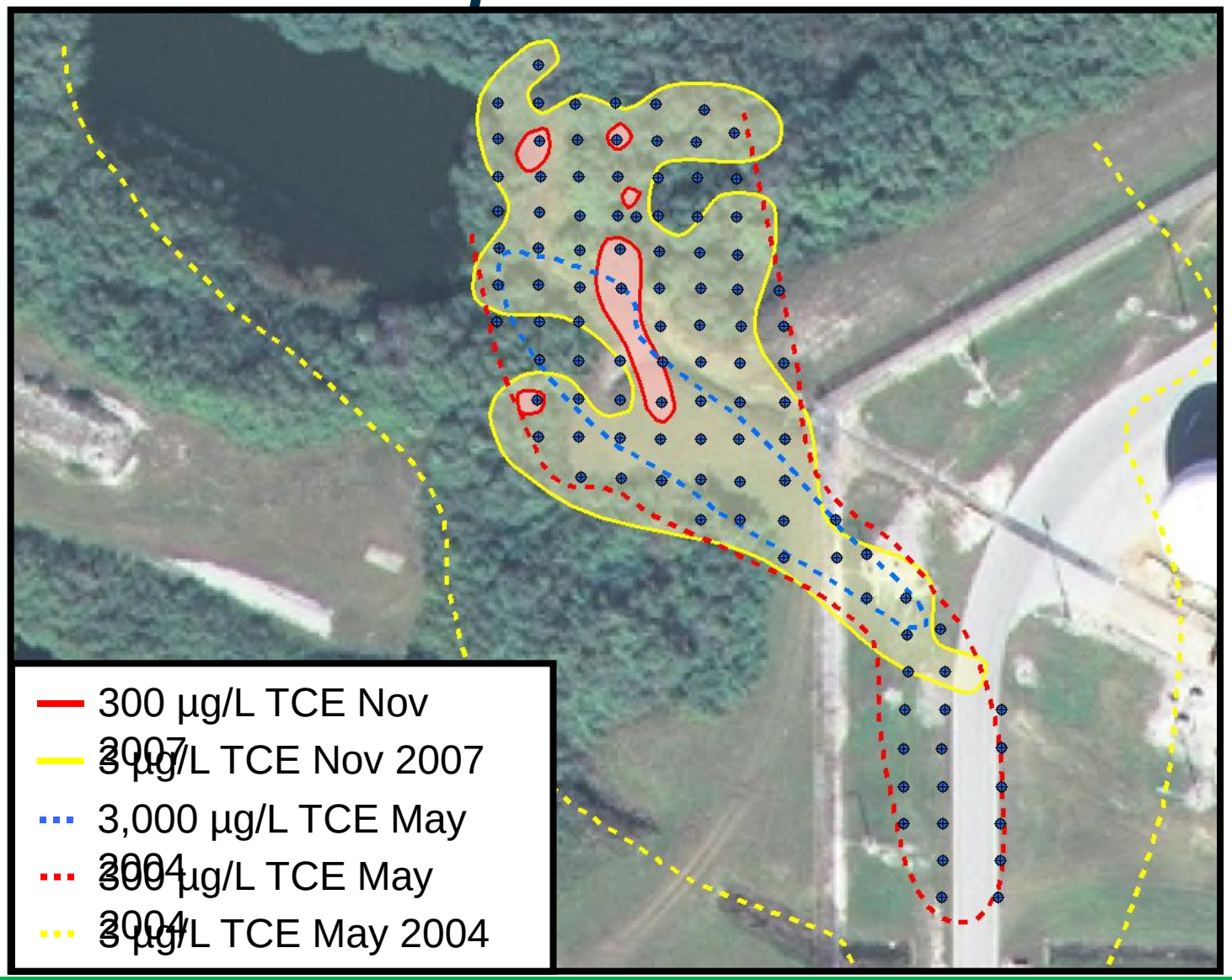
2009 Results



Groundwater Sampling Results - pH

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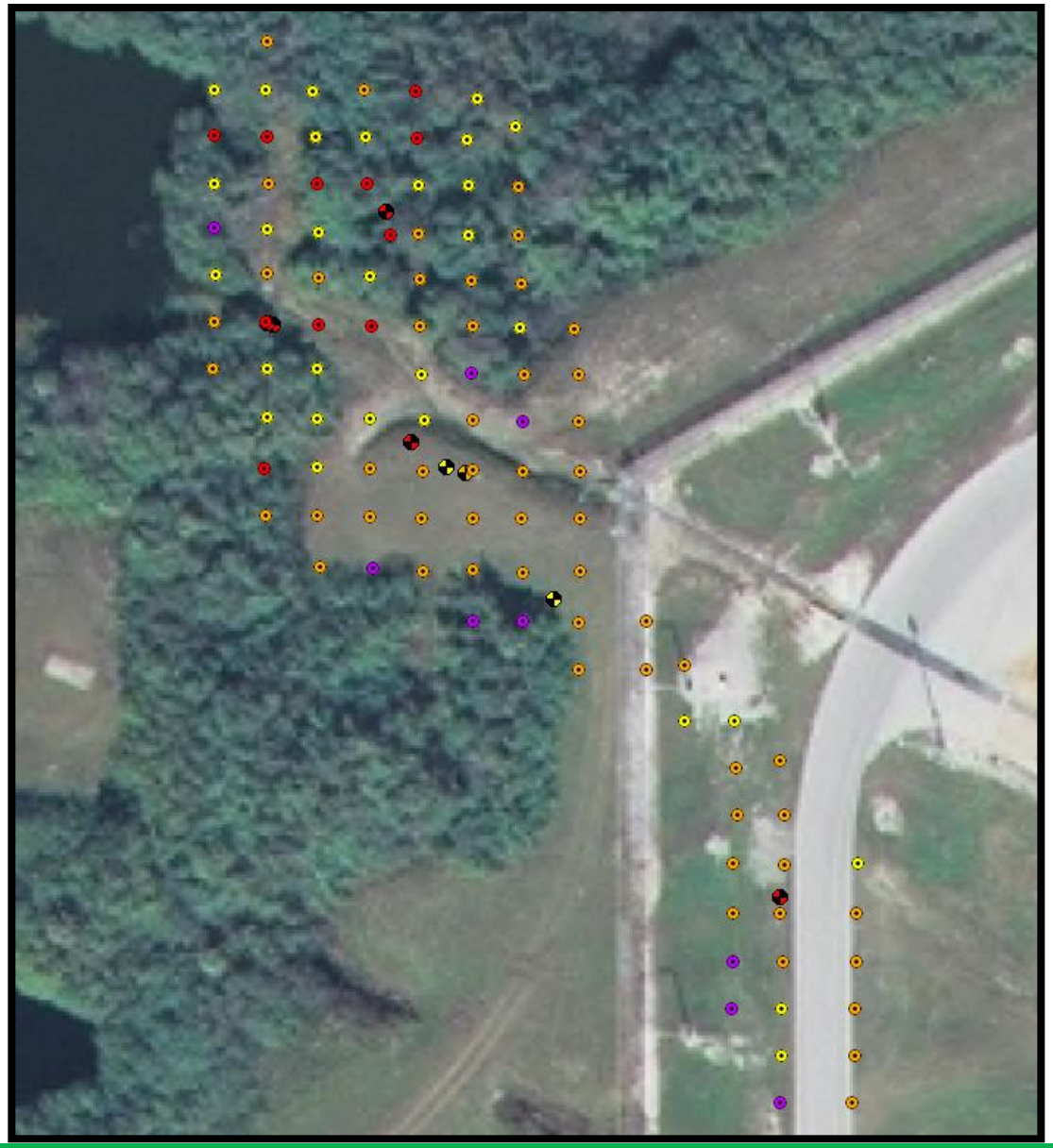
2009 Results

Legend

- pH < 6.00
- pH 6.0 - 6.49
- pH 6.5 - 7.0
- pH > 7.0



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Optimization Strategy

- Changed electron donor to EOS®
  - *Slow release electron donor*
  - *Eliminates need for multiple injection events*
  - *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 $\leq$ 6.3

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Groundwater Sampling Results TCE Mass Removal

	January-May 2006	March 2009	
Well ID	TCE (µg/L)	TCE (µg/L)	% TCE Reduction
TA01S	6,400	94.5	98.5
TA02S	4,800	2,000	58.3
TA03S	120	6.8	94.3
TA04S	15	3.6	76.0
TA09S	470	0.45	99.9
TA13S	2,900	10.3	99.6
TA13I	2,200	1.1	99.9

Site History and Background
Implementation
Results and Optimization
2008 Results

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Groundwater Sampling Results Mass Removal

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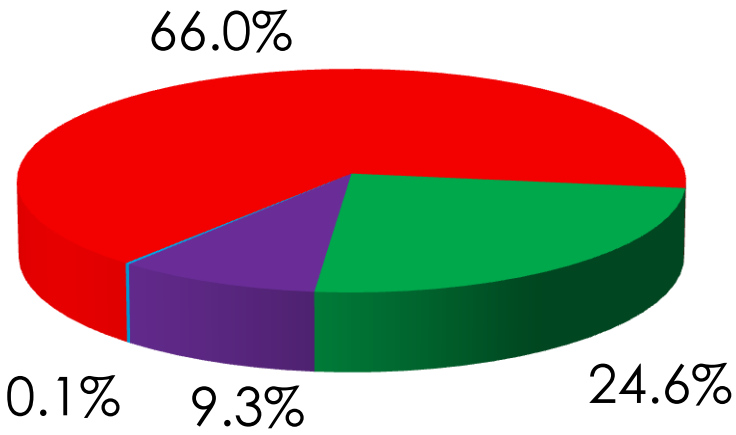
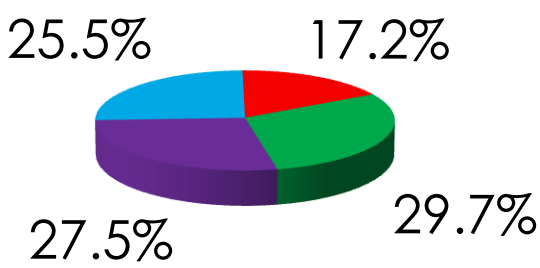
2008 Results

January/May 2006



March 2009



TCE cDCE VC Ethene

- 64% CVOC mass reduction since 2006
- 88% TCE reduction since 2006 (5 of 7 MWs over 94%)
- *Dhc* increase in MWs from $<10^4$ to $>10^7$ (as high as $>10^8$) gene copies/l

Technologies Evaluated/CO_2 Footprint

- Bioremediation (installed solar system with electron donor injections)
- Pump and Treat (CMS evaluated three recovery wells and 10 total hp system)
- Air Sparge (CMS evaluated ~45 sparge wells and 15 hp system)
- Multi-phase extraction (CMS evaluated ~15 extraction wells and 25 hp system)

Bioremediation	Pump & Treat	Air Sparge	Multi-Phase Extraction
CO_2 Equivalents [Metric Tons/Year]			
5.2	39.5	29.5 to 59.3	49.2 to 98.8

Notes:

- Electricity Emission Factors Source: U.S. EPA eGRID2006 Version 2.1 – Sub-region FRCC (Florida)
- Bioremediation: based on 25% to CH_4, 25% to CO_2 and 50% in biomass/carbon cycle
- Air Sparge & Multi-Phase Extraction: Range represents 50 to 100% operational cycle

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Conclusion

- Green remediation approach is providing for the ongoing remediation of groundwater impacts at LC39B
- Pumping at low flow rates using solar powered system is meeting project objectives:
  - *Solar panels provide adequate power supply*
  - *Quick installation/mobilization and demobilization*
  - *Reusable system/components*
- Optimization of system (ongoing process) has had a positive impact on site cleanup
- Operational CO_2 footprint significantly less than traditional air sparge, P&T, or MPE systems

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- Rosaly Santos-Ebaugh, PE, NASA Remediation Project Manager
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QUESTIONS?

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